The Effect of Computer Simulation on Grade 11 Learners’ Conceptualisation of Stoichiometric Chemistry

by

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Declaration

I, ANITA JOHN PHILIP, declare that the thesis, *The effect of computer simulations on Grade 11 Learners' conceptualisation of stoichiometric chemistry*, submitted for the qualification of Doctor of Philosophy in Natural Sciences Education at the University of the Free State, is my own, independent work.

All the references that I used have been indicated and acknowledged by means of complete references.

I further declare that this work has not previously been submitted by me at another university or faculty for the purpose of obtaining a qualification.

01-03-2021

SIGNED DATE

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Abstract

This study, titled *The Effect of Computer Simulation on Grade 11 Learners' Conceptualisation of Stoichiometric Chemistry*, was carried out at a school in the Frances Baard District of the Northern Cape province of South Africa. Stoichiometric chemistry is a topic in physical sciences in Grades 10–12 in the South African secondary school curriculum. Poor conceptualisation of the topic by learners and, hence, their failure to apply the concepts to problem-solving in the same and other topics in chemistry, cause concern. The study was conducted with the theoretical framework of activity theory. The study employed a mixed method design that consisted of a pre-test post-test experimental design, a questionnaire and interviews. Two Grade 11 physical sciences classes were involved in the study, one as a control group of 30 learners and the other as an experimental group of 32 learners. Both groups were taught stoichiometric chemistry after the SCAT pre-test. The experimental group obtained an intervention comprising computer simulations during teaching, while the control group was taught using the lecture method. After the post-test was written, a questionnaire was distributed to all learners, and interviews were conducted with six learners of each group. The ANOVA that was performed shows that learners of the control and experimental groups were comparable in terms of prior knowledge of the topic of stoichiometric chemistry. The paired t-test shows that both groups improved their performance in stoichiometric chemistry. However, the ANCOVA results show that the experimental group had a greater improvement in performance than the control group. The results of the qualitative test response analysis of the SCAT post-test, questionnaire and interviews show that the experimental group conceptualised stoichiometric chemistry better than the control group. The quantitative and qualitative data was triangulated, and it also indicated that the experimental group conceptualised stoichiometric chemistry better than the control group.

Keywords:

Stoichiometric chemistry; conceptualisation; activity theory; computer simulation; intervention

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List of abbreviations and acronyms

ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
CAI	Computer-assisted instruction
CAPS	Curriculum and Assessment Policy Statement
CBS	Computer-based simulations
CCL	Collaborative creativity learning
CG	Control group
DBE	Department of Basic Education
EG	Experimental group
FET	Further Education and Training
ICT	Information and communication technology
NIMB	Notions of learning, ICT in education, Model for learning design and Bloom’s modified taxonomy framework
NSC	National Senior Certificate
PCK	Pedagogical content knowledge
PhET	Physics education technology
RTOP	Reformed Teaching Observation Protocol
SCAT	Stoichiometric Chemistry Achievement Test
SD	Standard deviation
SI	International System
SPSS	Statistical Package for the Social Sciences
TA	Thematic analysis
TPACK	Technological pedagogical and content knowledge

UFS	University of the Free State

CHAPTER 1:
INTRODUCTION AND ORIENTATION OF THE STUDY

1.1. INTRODUCTION

As everything is made up of elements, knowing some chemistry helps us make day-to-day decisions about our lives. In our day-to-day lives, chemistry is important in many areas, such as health care and beauty, food security, agriculture, chemical industries, transport, science and technology, and more. For a science student, chemistry is one of the important subjects of study, as it infiltrates other disciplines, like agriculture, biotechnology, engineering and medicine, to improve the quality and comfort of present-day human life (Eilks, Sjöström & Zuin, 2017:100; Kotoka, 2013:12; Mihindo, Wachanga & Anditi, 2017:65). Chemistry is a field of study in which students can apply their chemistry knowledge by evaluating benefits, costs and risks associated with products and processes, to make informed decisions. It is regarded as a discipline in science that meets the needs of people in the field of agriculture, pharmacy and chemical industries. It also explains and predicts behaviour and happenings in nature by making use of theoretical models (Eilks *et al.*, 2017:97; Sevian & Bulte, 2015:55). For a developing country, like South Africa, chemistry and chemistry education play a vital role in improving and sustaining the development – economically, ecologically and for producing behavioural change in citizens – so that they use the environment sustainably (Eilks & Hofstein, 2015:2; Kurwa, 2016:1).

These assertions by researchers acknowledge the value and importance of chemistry and, hence, the need to learn the subject by conceptualising at school and at tertiary levels. Researchers cite the following as among the reasons for poor conceptualisation and performance in the subject, which happens in both secondary and tertiary levels of education: pre-existing conceptions and misconceptions of learners, learning difficulties due to abstract concepts in chemistry, the incompetency of teachers, who fail to unlock the required knowledge, lack of laboratories and other facilities, absence of the required attitude in teachers and learners towards the subject, time constraints that prevent adequate practise time for learners, lack of professionalism of subject teachers and unfavourable teaching environments. These shortcomings result in a lack of motivation, inadequate self-discipline, and lack of concentration and interest in chemistry, resulting in negative attitudes towards learning it; moreover, learners discontinue their studies in chemistry due to these reasons (Carter & Brickhouse,1989:223; Edomwonyi-Otu & Avaa, 2011:4; Kurwa, 2016:4; Mammino, 2014:198; Mihindo *et al*., 2017:65; Nakhleh, 1992:191; Ross, Guerra & Gonzalez-Ramos, 2020:358; Sirhan, 2007:3; Suits & Sanger, 2013:2; Woldeamanuel, Atagana & Engida, 2014:32).

Students' conceptual understanding of chemistry plays an important role in shaping their scientific understanding. Chemistry is a pure science subject that is considered to be difficult at secondary school level, because it contains qualitative and quantitative aspects of chemical reactions that need to be conceptualised to solve most questions (Osman & Sukor, 2013:434). It was reported that many first-year chemistry students at tertiary level have inadequate knowledge of the fundamental principles that underpin the study of chemistry (Ross, 2016:25). This could be due to the lack of conceptualisation of the fundamental principles of chemistry at school level, as mentioned above. Researchers point out that chemistry conceptualisation happens at three levels: sub-microscopic, macroscopic and symbolic. The interactions and distinctions between these three levels are important, as they contribute to understanding chemistry concepts. To conceptualise the abstract concepts in chemistry, students and learners need to think about and convert between the three levels (Potgieter, Rogan & Howie, 2005:122; Santos & Arroio, 2016:4).

Stoichiometric chemistry, which was the focus of this study, is an important part of chemistry; it is the mathematical chemistry that studies the quantitative aspects of chemical reactions. This could be the reason why this field of chemistry is highly conceptual and abstract (Malcolm, Mavhunga & Rollnick, 2018:134).

To study the quantitative aspects of chemical change, one needs to conceptualise the mole concept, which is the foundation of stoichiometric chemistry. The mole concept was introduced by Ostwald at the beginning of the 20th century, in the context of weight or mass of a substance (Omwirhiren, 2015:3). The international system of units now has mole as unit for amount of a substance. Omwirhiren (2015:3) asserts that any learner or student who needs to study the various concepts in stoichiometric chemistry must first master the mole concept of simple stoichiometry. The mole concept and its applications feature throughout quantitative chemistry at the senior secondary school level, and learners need to master the concept (Omwirhiren, 2015:1).

Stoichiometric chemistry deals with the study of the quantitative aspects of mass-mole relationships, chemical formulae and reactions. To understand the microscopic and macroscopic levels of a chemical reaction, as discussed above, the stoichiometry of the reaction becomes important. Researchers (Brown *et al.,* 2013:100; Chandrasegaran, Treagust, Waldrip & Chandrasegaran, 2009:14; Fang, Hart & Clarke, 2016:182; Hanson, 2016:2; Gauchon & Méheut, 2007:363; Marais & Combrinck, 2009:88; Urban, 2016:984) point out that, in chemistry, stoichiometric chemistry is a topic that is very difficult, and few learners/students like and succeed in learning it – most of them struggle to conceptualise it.

Stoichiometric chemistry, which comprises of fundamental concepts in quantitative chemistry, infiltrates the other branches of chemistry, like electrochemistry, organic and inorganic chemistry and physical chemistry. Therefore, to understand the quantitative aspects of any of the branches in chemistry, conceptualisation of stoichiometric chemistry is essential (Malcolm, Mavhunga & Rollnick, 2018:134; Schmidt & Jignéus, 2003:306; Sookrajh & Paideya, 2010:758). However, researchers consider stoichiometric chemistry to be one of the most difficult, abstract and least attractive sections of high school science, and a topic that usually results in low marks in tests and examinations (Boujaoude & Barakat, 2003:1; Bridges, 2015:1; Fach, De Boer & Parchmann, 2007:13; Fang *et al*., 2016:181; Malcolm *et al*., 2018:134; Marais & Combrinck, 2009:88; Schmidt & Jignéus, 2003:306; Tigere, 2014:12; Upahi & Olorundare, 2012:181). The problem-solving strategies used in stoichiometry, and poor conceptualisation, have long been of concern to researchers around the world – at least since the early 1990s (Atwater & Alick, 1990:157; BouJaoude & Barakat, 2000:91; Bridges, 2015:4; Fach *et al.*, 2007:13; Schmidt, 1994:191; Tigere, 2014:12). According to researchers, poor conceptualisation of stoichiometric chemistry can affect the interest of students in learning chemistry; researchers are also concerned that there has been a decline in the number of chemistry students at an advanced level all over the world (Broman, Ekborg & Johnels, 2011:43; Fang *et al*., 2016:215; Malcolm *et al*., 2018:134), and researchers regard the poor conceptualisation of stoichiometric chemistry as one of the reasons for this phenomenon. Therefore, improving learners' learning and understanding of stoichiometric chemistry could possibly open doors to further studies for more students in the field of chemistry and other science-related careers (Agung & Schwartz, 2007:4; Arya & Kumar, 2018:2).

With respect to the concerns mentioned above, teachers play an important role in the learners' mastery of stoichiometric chemistry. Teachers must know how to present the concepts in such a way that learners conceptualise the content. For meaningful learning of stoichiometric chemistry, teachers need to transform their own subject matter knowledge into a form that is comprehensible to learners (Fang *et al.*, 2016:182; Okanlawon, 2010:31–34). According to Okanlawon (2010:32), in teaching stoichiometry, teachers' pedagogical content knowledge (PCK) needs to be transformed into meaningful learning through the process explained in Figure 1.1.

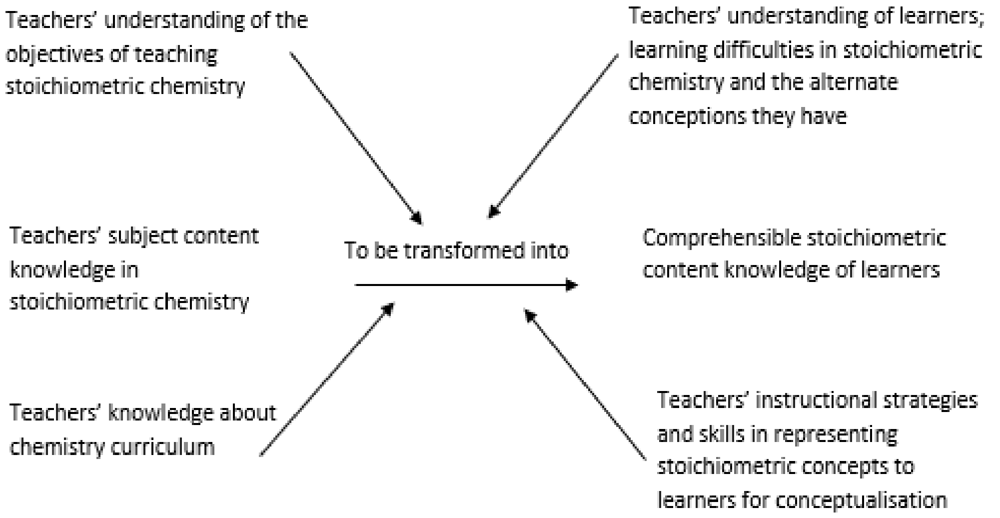


Figure 1.1: Process of transforming PCK in stoichiometric chemistry

According to Okanlawon (2010:32), during the process of making stoichiometric chemistry content comprehensible to learners, teachers need to bring together their knowledge about chemistry and the curriculum, the stoichiometric subject knowledge, the objectives of teaching stoichiometric chemistry, instructional strategies and skills that best represent the concepts for conceptualisation, the learning difficulties in the topic and alternate conceptions that learners have.

Studies done around the world about learners' understanding of chemistry suggest that learners who fail to satisfactorily understand its concepts, fail because of the use of a traditional teacher-centred lecture method for teaching. Such a method will only help learners to understand the subject at a ‘knowledge level’, and is unlikely to lead to in-depth understanding (Özmen, 2008:424). Due to the mentioned instructional problem, the use of algorithmic problem-solving has become common, without conceptual understanding by learners being ensured (BouJaoude & Barakat, 2003:92; Bridges, 2015:107; Fang *et al*., 2016:183; Furió, Azcona & Guisasola, 2002:279; Omwirhiren, 2015:2). Innovative advances in technology mean computer simulation is now a widely accepted tool for teaching and learning, as it combines visual and interactive learning that promote application of knowledge (Eskrootchi & Oskrochi, 2010:238; Nishikawa & Jaeger, 2011:136).

I have been a chemistry teacher in schools in South Africa for many years, and mostly used the lecture method to teach stoichiometric chemistry. I realised that this teaching method does not help learners to conceptualise stoichiometric chemistry. This research sought to determine the effect of computer simulation on the conceptualisation of stoichiometric chemistry in Grade 11 in South Africa.

1.2. BACKGROUND TO THE STUDY

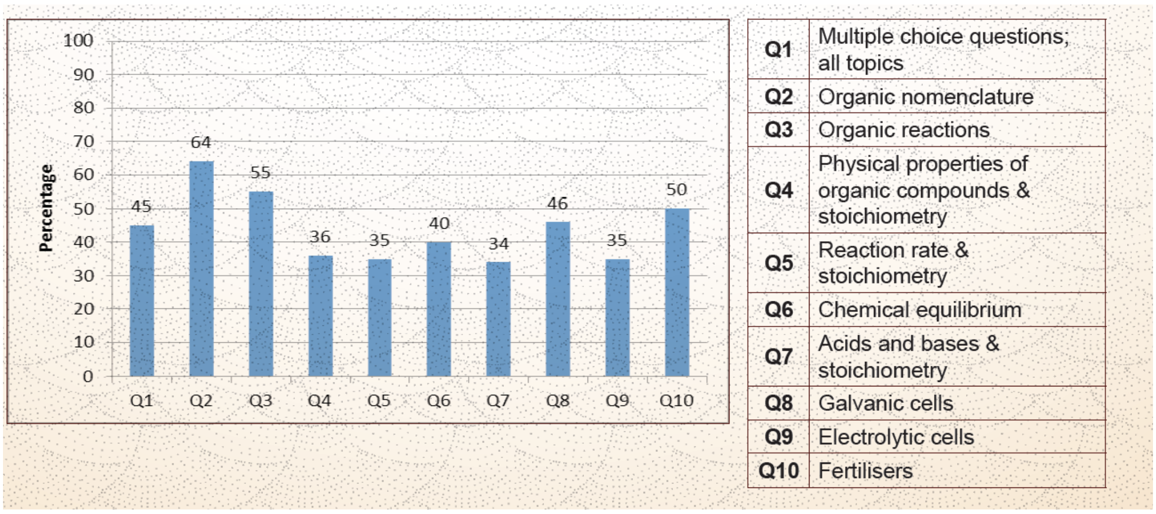
This section will discuss the background of research done on the need for learners at high schools in South Africa to conceptualise stoichiometric chemistry.

1.2.1 Poor performance in stoichiometric chemistry

South Africa needs suitably qualified teachers, engineers, doctors, research scientists and other science-oriented professionals for the development of the country. However, learners’ weak performance in physical sciences in Grade 12 affects the enrolment of science students at universities badly (Mji & Makgato, 2006:254). Kurwa (2016:1) reports that the production of such science-oriented professionals is an outcome of successful science education, which leads to good performance in assessments.

In South Africa, the National Senior Certificate examination (NSC) is the main school-leaving certificate that learners need to enrol for tertiary studies or any other career. So, good performance in the NSC examination in physical science – which consists of physics and chemistry – is important for learners, and serves as a gateway to science-related careers.

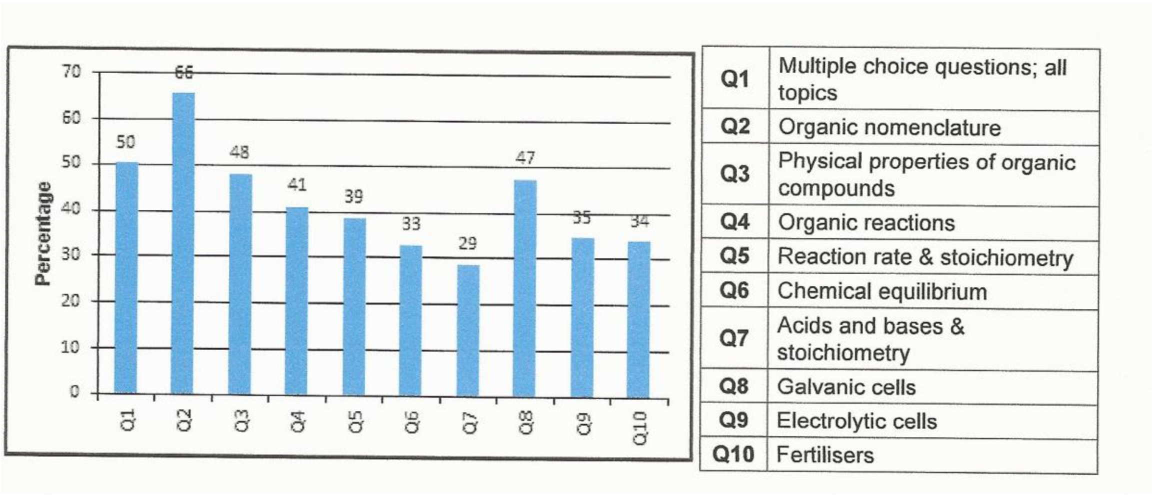
It was reported that the results of the NSC Grade 12 chemistry examination were not satisfactory for the years 2013 to 2016, due to poor learner understanding of the quantitative aspects of chemical change – which is the stoichiometry of a chemical reaction (Ndlovu, 2017:2). The importance of stoichiometric chemistry in studying chemistry was discussed in Section 1.1. The diagnostic report of 2017 reported that stoichiometric chemistry was poorly understood (DBE, 2017:185). In 2015 and 2016, the NSC chemistry examination had two questions based on stoichiometric chemistry. In 2015, the average mark was 35% and 34%, and in 2016, the average mark achieved by learners was 39% and 29% respectively for the two questions. Figures 1.2 & 1.3 shows the average marks per questions extracted from the diagnostic report of the NSC examination in 2015 and 2016.



Q1	Multiple choice questions; all topics
Q2	Organic nomenclature
Q3	Organic reactions
Q4	Physical properties of organic compounds & stoichiometry
Q5	Reaction rate & stoichiometry
Q6	Chemical equilibrium
Q7	Acids and bases & stoichiometry
Q8	Galvanic cells
Q9	Electrolytic cells
Q10	Fertilisers

Figure 1.2: NSC chemistry examination, 2015, average marks per question

Source: DBE (2015a)

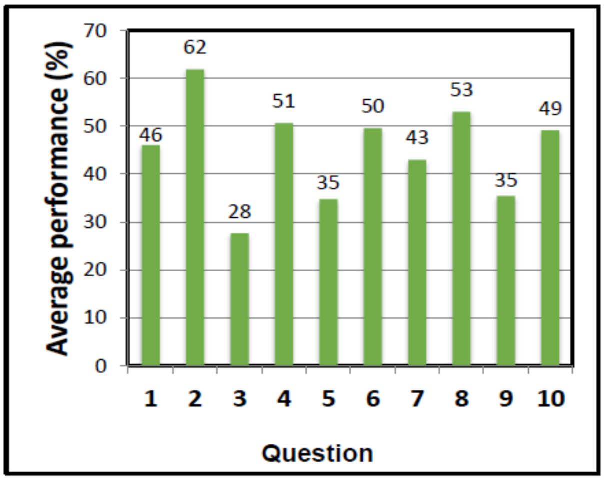


Q1	Multiple choice questions; all topics
Q2	Organic nomenclature
Q3	Physical properties of organic compounds
Q4	Organic reactions
Q5	Reaction rate & stoichiometry
Q6	Chemical equilibrium
Q7	Acids and bases & stoichiometry
Q8	Galvanic cells
Q9	Electrolytic cells
Q10	Fertilisers

Figure 1.3: NSC chemistry examination, 2016, average marks per question

Source: DBE (2016)

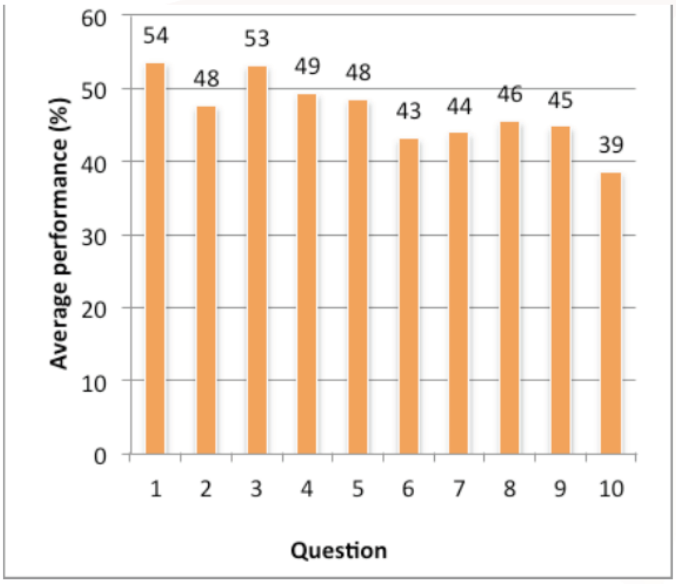
The poor performance of learners in these questions negatively affected their performance in chemistry which, in turn, affects the intention of learners to undertake further studies in chemistry (DBE, 2015a, 2016). In 2017, the chemistry examination also had two questions based on stoichiometric chemistry, and the performance of learners was reported as 35% and 43% for these two questions respectively (DBE, 2017:185). In 2018, there was a slight improvement in the total marks achieved for the questions requiring calculations based on stoichiometric chemistry, and the performance was 48% and 44% (DBE, 2018:164). Figures 1.4 and 1.5 shows the average marks per question for the NSC examination in chemistry for the years 2017 and 2018 extracted from the diagnostic report. To improve these marks, the diagnostic report suggests that stoichiometric chemistry is taught properly (DBE, 2017:185, 192; DBE, 2018:163).



Q1	Multiple-choice questions; all topics
Q2	Organic nomenclature
Q3	Physical properties of organic compounds
Q4	Organic reactions
Q5	Reaction rate & stoichiometry
Q6	Chemical equilibrium
Q7	Acids and bases & stoichiometry
Q8	Galvanic cells
Q9	Electrolytic cells
Q10	Fertilisers

Figure 1.4: NSC chemistry examination, 2017, average marks per question

Source: DBE (2017)



Q1	Multiple-choice questions; all topics
Q2	Preparation and nomenclature of esters
Q3	Physical properties of organic compounds
Q4	Organic reactions
Q5	Reaction rate & stoichiometry
Q6	Chemical equilibrium
Q7	Acids and bases & stoichiometry
Q8	Galvanic cells
Q9	Electrolytic cells
Q10	Fertilisers

Figure 1.5: NSC chemistry examination, 2018, average marks per question

Source: DBE (2018)

In 2019, the Grade 12 NSC examination for chemistry had a question from the topic acids and bases, which required calculations with limiting reagents, and only 45% of learners answered it correctly. To improve learners' performance, the diagnostic report suggests that learners need greater exposure to conceptualising stoichiometric calculations for limiting reagents (DBE, 2019:224).

As shown in the Figures 1.2–1.5 above, the questions for stoichiometric chemistry had poor performance, which indicates that learners are unable to apply stoichiometric chemistry concepts. Malcolm *et al.* (2018:136) reports that the lack of proficiency of learners in South Africa in stoichiometry is confirmed by their performance in the stoichiometric chemistry calculation-based questions in the final matriculation examinations over the past years. Due to the importance of stoichiometry in chemistry, the Curriculum and Assessment Policy Statement (CAPS) recommends that the basic mole concepts and its calculations must be dealt in Grade 10 physical sciences, and the more complex calculations, which involve limiting reagents and percentage purity, in Grade 11, under the knowledge area *chemical change*. It is also recommended in the NSC diagnostic report that, “Stoichiometry involving word questions should be extended to all sections of chemistry since all molecules undergo chemical change” (DBE, 2016:194). In Grade 12 chemistry, complex stoichiometric concepts are integrated with other knowledge areas, such as matter and materials and chemical systems (DBE, 2017:14). The fundamentals of stoichiometric chemistry and how to solve problems based on it are included in the Grades 10 and 11 curricula for physical sciences. It has been pointed out in literature for the past four decades that, due to the difficulty of the mole concepts, teachers use the algorithmic method, rather than developing learners’ conceptual understanding (Fang *et al*., 2016:183). Learners need to acquire proficiency in solving stoichiometric chemistry problems, as it is important for learners’ achievement in topics such as chemical equilibrium, acids and bases, at high school, and analytical chemistry, at tertiary education levels (Tigere, 2014:13). Calculations based on organic reactions using the concepts in stoichiometric chemistry are also included when learning organic chemistry (Ndlovu, 2017:2–3). It is reported that misconceptions in stoichiometric chemistry can cause students to have misconceptions in chemical equilibrium concepts and, hence, it needs to be eliminated (Jusniar, Budiasih, Effendi & Sutrisno, 2019:141).

If learners’ fail to conceptualise these concepts, they will not be able to apply it in stoichiometric chemistry-based questions in Grade 12 – this failure could be the reason for the poor performance of learners in the NSC chemistry examination. It has also been noticed that, due to a lack of understanding of stoichiometric chemistry concepts, many learners discontinue their enrolment in physical sciences, either in the middle of Grade 10, or in Grade 11. This decrease in learners affects the number of learners enrolling for physical sciences in Grade 12, not only in Northern Cape province, but also in other provinces which, in turn, affects enrolment at tertiary level (Mabodoko, 2017:101).

My personal experience of teaching learners at schools has been that stoichiometric chemistry is a stumbling block for them in learning chemistry. As mentioned, instructional deficiencies could be the major reason for learners' poor conceptualisation of the applications of stoichiometric chemistry. Even though stoichiometric chemistry is the foundation of the quantitative aspects of chemical change, and it needs to be understood well by learners, it has been reported that teachers find it difficult to teach the concepts effectively (Malcolm *et al*., 2018:135). To teach chemistry, many teachers use the lecture method for lessons. In this type of transfer of information, students and learners listen to the lecture, merely write down the concepts presented, and memorise and reproduce them (Ochonogor, 2011:644; Berrett, 2012:2). According to Taylor (2014:108), the lecture method emphasizes a steady flow of information. So, even if learners ask questions on any concept taught during the lesson, it does not open doors for discussion, as explanations by the teacher are just used to clarify certain issues. Mostly, a lesson conducted using the lecture method becomes a one-way communication of facts, principles and concepts that the teacher wants the learners to know.

In short, the lecture method only leads to the learners accumulating 'raw knowledge' and does not help them to conceptualise the content (Fang *et al*., 2016:183; Hassan, *et al.,* 2015: 4080; Kotoka, 2013:1; Mji & Makgato, 2006:254). Therefore, it can be assumed that the lecture method can affect learners' understanding of concepts. As a solution for the above concern, researchers emphasize the need for new instructional approaches and methodologies, like collaborative learning, mental models and using computer simulation, to prepare chemistry learners (Kotoka, 2013:75; Opara, 2014:90; Sunyono, Yuanita & Ibrahim, 2015:40).

1.2.2 Using computer technology in teaching

Using traditional teaching methods, for example, the lecture method, to teach abstract concepts does not always seem to be effective; therefore, researchers recommend using other instructional approaches. One such recommendation is using computer simulation. Researchers assert that technology-based learning can help to address the issues of learning and understanding difficult subjects (Kotoka, 2013:75; Mihindo *et al*., 2017:66; 2012:402; Nkemakolam, Chinelo & Madichie, 2018:288; Plass *et al*.). In South Africa, the education policy states that computer technology should be integrated in teaching to promote higher-order thinking skills (DoE, 2003). As technology advances, the variety of tools for teaching increases. It has been reported that using information and communication technology (ICT) to teach benefits teachers, students and the future of chemistry (Gluck, Dillihunt & Gilmore, 2014:2).

Researchers also report that it is crucial to create innovative technology to increase and enhance pedagogical approaches to creating interest in learning chemistry (Gluck *et al.*, 2014:1). Using computer technology to teach can help students rearrange their thoughts on a chemical phenomenon and, thus, provide an opportunity to improve their conceptual understanding (Pekdağ, 2010:110). Hesser and Schwartz (2013:6) point out that students can learn better by making use of game-based scenarios, as well as computer simulation. The quoted reports by various researchers over the past years show that the usefulness of computer technology to enhance learning is acknowledged worldwide.

Computer simulation is a computer program that attempts to simulate a model of a particular system, thereby enabling a user to manipulate the simulation for a topic given under various conditions (Khan, 2011:216). Among other teaching tools in ICT, such as e-books and video games, that are used to teach concepts, computer simulations are the digital tool that helps in inquiry-based learning. Computer simulations enable maximum interaction and participation by learners (Devalaki, 2019:362). This type of learning supports inquiry-based instruction, by allowing learners to visualise and explore concepts that are difficult to observe and manipulate. These benefits could be the reason why simulations have become widespread in classrooms around the world, as science teachers and learners gain access to the World Wide Web from home and at school (Finkelstein *et al.,* 2005:10; Khan, 2011:216; Siddiqui & Khatoon, 2013:137). Simulation also helps to dispel misconceptions learners have and ameliorates their comprehension of concepts (Jimoyiannis & Komis, 2001:200). Devalaki (2019:362) supports this reasoning, by reporting that simulations promote conceptual understanding, thereby introducing conceptual change more effectively than traditional instructional practices would. Doing so is possible because simulations give multiple representations of phenomena and, with the assistance of the teacher, learners can exploit the simulation fully, repeat procedures until learning has been achieved, and they can apply the knowledge gained to new situations. A teacher with adequate content knowledge can integrate computer simulations in lessons with other traditional practices and learning experiences, and the targeted concepts can be mastered by increasing learners' interest in science (Devalaki, 2019:362).

Researchers also report about the use of computer simulation to teach various areas of chemistry. Bailey (2007:31) reports that students can achieve a better understanding of the relationship between the microscopic and macroscopic levels of gases using computer animation. Udo and Etiubon (2011:215) recommend that chemistry teachers use computer simulation due to its high facilitative effect on student performance. Another study showed that the visual information provided by computer simulations helps learners to connect their understanding of chemical reactions to chemical equations (Liu, 2005:187). Using computer-aided teaching for the topic of acids and bases had a positive effect on the achievement of students (Bayrak & Bayram, 2010:235). Studies have also been done on the impact of using computer simulation to teach various topics in chemistry, such as atomic combinations (Kotoka, 2013), salt solubility (Gil & Paiva, 2006), chemical equilibrium (Sarıçayır, Şahin & Üce, 2006), chemical bonding (Özmen, 2008) and electrochemistry (Liu, 2005). Findings of the positive impact of using computer simulation to teach, lead Nkemakolam *et al.,* (2018:288), after conducting research on the use of computer simulation for teaching in Nigeria, recommend that chemistry teachers should make use of computer simulation to improve students' achievement in chemistry.

Though research has been done on the difficulties and problems learners experience learning stoichiometric chemistry and therefore performing poorly in the topic (see 1.1 & 1.2.1), a literature search using JSTOR, ERIC, SpringerLink, Worldwide Science, EBSCOhost and Google Scholar, on the study of teaching stoichiometric chemistry with computer simulations in Africa, did not yield any results. It was concluded that studies on the conceptualisation of stoichiometric chemistry have been done mostly in the West and Asia (see 1.1 and 1.2.1). The West African Examiners Council express concern that students perform poorly in problem-solving of stoichiometric calculations (Baah & Ampiah, 2012:162; Opara, 2014:85). Hanson (2016) also expresses concern that no attempt has been made to study students' understanding of stoichiometric chemistry in West Africa. The literature reported above supported and encouraged the researcher to study whether using computer simulations can enhance the conceptualisation of stoichiometric chemistry.

1.3. Problem statement

South Africa's mining, chemical and agricultural industries play an important role in the development and economic growth of the country. Therefore, there is a need for more professionals and skilled people in the field of chemistry (Burger, 2019:1). To meet the requirement, more learners in Grade 12 need to qualify to study science-related subjects at the tertiary level; however, the number of learners who qualify is reported to be small (Bhaw & Kriek, 2020:1). It was reported that "chemistry generally is a subject involving fundamental scientific knowledge, reasoning skills, abstract concepts, and problem-solving calculations" and, hence, students consider chemistry to be a difficult subject (Marais & Combrinck, 2009:88). Concepts in stoichiometric chemistry need to be applied for calculations in other topics, such as reaction rates, chemical equilibrium, organic chemistry and electrochemistry (see 1.2.1). In stoichiometric chemistry, students must apply abstract thinking concerning the quantity of substances; this makes chemistry learning more difficult, hence, discouraging learners and making the subject less attractive to high school learners (BouJaoude & Barakat, 2003:17; Fang *et al*., 2016:183; Schmidt & Jignéus, 2003:206).

The poor performance of learners in chemistry examinations in Grade 12 in South Africa has raised concern (see 1.2.1). Global concerns regarding the poor conceptualisation of stoichiometric chemistry, and the effect it has on the learners' decision to discontinue chemistry learning at school and at the tertiary level were also discussed. To continue studies in chemistry, it is important that learners conceptualise stoichiometric chemistry and master its application. If learners conceptualise the topic better at the high school level, it will improve their performance in chemistry and encourage them to continue their studies in chemistry. As professionals in the field of chemistry, they can contribute to the economic growth of society and to the country itself, which will enhance the development of the country (Semeon, 2014:2).

The research problem, therefore, relates to a study on improving the conceptualisation of stoichiometric chemistry. Various researchers, such as Malcolm *et al.* (2018), Nkemakolam *et al.* (2018), Özmen (2008), and Rutten, Van Joolingen and Van der Veen (2012), all point out that using computer technology in education can help to deepen learners' understanding of scientific concepts. Therefore, this study focused on the effect of using computer simulation on learners' conceptualisation of stoichiometric chemistry at high schools in South Africa.

1.4. Research questions

The discussion thus far has referred to the importance of being able to conceptualise stoichiometric chemistry and, therefore, the following research questions arise.

1.4.1 Primary research question

The primary research question was as follows:

> What is the effect of computer simulation on Grade 11 learners' conceptualisation of stoichiometric chemistry?

The following secondary questions guided the investigation to answering the primary research question.

1.4.2 Secondary research questions

1) What are the value and importance of teaching and learning chemistry in the South African context?
2) What influence does computer simulation have on learning when it is integrated with the teaching of chemistry?
3) How effective is the use of computer simulation in the teaching of stoichiometric chemistry concepts?
4) What recommendations can be made regarding the effect of computer simulation on the teaching and learning of stoichiometric chemistry for

improving its conceptualisation in the Further Education and Training (FET) phase at schools?

1.5. Aims and objectives of the study

The aim of the study and the objectives to achieve the aim will be given in Sections 1.5.1 and 1.5.2.

1.5.1 Aim of the study

The aim of the study was to determine the effect of computer simulation on Grade 11 learners' conceptualisation of stoichiometric chemistry.

The following objectives guided the study to achieving the aim.

1.5.2 Objectives of the study

- To determine the value and importance of teaching and learning chemistry in the South African context;
- To determine the influence of computer simulation in learning when it is integrated with the teaching of chemistry;
- To determine whether learners who are exposed to computer simulation in the teaching of stoichiometric chemistry conceptualise the concepts better than learners who are not exposed to computer simulation in the teaching of stoichiometric concepts; and
- To make recommendations regarding the effect of computer simulation on the teaching and learning of stoichiometric chemistry for improving its conceptualisation in the FET phase at schools.

The first two objectives were pursued by means of a non-empirical study conducted by means of a literature review. The third objective was pursued by means of an empirical study using a mixed methods design. The fourth objective was the result of the findings and conclusions of the first three objectives. First, in striving to achieve the third and fourth objectives, the following hypotheses were formulated.

1.5.3 Research hypotheses

For the empirical study, the following null (H_0) and alternative (H_a) hypotheses were formulated.

H_0 1 The learners in the control group and experimental group are not comparable in terms of their knowledge of stoichiometric chemistry.

H_a 1 The learners in the control group and experimental group are comparable in terms of their knowledge of stoichiometric chemistry.

H_0 2 There is no significant difference between the mean pre-test and post-test scores of learners in the control group.

H_a 2 There is a significant difference between the mean pre-test and post-test scores of learners in the control group.

H_0 3 There is no significant difference between the mean pre-test and post-test scores of learners in the experimental group.

H_a 3 There is a significant difference between the mean pre-test and post-test scores of learners in the experimental group.

H_0 4 There is no significant difference between the mean post-test scores of learners in the control group and experimental group.

H_a 4 There is a significant difference between the mean post-test scores of learners in the control group and experimental group.

The second part of striving to meet the third objective was to determine qualitatively whether any conceptualisation of stoichiometric chemistry took place.

1.6. Research paradigm and theoretical framework of the study

The focus of the study was to determine the effect of computer simulation on the conceptualisation of stoichiometric chemistry by Grade 11 learners. Hence, this study formed part of physical sciences education in the discipline of education.

A mixed method approach, with pragmatism as the paradigm, was used for the study. Pragmatism as philosophy emphasizes practical consequences as the essential criteria to determine means and value. Pragmatism was developed by philosophers such as Charles Sanders Pierce (1839–1914), John Dewey (1859–1952) and William James (1842–1910), who share the idea that thinking was closely related to action. They claim that human action is the source of reflection, which can be developed into a conceptual understanding of the world (Östman, 2005:94).

Pragmatism assigns importance to the research problem; hence, it allows researchers to be flexible enough to choose the most practicable approach to addressing the questions that they want to find a solution for. Therefore, pragmatism allows the researcher to make use of both quantitative and qualitative approaches in one study, which supports the use of mixed methods as the methodology for a study.

Pragmatism has, over the past decades, been considered as the best philosophical foundation for justifying the use of mixed methods in a study (Mahat, 2019;16; Datta, 1994; Morgan, 2007; Tashakkori & Teddlie, 2009). Creswell (2009:11) claims that pragmatism opens doors to multiple methods, and various forms of data collection and analysis, and that inquirers can draw liberally from both quantitative and qualitative assumptions when engaged in research – this was the reason for choosing pragmatism as the paradigm for this study. Quantitative and qualitative approaches have similar fundamental values, which allow their combination in a single study (Maree, 2016:315). Therefore, in this study, the numerical data collected from the pre-test post-test experimental design and the data from the interviews and questionnaire were analysed to address the various aspects of the same general research problem, to achieve a more holistic understanding of the research problem.

As the study involved teaching stoichiometric chemistry to learners, the PCK of teachers in the study was very important. PCK was defined by Shulman in 1987 as the ability of teachers to transform their content knowledge and pedagogical knowledge into an understanding of how particular topics are organised, represented, adapted and presented, so that instruction meets the diverse interests and abilities of students (Shulman, 1987:2).

As the study involved the use of computer simulation to teach the experimental group, the technological pedagogical content knowledge (TPACK) of the teacher responsible for teaching the experimental group also played an important role. Khan (2011:215) reports that, for subject education with the help of computer simulation, TPACK makes explicit the connections in a teacher's conceptualisation of educational technology for teaching subject matter. TPACK is the theoretical framework presented by Koehler and Mishra (2006), who argue that it is central to teachers' work with technology. TPACK refers to the intersection of teachers' content knowledge, pedagogical knowledge and technological knowledge. Teachers need to, first, be familiar with a complete set of technology-enriched learning activities that are based on a knowledge area and, later, they can effectively choose among the activities, and combine and use them in a suitable lesson.

A teacher with adequate TPACK to enhance learning can involve learners in activities while making use of computer technology for teaching. According to Jonassen (2002), activities executed by learners, and their learning, are interdependent. While the teacher's TPACK was considered important in this study, the activities executed by the learners after infusing computer simulation played an equally important role. Therefore, the study made use of activity theory as the theoretical framework. Activity theory originated in the 1920s, in the work of Vygotsky, Leont'ev and Rubinstein, and supports human-computer interaction. Activity theory was expanded by Engeström in 1987. The Engeström model, which was used in the current study, describes the context of computer-supported activities, its structure and development, with the experimental approach involving intervention to gather data and draw conclusions (Kaptelinin & Nardi,1997:2).

For a topic such as stoichiometric chemistry, learners need to construct knowledge through activities. Hence, activity theory helps in designing a constructivist learning environment in which learners construct their own knowledge and understanding (Duffy & Jonassen,1992:2; Jonassen & Rohrer-Murphy,1999:61; Singh & Yaduvanshi, 2015:1). In applying activity theory, the teacher, by using computer simulation, creates an environment that should be conducive for learners to reach their level of development. Activity theory will portray the inter-relationship between the subject, object and mediating tools, set in a social context of rules and the community (Naidoo, 2017:4). In activity theory, the relationship between subject (individual/group) and object (objective) forms the core of an activity. The object of the activity encompasses the activity's focus and purpose, while the subject – a person or group engaged in the activity – incorporates the various motives of the subject(s) by making use of tools, resulting in intended and unintended outcomes (Hasan & Kazlauskas, 2014:9; Kotoka, 2013:10; Naidoo, 2017:4). A detailed literature review on activity theory as a theoretical framework, and an explanation of how the study was conducted under this framework, will be presented in Chapter 3.

1.7. Research design

According to Case and Light (2011:205), methodology does not only refer to the choice of data collection method but is also a theoretical justification for the use of methods and the kind of knowledge that can generated. I used a mixed methods design for this study. Mixed methods design involves the collection and analysis of both quantitative and qualitative results. For the current study, a pre-test post-test experimental design, a questionnaire and interviews were used.

According to Creswell (2009:207), mixed methods can enable a researcher to collect, analyse and integrate quantitative and qualitative research in a single study. A mixed method approach also provides a better understanding of the research problem than either a qualitative or quantitative approach alone, as it will enable effective triangulation of data (Alharbi, 2014:76; Shorten & Smith, 2017:74). Triangulation is the process whereby two or more methods are used to verify the results of a piece of research, thereby giving more confident and stronger results (Honorene, 2017:92). The sequential explanatory mixed methods design is considered to be a primary model in the social sciences today, and is characterised by the collection and analysis of quantitative data in a first phase of research, followed by the collection and analysis of qualitative data in a second phase. The word ‘explanatory’ in the design name suggests that the qualitative findings in the second phase help to explain the findings of the quantitative data collected in the first phase (Maree, 2016:317). For the current study, the sequential explanatory mixed methods design was used, and the above sequence was followed.

1.7.1 Sequential explanatory mixed methods design

In this research, quantitative data was collected by pre-test post-test experimental design. After the post-test, self-administered questionnaires were distributed to all learners in both groups. The questionnaire contained questions regarding teaching methods, how it impacted the learning of the control and experimental groups, and their conceptualisation of stoichiometric chemistry. The questionnaire, thus, also solicited information appropriate for analysis (Babbie, 2007:246). The questionnaire was followed by semi-structured interviews (De Vos, 2002:267-268) with 12 selected learners. The outcome of the quantitative study was verified and substantiated through the learner interviews and questionnaire. While the questionnaires provided evidence of patterns in large populations, the interview data gathered more in-depth insights on participant attitudes, thoughts and actions (Coiro, Knobel, Lankshear & Leu, 2014:134). These methods were suitable for this research, as the depth of understanding afforded by the qualitative methods complemented the breadth of understanding afforded by the quantitative methods; one set of methods explained or elaborated upon the findings through the findings of the other set of methods (Palinkas *et al.,* 2015:2). The data collected from the sequential explanatory design was analysed and reported. It is regarded as explanatory as the initial quantitative results are explained further with the qualitative research, thereby giving a deeper understanding of the phenomenon under study. It becomes sequential when the initial quantitative phase is followed by the qualitative phase (Subedi, 2016:572). Mixing of the data occurred when the initial quantitative results from the pre-test post-test experimental design, and a small section of the questionnaire, informed the secondary qualitative data collection from the questionnaire and interview. Triangulation happens when the results from the quantitative and qualitative data collected provide an explanation for one aim (Creswell & Creswell, 2017:196). The sequential experimental design for the current study is represented in Figure 1.6.

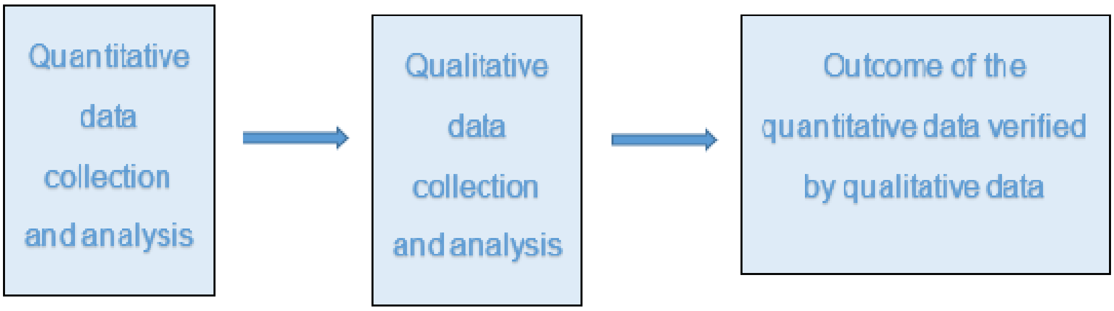


Figure 1.6: Sequential explanatory mixed method design

1.7.2 Population and sampling

The population of the study was Grade 11 learners who had chosen physical sciences as a subject in the Northern Cape province in South Africa. For the study, learners in the Frances Baard district were selected, as it was the district with highest enrolment of learners for physical science in the province, though it experienced the worst performance in chemistry compared to other districts in the province (DBE, 2017). The selection of a school from this district was convenient for me as the researcher, as I served as a lecturer in the same district. Hence, schools in this district were accessible.

The next step was to decide on a sample for the study. Sampling – the process of selecting a segment that is representative of a whole – is an important step in the research process, as it helps to inform the quality of inferences made by the researcher (Onwuegbuzie & Collins, 2007:281). To achieve the purpose of the study, I needed two Grade 11 classes with learners of comparable performance in stoichiometric chemistry, taught by two different teachers. Hence, the sample consisted of 62 learners, in total, from two different classes. Purposive sampling was used to select the participants for the study, as the sampling was done with a specific purpose in mind (Maree, 2016:198). In purposive sampling, the researcher selects a sample so that it is the most characteristic representation of the population that serves the purpose of the study (De Vos, Delport, Fouché & Strydom, 2011:232; Edmonds & Kennedy, 2016:19).

Selecting the right school for the study was done with the help of the subject coordinators of physical sciences of the Northern Cape province. The subject coordinators helped to identify a school with two physical sciences teachers teaching two different Grade 11 classes. The two teachers were graduates in science with postgraduate diplomas in education, and had similar experience of teaching physical sciences. The two Grade 11 classes were randomly assigned as control and experimental groups. Discussions on the sequence of teaching stoichiometric chemistry took place prior to the lessons, to ensure that the teachers taught the topics in the same order. The teacher teaching the experimental group was given extra training on how to use computer simulations (PhET) in the teaching of stoichiometric chemistry. The lessons the teachers presented were observed using an observation schedule. All learners in both groups were given the questionnaire. Six learners from each group – learners who scored top, middle and lowest marks for the post-test – were selected to participate in interviews. Purposive sampling was used for the selection of the learners to be interviewed.

1.7.3 Data collection

The data was collected both quantitatively and qualitatively. For the study using sequential explanatory design, the quantitative data was collected first, and the results of this data informed the second qualitative form of data collection (see 1.7.1). Weight was typically assigned to the quantitative data. In this research, I first collected the quantitative data through a validated Stoichiometric Chemistry Achievement Test (SCAT) for the pre-test and post-test, which was administered on the control and experimental groups. All learners in both the control group and the experimental groups wrote the SCAT at the same time in their respective classes. Thereafter, the experimental group received an intervention, during which they were taught stoichiometric chemistry by means of computer simulation. The control group was taught the same lessons on stoichiometric chemistry through the lecture method – they were taught in the usual way at the school, which was more teacher centred. The lessons conducted by the teachers were observed using an observation schedule. The observation schedule was designed by making use of themes and criteria under each theme, according to the Reformed Teaching Observation Protocol (RTOP). RTOP is an observational instrument that can be used to assess the degree to which mathematics and science teaching is reformed by including interactions among learners, and interactions between teacher and learners. It also includes aspects of active learning, with an emphasis on fundamental concepts and the incorporation of learner ideas into class trajectory (Viskupic *et al*., 2019:209; Watley, 2017:23. The observation schedule was first designed, validated and piloted by Evaluation Facilitation Group of the Arizona Collaborative for Excellence in the preparation of teachers (ACCEPT) (Maclsaac & Falconer, 2002:479; Sawada *et al*., 2002:1).

The performance of both groups in the SCAT was subsequently measured via a post-test, which was the same as the pre-test. A structured questionnaire that was self-administered by learners was given to all learners in both groups immediately after the post-test. The questionnaire was structured by following the rules provided by Kabir

(2016) and adapted from the questionnaires used by Kotoka (2013) and Kunnath (2017). The questionnaire helped me to understand the experiences of all the learners regarding the teaching methods and their conceptualisation of the topic. The administration of the questionnaire was followed by semi-structured interviews with 12 learners selected from the control and experimental groups, about their experiences in the conceptualisation of stoichiometric chemistry and the teaching method used for the lessons. Semi-structured interviews help to corroborate data that was gathered from other data sources which, in this study, were the post-test and the questionnaire. In semi-structured interviews, the researcher develops questions based on a line of inquiry in advance of the interview (Maree, 2016:93). Open-ended questions provide flexibility to conduct an in-depth investigation by asking probing questions, thereby making a truer assessment of the respondents’ perspectives (Akbayrak, 2000:4). The interviews with the learners were recorded, so that the data could be transcribed for data analysis.

According to Berg (2007:96) and Creswell (2003:5), a qualitative method provides opportunities to employ different knowledge claims, enquiry strategies and data collection methods, and gives direct explanations for human actions through comprehensive speech interaction. Therefore, the interviews I conducted helped to verify the post-test results with explanations about the conceptualisation of stoichiometric chemistry and the teaching methods that were used with the control and experimental groups respectively. The explanatory sequential design that I used is the most straightforward mixed method design, whereby qualitative findings helped to explain and clarify the general picture of the quantitative results (Creswell & Creswell, 2017:196; Creswell & Plano Clark, 2017:89).

1.7.4 Reliability and validity of the instruments

To collect data for a study, the instruments that are used must produce stable and consistent results – this ensures reliability of the data. The validity of the instrument refers to the extent to which it measures what it is supposed to measure (Maree, 2016:239). Therefore, reliability and validity both need to be addressed throughout the research process.

To ensure validity of the experimental design, the control and experimental groups were subjected to different methods of teaching. The two Grade 11 physical sciences classes at the school were randomly assigned as control and experimental groups (Maree, 2016:169). The SCAT tests, the questionnaire and the interview questions were submitted to three experts in physical sciences education for validation. They were requested to moderate the instruments and make the necessary corrections and changes. These instruments were also pilot tested with colleagues and learners from another school, to make sure that they measured what they were intended to measure (Killen, 2015:377; Leedy & Ormrod, 2014:198). The reliability of the SCAT results (pre-test and post-test) was established after validity considerations using the Cronbach's alpha. The Cronbach's alpha is used to measure the internal reliability of an instrument; a coefficient of 0.90 shows high reliability, 0.80 indicates moderate reliability and 0.70 represents low reliability (Maree, 2016:239).

The reliability of the observation schedule was also ensured by having themes and criteria guide observations. All the themes and the criteria under each theme were familiar to the observer, who was also the researcher. This ensured validity of the observation schedule.

While reliability needs to be ensured for quantitative data, trustworthiness corresponds to reliability for qualitative data. To ensure trustworthiness of the qualitative section of the questionnaire, criteria such as credibility, transferability, dependability and confirmability were considered (Maree, 2016:123). The Cronbach's alpha reliability coefficient was calculated to ensure the reliability of the quantitative section of the questionnaire. The validity of the whole questionnaire was ensured by focusing on face validity, content validity and construct validity. The questionnaire was scrutinised by experts in the field and was also pilot tested with learners of another school. I ensured that the questions of the questionnaire covered the constructs and were based on the secondary research questions that were answered by conducting the empirical study.

To ensure validity of the interview questions, the questions were constructed so that they connected with the third secondary research question. The quantitative section of the questionnaire was used as a guide to devise the interview questions, and extrapolation and a comprehensive description of information ensured the validity of the interviews. During the interviews, I avoided asking leading questions. I recorded the interviews, took notes and gave the interviewees the chance to sum up and clarify the points they had made (Alshenqeeti, 2014:43; Ary, Jacobs, Sorensen & Razavieh, 2010:501).

1.7.5 Data analysis

In a research study, analysis, interpretation and reporting involves summarising the data that has been collected and presenting the results to communicate the important features of the achievement of the research aims and objectives (Creswell & Creswell, 2018:16). Both descriptive and inferential analysis of the quantitative data obtained from the pre-test and post-test was done. Descriptive analysis transforms raw data into a form that is easier to understand, interpret, order and manipulate, to obtain descriptive information (Zikmund, 2003:1). Inferential analysis enables a researcher to make inferences about large populations on the basis of data in relatively small samples. Inferential statistics are based on probability theory and the process of hypothesis testing (Allua & Thompson, 2009:168; Leedy & Ormrod, 2014:262).

The descriptive part of data analysis included graphs and numerical values obtained from the pre-test and post-test (SCAT). The shape of the distribution was also described. The data was also graphically represented, which helps to clarify the main characteristics of the distribution (Maree, 2016:207–213). For the study, the quantitative data analysis was done using the Statistical Package for the Social Sciences (SPSS 24) for hypothesis testing (Campbell & Stanley, 2015:13).

One-way analysis of variance (ANOVA) was used to determine whether there were any statistically significant differences between the two groups before the lessons were presented. A paired t-test was used to determine whether there was any statistically significant difference between the pre-test and post-test scores for each group on the SCAT. Analysis of covariance (ANCOVA) was used to determine whether there was a significant difference between the scores of the control and experimental groups when differences in pre-test scores were controlled. The effect size, to test for practical significance of any possible statistically significant difference observed by the ANCOVA, was also determined.

A qualitative test response analysis for the SCAT was also done, by analysing the responses of both pre-test and post-test for the same 12 learners that were interviewed. The response analysis helped me to understand whether an improvement in performance was due to conceptualisation of the concepts in stoichiometric chemistry.

Though all learners answered the questionnaire, the analysis was done only for the questionnaire responses of the 12 interviewee learners. The qualitative section of the questionnaire was analysed by conducting a thematic analysis. The quantitative section of the questionnaire, which consisted of questions answered by means of a Likert scale, was also analysed. The audio-recorded interviews with the learners of both control and experimental groups were transcribed and coded, and themes were identified for thematic analysis. Audio recordings must be transcribed verbatim, that is, written down word for word (Maree, 2016:115). The thematic analysis helped me to make inferences about experiences shared by the learners in the interviews and questionnaire (Javadi & Zarea, 2016:33). The data analysis, thus, helped to determine whether there had been any improvement in the performance of learners and whether conceptualisation of stoichiometric chemistry happened after the intervention.

1.8. VALUE OF THE RESEARCH

According to the CAPS for physical sciences, Grades 10–12, “Physical Sciences plays an increasingly important role in the lives of all South Africans owing to their influence on scientific and technological development, which are necessary for the country’s economic growth and the social wellbeing of its people.” The CAPS envisages physical sciences as a subject that prepares learners for future learning, employment, citizenship, holistic development and environmental management (DBE, 2013:8). Stoichiometric chemistry plays an important role in students’ motivation to enrol for further chemistry studies at the tertiary level. Proficiency in stoichiometric chemistry plays an important role for people in the chemical industry, who need to determine, for instance, the quantities of reactants and products, and levels of water, air and ground pollution (Tigere, 2014:13).

The poor performance of learners in chemistry, and the need to apply stoichiometric chemistry to other topics in chemistry and in chemical industries, emphasizes the importance of learners in Grade 11 conceptualising stoichiometric chemistry. Even though there are a variety of ways to make learning chemistry more accessible, teachers may not be able to implement them unless they have been tried out in the South African context. Researchers recommend using computer simulation as a tool in teaching to enhance learning (see 1.2.2).

This recommendation stimulated me to undertake a study on the effect of using computer simulation to conceptualise stoichiometric chemistry at high schools in the Northern Cape province of South Africa. The study sought to verify the researchers' assertions, by applying computer simulation to teach stoichiometric chemistry. If there is a significant improvement in the performance of the learners who were taught using computer simulation, compared to that of the learners taught by the traditional lecture method, then the use of computer simulation to teach and conceptualise stoichiometric chemistry can be recommended. The findings of this study could, therefore, propose a new pathway for the teaching of stoichiometric chemistry, not only in South Africa, but also in other countries in Africa, where chemistry education is a serious concern. The research will, therefore, contribute to enhancing chemistry education, and open up new possibilities in the teaching and learning of stoichiometric chemistry, by providing information that can be used to make recommendations to chemistry teachers and learners in South Africa and other parts of Africa. This, in turn, will contribute to increasing the number of skilled professionals in the chemical industry.

1.9. DEMARCATING THE FIELD OF STUDY

Chemistry education in secondary school education was the contextual background of the research. Failure to conceptualise stoichiometric chemistry and its effect on learners' performance in chemistry has been reported as a concern. Hence, this study attempted to determine the effect of using computer simulation to improve the conceptualisation of the topic and forms the demarcation of the field of this study. The study falls under science education, in the subsection of physical sciences education. The study was conducted at a high school in the Frances Baard district of the Northern Cape province. The study focused on the teaching of the subject – the effect of using computer technology in teaching the subject– the pedagogy of teaching – the effect of the pedagogy of teaching, and the use of TPACK for the conceptualisation of a topic.

1.10. ETHICAL ASPECTS OF THE RESEARCH

Ethical clearance (No. UFS-HSD2018/1292) to conduct the study was obtained from the University of the Free State (UFS) (see Appendix L). The research adhered to the values and principles stated in the policy of the UFS. It was ensured that the research that was conducted adhered to all applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Permission to conduct the experimental design, conduct the interviews and administer the questionnaire was obtained from the Department of Education in the Northern Cape and the relevant authorities of the school involved. Consent from parents of minor learners and from the learners older than 18 years for their participation was also obtained. All the elements of moral and general ethics principles were followed. No behaviour by participants or any other personal details that would enable identification were disclosed to any other individual. Only relevant and useful information was collected from the participants. I refrained from plagiarism and any work consulted for the study is acknowledged.

1.11. LAYOUT OF THE STUDY

The thesis consists of six chapters. Figure 1.7 explains the layout of the chapters diagrammatically.

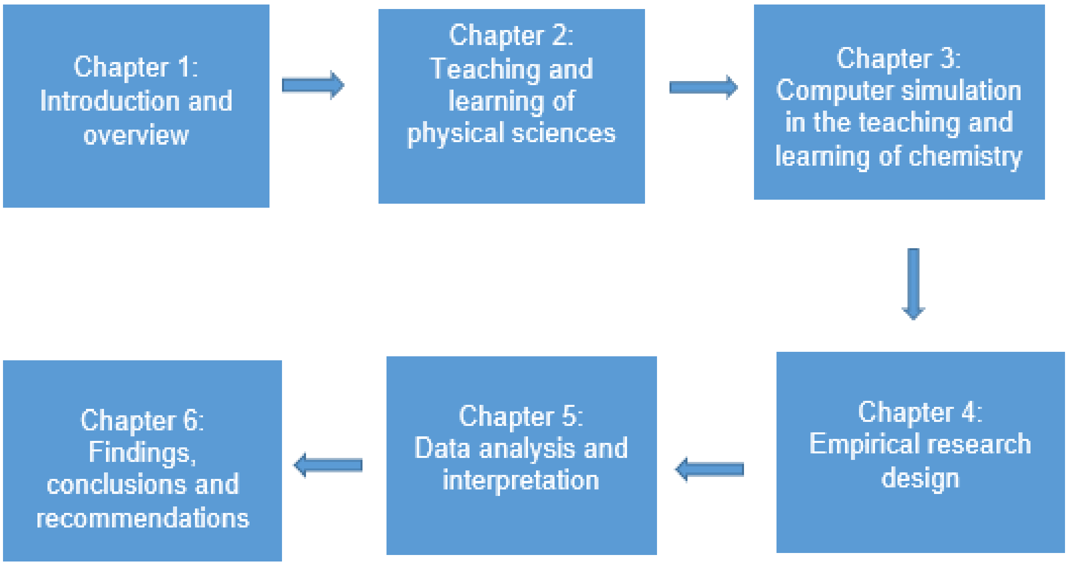


Figure 1.7: Layout of the study

The next five chapters are structured as follows:

- Chapter 2 concentrated mainly on the non-empirical study, by presenting a literature review of the teaching and learning of chemistry and, specifically stoichiometric chemistry. Physical science as a subdiscipline of science, the importance of teaching and learning the subject, the value and importance of learning the subject, the process of teaching and learning of physical sciences, chemistry and stoichiometric chemistry, were unfolded in this chapter. Therefore, the first secondary research question was addressed in this chapter.
- Chapter 3 presented the literature review done on computer simulation in the teaching and learning of chemistry. The impact of using computer technology and simulation, different types of simulation, the perspectives of teachers, and their experiences of infusing simulation in the teaching and learning of chemistry, were reviewed in this chapter. This review contributed to addressing the second secondary research question.

- The research design was discussed in Chapter 4. With the support of a related literature review, it addressed the philosophical worldview of the study, research methodologies used, and the specific research methods applied in the study.
- The representation, analysis and discussion of the data collected through the mixed methods are discussed in Chapter 5. The secondary research questions structured for the empirical study is answered in this chapter.
- In Chapter 6, a summary of the research findings, conclusions and recommendations are provided. The chapter also discusses the significance and limitations of the study. Proposals for further research are also included in this chapter.

1.12. SUMMARY

In this chapter, the need to strive to improve the conceptualisation of stoichiometric chemistry was established. The need to improve conceptualisation of chemistry and physical sciences, as a subject, becomes evident when considering the need for more students to pursue careers as scientists, engineers, doctors and other science-related professions (see 1.1). It was explained that stoichiometric chemistry is a topic that is characterised by poor conceptualisation by learners, which leads them to believe that learning chemistry is difficult. The poor performance of learners in chemistry at high school, because they fail to conceptualise stoichiometric chemistry, was discussed (see 1.2.1). Integrating computer technology in education to improve teaching and learning was also explored. The literature review showed that making use of computer simulation instead of traditional instructional methods to teach chemistry could improve conceptualisation (see 1.2.2). Therefore, the primary aim of the study was to determine the impact of using computer simulation to improve conceptualisation of stoichiometric chemistry.

The study was conducted with learners in Grade 11 in the Frances Baard district of the Northern Cape province, as it was the district with the largest enrolment of learners in physical sciences in the province. The aim and objectives of the research were outlined in this chapter. The research methodology, data collection techniques, sampling, analysis of the data, the validity and reliability of the data collected were also discussed.

CHAPTER 2:
TEACHING AND LEARNING OF PHYSICAL SCIENCES

2.1. INTRODUCTION

The aim of this research was to determine the effect of using computer simulation to improve Grade 11 learners' conceptualisation of stoichiometric chemistry. The first step in the attempt to achieve this aim was to determine the value and importance of the teaching and learning of chemistry in the South African context through a non-empirical study. Stoichiometric chemistry falls under the learning area of physical sciences, which consists of physics and chemistry in the South African school curriculum. This chapter will focus in conducting a literature review of the nature and structure of science, different perspectives on learning science, physical sciences as a subdiscipline of science, the importance of physical sciences, chemistry as a branch of science, and the importance and value of learning chemistry.

As conceptualisation of stoichiometric chemistry by learners at secondary schools in South Africa is the focus of the study, teaching of the topic, and the learning difficulties and misconceptions involved, will also be discussed in this chapter. In the South African context, the youth attending schools are referred to as learners, and those at university level are referred as students. Hence, both terms are used in the current study.

2.2. NATURE AND STRUCTURE OF SCIENCE

The aim of the study was to determine the effect of computer simulation on Grade 11 learners' conceptualisation of stoichiometric chemistry. Hence, a literature review on teaching and learning of chemistry and stoichiometric chemistry was important for the study. As chemistry falls under science, a review of the nature and structure of sciences is presented. Learning science is a journey that never ends. Science is the body of knowledge that includes processes and products that represent the systematic understanding of the structure and behaviour of the physical and natural worlds. Scientists are striving to understand how the natural world works and what the nature of science is (Cartier, Rudolph & Stewart, 2001:7). Researchers have acknowledged that science is the body of knowledge that has been established and is continuously being extended, refined and revised (Casey, 2012:2; Firman, 2020:1). To understand the natural world and how it works, scientists and researchers gather information by making observations of the natural world and verifying and interpreting information.

Due to the complex nature of science, and because conceptions about the nature of science are tentative and dynamic, there is no agreed definition of the nature of science. However, the nature of science refers to what science is, how it works, the epistemology of science and the characteristic way of learning about the natural world (Herman, 2010:13; Karakaş, 2019:176). Researchers report that science has certain characteristics that distinguish it from other spheres of human endeavour, and that these characteristics evolved as science grew, and now defines the nature of science (Firman, 2020:3; Yalçinoğlu & Anagün, 2012:119). Therefore, nature of science is a multifaceted concept that defines how science works, and which involves history, sociology, philosophy of science and the characteristics of scientific knowledge (McComas, 2006:5). Knowing how science works helps us to do better science, which enables us to apply better methods and formulations (Hung, 1997:2). It is acknowledged by science educators that scientific knowledge is derived from observations of the natural world, and depends on scientific theory or laws, and human inferences made from observations, imaginations and creativity, which are subject to change (Karakaş, 2019:176).

The nature and structure of science have been widely researched, and the following are the main points of the characteristics of the nature of science (Firman, 2020; Karakaş, 2019; Rao & Ramulu, 2016; Vaisakha, 2013).

- People have different perspectives on the way they look at nature.

  People have different understandings about the natural world and certain phenomena in nature (Rao & Ramulu, 2016:4). This characteristic of science can be explained with examples. During an epidemic, while the common man prays and seeks divine intervention, a scientist will be working to develop preventive strategies to fight the disease. This does not mean that scientists do not pray or believe. While working, the scientists could be praying for their scientific strategies to be successful. At the time of an eclipse, some people pray and fast to protect them from the ill effects they believe flow from the phenomenon. In turn, a scientist sees an eclipse as a natural phenomenon and starts to investigate it. This shows that the way a common man sees nature is not the same way as a science-oriented person sees it.

- Science is regarded as a highly dynamic body of knowledge that is empirical.

  Researchers have an explanation for the above statement. Science and the knowledge that is generated expands rapidly and is based on observations and interpretations. Every day, research is being conducted and the amount of knowledge that can be gained from science through scientific explanations increases (Firman, 2020:3; Karakaş, 2019:177; Rao & Ramulu, 2016:4).

- Science is an interdisciplinary area of learning.

  Science has flourished and been influenced by different cultures; earlier it was known as natural philosophy (Karakaş, 2019:179; Vaisakha, 2013:3). Later, the knowledge acquired about science was classified into different disciplines, like physics, chemistry, biology, geology and astronomy. The knowledge from each of these disciplines cannot be seen in isolation, as several scientific topics fall under more than one discipline. For the current study, which is about the conceptualisation of stoichiometric chemistry, the topic is quantitative analysis that is done through mathematical calculations. This shows that the topic that falls under chemistry cannot be studied in isolation. Therefore, to study one discipline in science, requires the integration of other disciplines (Vaisakha, 2013:3; Rao & Ramulu, 2016:5).

- Science is an international enterprise, as people from all over the world are involved in the process of science.

  Science does not belong to any country alone, as all the knowledge and development that is science are the fruit of the hard work of people from different countries around the world (Rao & Ramulu, 2016:6).

- Science is always tentative.

  In the earlier theories in science, the earth was believed to be the centre of the universe, while the sun revolved around the earth. The belief was very strongly supported by religion. Later, the argument that the sun was at the centre of the solar system, and that it is the earth that revolves around the sun, was proved to be correct, and accepted. The community of scientists continuously tests the truthfulness of knowledge. As a result, several theories in science were later revised, or abandoned completely, when new evidence was found to be true (Firman, 2020:3; Vaisakha, 2013:6).

- Scientists always observe the natural world with suspicion.

  A new observation is not accepted just as it is. Scientists participate in debates and conduct experiments. A finding will be accepted to be true only after testing and when identical results are obtained by all those who conduct the experiment (Firman, 2020:3; Vaisakha, 2013:12).

- The study, development and progress of science demands tenacity and perseverance.

  When a scientist gets an inspirational idea or creative thought during certain observations, it must be taken forward until a logical conclusion is reached. Sometimes, scientists work alone all the way to a discovery or invention, while at other times, certain scientists make a start and others join in developing the idea further (Rao & Ramulu, 2016:10).

- Scientific methods have mostly been part of investigations and experiments, as a process of constructing knowledge.

  A scientific method involves observing, hypothesising, predicting and testing by experimentation, interpreting gathered information, and generalising with a scientific theory. Therefore, in science, knowledge is being constructed by applying the scientific method (Rao & Ramulu, 2016:15-22).

Scientific knowledge is purely objective, however, the line of investigations and the scientific decisions made by a scientist makes the scientific knowledge subjective in nature (Mannan, 2016:44). The nature of science conveys the empirical and tentative nature of scientific knowledge, the subjectivity and creativity of science, and the status and function of laws and theories in science. The nature of science influences the scientific reasoning skills needed to interpret and evaluate conflicting evidence in science. Understanding the nature and structure of science fosters the ability to interrelate scientific concepts and acquire scientific content knowledge (Michel &

Neumann, 2016:951). The conceptual change in students during science learning can be linked to changes in their views of the underlying concepts and principles of the nature of science (Duit &Treagust, 2012:110). Teaching the nature of science is not part of the science curriculum in South Africa. However, a science teacher needs to look through the lens of the nature of science while teaching to achieve conceptualisation of various topics in science and to develop conscience regarding the use of science. Furthermore, a deep understanding of the nature of science helps teachers to structure an inquiry-learning environment, which is very important in science learning (Clough, 2018:2).

2.3. SCIENCE AND CITIZENSHIP

Knowledge gained through science, and the application of that knowledge, have resulted in many discoveries that have improved the quality of human life (Voulvoulis & Burgman, 2019:1093). With the knowledge of science citizens can encourage others to appreciate and participate in the responsible use of the contributions that science and technology have made for the benefit of society. The aim of science education is to develop a scientific attitude, and to help society to make rational choices when confronted with various possibilities and challenges (Vaisakha, 2013:31). A good citizen needs to engage with the environment and take an active role in society. The knowledge and skills that science provides, helps citizens to interpret issues related to the environment, and solve problems by understanding the science behind it. Researchers claim that it is not possible to understand the world we live in, or to recognise the impact we have on it, without a proper background of the science that explains and supports it (Ross, Lakin, Mckechnie & Baker, 2015:23).

Ngema (2016:20) reports on the relevance of science in three dimensions, namely, individual, societal, and vocational. Individually, science equips learners with the intellectual skills that contribute to their everyday lives and futures. When viewing science in the societal dimension, learning science equips learners to participate in and contribute towards the development of the society. The importance of learning science in the vocational dimension is that it prepares learners for various careers in higher education. Learners who pass well in science meet the requirements of the career they will choose for further studies in science subjects; this will lead to a student getting a good job, with a good pay in professions related to science, and, hence, contribute to society's economic growth (Ngema, 2016:20).

From the above review, it can be understood that learning science and about the way science and technology have developed helps every learner and student to understand the contribution science has made and how they have affected our lives, culture and society. Good citizens must know how to behave responsibly towards themselves, others, and the environment in which they live. When people relate what they have learned in science to everyday life, they start to acknowledge the contributions that knowledge through science has made to the world, and how it prepares them to be good citizens.

2.4. PHYSICAL SCIENCES AS A SUBDISCIPLINE OF SCIENCE IN THE SCHOOL CURRICULUM

Science is "the intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment" (South African Concise Oxford Dictionary, 2005:1047). In the South African context, science in the school curriculum in the FET phase consists of the topics life sciences and physical sciences. The focus discipline of the study, physical sciences, helps society to understand how the physical environment around it works to its benefit and, hence, society is responsible for taking care of it. The aim of teaching physical sciences as a subject is to equip learners with the skills to investigate physical and chemical phenomena, thereby making them aware of their environment. It also teaches citizens to be scientifically literate, and contributes to their social transformation (Das, Amita & Singh, 2014:16).

Physical sciences are subdivided into physics and chemistry. In the South African physical science curriculum, an important aspect is that all three grades (10–12) in the FET phase have the same theme, which has a progression from one grade to the next. In both physics and chemistry, the curriculum emphasizes the importance of integrating practical work with classroom teaching. In addition to learning theoretical concepts, the curriculum recommends that learners need to acquire scientific knowledge by carrying out their own scientific enquiries through practical experiments, investigations, and projects. This helps in making them independent and self-reliant, and creating in them an awareness of the environment they belong to (DBE, 2013:8).

2.5. THE IMPORTANCE OF PHYSICAL SCIENCES IN SCHOOLS

Physical sciences involve investigation, experimentation, explanation and prediction of physical and chemical phenomena through scientific inquiry by the application of scientific models and theories, to understand how the physical world works (DBE, 2013:8). The aims and objectives of learning physical sciences, the role of physical sciences as a subject in the South African context, and the curriculum followed in South Africa is discussed in this section.

2.5.1 Aims and objectives of learning physical sciences

In most countries, the science curriculum has two aims. In the first instance, the aim is to provide every young person with sufficient understanding to enable them to participate effectively and confidently in the modern world's activities and, secondly, to provide the foundation for further studies in science at the tertiary level (Millar, 2004:1). As a physical sciences teacher, I have realised that this statement is true, because it is through physical sciences education that learners are exposed to universally applicable problem-solving and critical thinking skills, which make physical sciences more relevant to their lives. In addition to daily life application, an above-average pass in physical sciences opens the door for learners to science-related learning at tertiary level. Physical sciences also contribute, directly or indirectly, to the environment, health, peace and equity (Vaisakha, 2013:33–38). Physical sciences learning is important for the health of a person's personal lifestyle and civic life (see 2.3), which enables someone to take an informed part in social decisions and economic life and to respond positively to science-related matters (Das *et al*., 2014:16).

For example, in the South African NSC curriculum, in Grade 12, learners study the factors affecting the rate of a reaction. Once they have this knowledge, they can apply their understanding about these factors and use less time for cooking and, hence, reduce their usage of electricity. This knowledge can also be transferred to their fellow citizens. The knowledge about conservation of energy and applying the knowledge of electric power helps a learner to reduce the usage of electricity and save energy. When more people apply this knowledge, electricity consumption could be reduced, thereby helping the electricity producer of the country. This is highly relevant in South Africa, where the electricity producer, Eskom, battles to meet the demand for electricity. Thus, learning physical sciences helps learners to acquire conceptual and procedural knowledge relevant to their daily lives (Rao, 2016:4188).

Another important benefit of learning physical science, as pointed out by Rao and Ramulu (2017:12), is that learners' overall behaviour changes, and they become more likely to discharge their social responsibilities. This corresponds with the aim of physical sciences, which is to relate physical sciences education to the natural and social environment, technology and society and, thereby, to develop an attitude of responsible citizenship (Rao, 2016:4189). For example, in South Africa, the road fatality rate is high. One can argue that a contributing factor to road fatalities is people's irresponsible behaviour due to lack of knowledge of physics laws and principles, which explain the consequences of speeding of vehicles and the necessity of wearing seatbelts. The risks of speeding are well explained by physics in terms of reaction time, braking distance and stopping distance. When comparing two cars with different speeds, with both drivers having the same reaction time, the car with a higher speed will have a longer braking distance and stopping distance compared to the car with a lower speed. As a result, a higher speed can lead to fatal accidents. When a moving car has to brake suddenly, passengers will continue moving at the speed of the car before braking, due to inertia. However, if a passenger is wearing a seatbelt, the belt will exert a force back on the passenger, holding him/her in position. This will stop the passenger from tumbling around in the car. Hence, the knowledge of wearing a seatbelt helps the passenger to prevent such a fatality. Another example of the benefit of learning physical sciences is that a person who has learned about global warming and its impact on the environment would be likely to consider reducing the emission of carbon dioxide into the atmosphere.

According to Rao (2016:4189) and Vaisakha (2013:52-65), all the important aspects mentioned above can be summarised as the following objectives of a physical sciences curriculum:

- To acquire knowledge and understanding of science for learners to build up further knowledge and to apply the knowledge;
- To imbibe inquiry and process skills of science;
- To develop a scientific attitude, and to think scientifically, critically and creatively;
- To imbibe certain values through science and to develop problem-solving skills;
- To understand the language of science and to communicate ideas and views; and
- To nurture natural curiosity, creativity and an aesthetic sense.

2.5.2 Role of physical sciences as a subject in the South African context

In the South African context, “physical sciences play an increasingly important role in the lives of all South Africans owing to their influence on scientific and technological development, which are necessary for the country’s economic growth and the social wellbeing of its people” (DBE, 2013:8). Physical sciences education provides learners with a foundation of technical skills, which are in short supply in the country, and provides the foundation for more advanced study of science (Dhurumraj, 2013:10; Millar, 2004:1). The science skills of the young generation are essential for the continued prosperity of the future of a country, as these skills contribute direct value and meaning to personal identity and life experience (Eilks & Hofstein, 2015:2; Jack & Lin, 2017:138). It has been reported that having physical sciences as a subject in high schools opens doors to tremendous opportunities to students at the tertiary level. It also plays an important role in locating a country and its citizenry in a globalised context (Dhurumraj, 2013:10). Another benefit of physical sciences is that it helps the learner to understand the nature of science and its relation to technology, society and the environment, through their knowledge of and skills in scientific enquiry, and problem-solving skills (DBE, 2013:8).

In addition to these benefits reported by researchers, the CAPS envisages physical sciences being a subject that prepares learners for future learning, employment, citizenship, holistic development and environmental management (DBE, 2013:8). By applying knowledge of physical sciences, worldwide economic, social, political and technological issues can be impacted (Mkandawire, 2009:24). The number of scientists and engineers produced by a country is an important indicator of a country's scientific and technological infrastructure, as well as its ability to contribute to the scientific and technological world (Koti, 2016:29). Learning physical sciences is, therefore, is not only important for a learner, but also benefits a country's sustained development. As a result, science education has been prioritised at a national level by South Africa, and the performance of learners in the NSC Grade 12 examination in physical sciences is reported every year – learners' performance in physical sciences over the period 2015–2019 was reported in Chapter 1 (see 1.2.1).

The discussion emphasizes the value of physical sciences as a subject in the South African school curriculum. Physical sciences are a high priority area in South Africa. The need to increase the number of scientists and engineers produced by the country, as reported above, points to the importance of having more learners enrolled for physical sciences at school level (Mabodoko, 2017:101). Moreover, these learners should continue studying physics and/or chemistry at the tertiary level.

When more learners enrol for the subject, the quality of teaching and learning may not be compromised. To improve the quality of education, an education sector plan was introduced in 2012, called Action Plan to 2014: Towards the Realisation of Schooling 2025, by the Department of Basic Education (DBE). Later, the Action Plan 2019 – Towards Schooling in 2030, replaced the initial action plan (DBE, 2015b). The action plan has 27 goals, of which the first 13 goals relate to learning and enrolment. Goal 6 of the action plan is to increase the number of learners who pass physical sciences in Grade 12 (DBE, 2015b:26). The action plan emphasizes the need to improve learners' performance at school level, as it will affect their academic careers at university, which, in turn, affects the development of the country. The plan also emphasizes the need for learners to successfully complete Grade 12, as an important prerequisite for improving economic growth and reducing income inequality in South Africa (DBE, 2015b:30). The Dinaledi Schools Programme, launched in 2001, also aimed to achieve improvement in performance by learners in physical sciences and mathematics. Thus, we can understand that physical sciences education has been prioritised nationally in South Africa. It was mentioned in the National Diagnostic Report of the NSC examination that only a small number of learners doing science are achieving good results and this is cause for concern, as it results in a shortage of professionals in science and related fields (see 1.2.1).

2.5.3 Physical sciences curriculum for South African schools

In the South African FET school curriculum, physical sciences consist of physics and chemistry, in Grades 10 to 12. An above average mark in physical sciences in Grade 12 is one of the prerequisites for further studies in engineering, medicine or other science-related courses (Kriek & Grayson, 2009:187). Depending on the performance of the learners in physical sciences in Grade 12, they can continue to study physics or chemistry at the tertiary level, according to their choice of career.

The curriculum for physical sciences in South Africa consists of six knowledge areas. They are matter and materials, chemical systems, chemical change, mechanics, waves, sound and light and electricity and magnetism. The physics part includes mechanics, waves, sound and light, electricity and magnetism and matter and materials. The chemistry part comprises matter and materials, chemical change and chemical systems (DBE, 2013:8).

2.6. TEACHING AND LEARNING PHYSICAL SCIENCES

In Section 2.5, the importance of studying physical sciences at secondary school level, and the need for good performance in the subject, were emphasized. Furthermore, the poor performance of learners in the subject was reported as cause for concern. Therefore, it is important to look into the teaching and learning of physical sciences. The teaching and learning of a subject depend on the teacher, the learner, and the content. The learning process involves mainly a conceptual change. Learners possess pre-instructional conceptions before they come to class. A conceptual change can happen only when the learner is dissatisfied with the current conception, or if the new concept is intelligible, plausible and fruitful. It is the responsibility of the teacher to introduce learners to this conceptual change through an appropriate and effective teaching process (Kurwa, 2016:18). The process of teaching and learning determines the achievement of the objectives of the content (Kotoka, 2013:24). To achieve the intended objectives, the teaching and learning of physical science should be done through scientific inquiry and the application of scientific models, theories and laws, in order to explain and predict events in the physical environment (DBE, 2013:8).

2.6.1 Teaching

The process of teaching plays an important role in the conceptualisation of any subject, and teachers are responsible for the process. Learners come to class with their own personal knowledge and experiences of the world they live in. While teaching science, the teacher's task is to create an awareness about the connections and relationships between classroom taught science content and learners' own personal knowledge and experiences of living in the world (Jack & Lin, 2017:138). This way of teaching, thus, helps to improve the conceptualisation of the topic.

2.6.1.1 Three approaches to teaching

Teachers' approach to teaching decides what they do as teachers. There are three basic approaches to teaching, and they are discussed below (Fenstermacher, Soltis & Sanger, 2015:4). The approach of the teacher determines whether the lesson is teacher centred or learner centred.

- Executive approach: The teacher following the executive approach is the sole manager of processes in the classroom. Outcomes are achieved using the best skills and techniques available. With this approach, the teacher carefully develops the curriculum materials and uses certain techniques to manage the classroom to produce learning.
- Facilitator approach: The teacher following the facilitator approach makes use of learners' prior experience and helps individuals grow personally, to reach self-actualization. Here, the teacher assigns high value to what learners bring to class and helps them to grow personally.
- Liberationist approach: With the liberationist approach, the teacher frees and opens the minds of the learners by assisting them to become well-rounded, knowledgeable, and moral human beings.

Researchers suggest that teachers need to be comfortable with all three approaches, even though they may have a preferred approach and this approach maybe dominant while the others are recessive. According to the situations in a classroom, a teacher maybe required to make the preferred approach recessive and bring in a different approach. Therefore, practicing all approaches are recommended by researchers, so that teachers can function well for effective teaching in different school settings, and with learners at different developmental stages, needs and interests (Fenstermacher *et al*. (2015:6) and Nezamedini, Rahimi and Borujeni (2013:286) also recommend that teachers are comfortable with all three approaches.

2.6.1.2 Teacher-centred and learner-centred classrooms

The three approaches explained above can be categorised into teacher-centred and learner-centred methods. Teacher-centred and learner-centred approaches each have their own strengths and weakness. A teacher-centred method can be more convenient for the teacher, because the teachers can pace the syllabus coverage, have control over the class and maintain discipline (Kotoka, 2013:26), which has advantages for the teacher. The executive approach is regarded as teacher centred, as the priority is the experiences of the teacher (Muganga & Ssenkusu, 2019:16). With a teacher-centred approach, learners do their work alone according to what they were taught, during or after the lesson. Here, the learners act as sources of answers for each other by following the instructions of the teacher exactly (Al-Zu’be, 2013:25).

In a learner-centred approach, the learners may work together in groups or pairs according to the activity provided. The approach emphasizes the experience of learners (Al-Zu’be, 2013:25; Muganga & Ssenkusu, 2019:16). The facilitator and liberationist approaches match the learner-centred approach, as the learners engage in active learning by participating in activities, rather than the teacher transmitting factual information (Labouta, Kenny, Anikovskiy, Reid & Cramb, 2018:1483). Teacher centred and learner-centred learning differs in the extent to which learner involvement takes place. In a teacher-centred approach, the teacher transfers knowledge through lectures, notes or handouts. The learners may be required to scribe what was taught, memorise the information and appear for assessments, which assess their ability to duplicate teacher-delivered material. However, a learner-centred approach requires learners to actively create their own knowledge through real-world experiences, activities and assessments facilitated by the teacher. Here, the duty of the teacher is to teach the learners the skills required to discover their own knowledge (Freire, 2018, in Muganga & Ssenkusu, 2019:17). Doing so helps learners to acquire so-called soft skills, such as problem-solving, critical thinking, collaboration, innovation and creativity (Froyd & Simpson, 2008 in Muganga & Ssenkusu, 2019:17; Huba & Freed, 2000:761, 763). However, in spite of its advantages, learner-centred teaching can be time consuming and may not be suitable for large classes. In such cases, a teacher can employ a mixture of teacher-centred and learner-centred approaches in the classroom (Muganga & Ssenkusu, 2019:17). Therefore, by mixing the teacher-centred method with the learner-centred approach, a teacher can have control over learning processes, while learners learn by using real-world materials, cooperative learning and inquiry-based investigations to develop the soft skills mentioned above (Muganga & Ssenkusu, 2019:17). In the context of learning physical science, mixing the methods can be achieved mainly through strategies such as demonstrations, questioning during demonstrations and direct teaching, deductive and inductive methods and problem-solving. The appropriate method and strategy can help learners to construct their own knowledge with the help of the teacher.

2.6.1.3 Inductive and deductive reasoning for teaching

The study of physical sciences consists of different types of knowledge, which includes facts, concepts, laws, generalisations, experiments and calculations. Hence, inductive and deductive reasoning are two teaching strategies that are often applicable in physical sciences lessons. Inductive reasoning moves from a specific set of observations to a specific pattern; in short, it moves from particular to general, and learners make specific observations and formulate generalisations (Babbie, 2013:22). A physical sciences teacher, through inductive teaching and learning, exposes learners to the skill of constructing their own knowledge by participating in activity-based learning (see 3.4).

In chemistry, learners study the law of conservation of mass in a chemical change as a basic concept. A teacher can use inductive reasoning to teach them about the importance of writing balanced equations for a reaction as follows. The teacher can write down the reactants and products in few reactions as an unbalanced equation and show that the total mass before the change is not the same as after the change. The imbalance is against the law of conservation of mass. However, by balancing the equations, the mass is conserved during a chemical change. By doing so, the teacher leads learners to the generalisation that all equations of reactions need to be balanced according to the law of conservation of mass. This realisation will help learners accept the general principle for a specific observation by reasoning inductively.

In deductive reasoning, a pattern that is logically or theoretically expected can be considered. Observations that test whether the expected pattern occurs can then be made. Hence, deductive reasoning moves from general to specific (Babbie, 2013:22). The laws and principles of physical sciences can be verified using deductive reasoning. While using deductive reasoning, learners can apply a generalisation to explain an observation. When using deductive reasoning to teach physical sciences, the teacher introduces the general principle and the learners practise the application of the principle. When teaching stoichiometric chemistry, the understanding of the mole concept and its general formula can be deductively applied to solve a calculation-based question.

Inductive reasoning is more learner centred and comes in different forms, such as learning through problem-solving, and learning through inquiry and discovery. Deductive reasoning is more teacher centred, as the learners receive knowledge from the teacher. However, later, it could become learner centred, when learners apply it to new situations (Rahmatian & Zarekar, 2016:255–256). In the teaching and learning of physical sciences, learners use both inductive and deductive reasoning to investigate natural phenomena and test or formulate generalisations.

2.6.1.4 Problem-solving

Due to rapid change in science and technology, the education system needs to be modified so that students can learn ways of accessing knowledge, and improving their skills of decision-making and problem-solving (Elvan, Güven & Aydoğdu, 2010:13). In problem-solving, learners or students are involved in active learning of new knowledge and field knowledge, and gaining skills to solve problems (Alberida & Barlian, 2018:2; Elvan *et al*., 2010:14, Kirtikar, 2013). Teachers can use problem-solving as a teaching strategy for teaching through problem-solving (Killen, 2015:259–260). When applying teaching through problem-solving, learners use their problem-solving skills to learn something new. When teaching through problem-solving, learners can use the following steps: i) understand the problem with the data available, ii) devise a plan by connecting the data with the unknown, relating to a similar problem or by considering auxiliary problems, iii) carry out the plan to get to the solution, and iv) examine the solution by looking back (Polya, 2004:33–36).

Teaching through problem-solving can be applied for learning many science concepts, by thinking systematically and relating the new problems to similar ones that have already been learned (Killen, 2015:265). Teaching through problem-solving is also applicable for conceptualising stoichiometric chemistry, where learners apply what they have learned to new situations.

To conceptualise the subject content in physical sciences, learners need to understand how to learn, comment on what they learned, and gain skills related to problem-solving by applying knowledge gained in the subject in daily life through scientific thinking. According to Polya (2004), problem-solving enables the teacher to introduce a learner-centred environment, in which learners construct their own knowledge using the scientific method, such as problem identification, hypothesising, analysing data and drawing conclusions (Alberida & Barlian, 2018:2). Science process skills are very important if learners are to solve science-related problems. Performing practical experiments is a way for learners to get involved in problem-solving through process skills. Process skills include observing, measuring, predicting, classifying and inferring (Elvan *et al*., 2010:15). To solve problems, learners need to have factual knowledge, conceptual knowledge and procedural knowledge.

- Factual knowledge refers to knowledge of certain terminology used in an academic discipline. Students need to acquaint themselves with these terms in order to solve problems in the discipline (Anderson *et al*., 2001:45; McMillan, 2011:43). Learners use facts to communicate, organise and conceptualise what they learn from a certain discipline in order to continue with problem-solving. In physical sciences, there is some terminology that forms a basis for the facts that learners use to communicate their understanding. For example, in physics, learners need to know the definitions of the different types of forces, directions of magnetic and electric fields, and the relationship between current through a circuit and resistance in the circuit. In relation to the current study, in stoichiometric chemistry, for example, learners need to know the laws of conservation of mass, moles, molar mass and limiting reactants and the mole-concept formulae.

- Conceptual knowledge is considered at a higher level than factual knowledge, as it is more complex and organised form of knowledge. By acquiring conceptual knowledge, the learners will be able to provide scientific explanations for concepts and to apply the explanations to solve problems (Anderson *et al*., 2001:48). In physics, for example, learners acquire conceptual knowledge of Newton's laws of motion and use it to explain how a force on an object affects its acceleration. In the current study, in stoichiometric chemistry, the conceptual knowledge about conservation of mass, limiting reactants and stoichiometric ratios in a balanced equation helps learners to solve problems related to a chemical reaction.
- Procedural knowledge enables a learner to apply factual and conceptual knowledge to solve problems. Procedural knowledge can be called the knowledge of how to do something (Anderson *et al.*, 2001:52). While factual and conceptual knowledge is concerned about the 'what' of the knowledge, procedural knowledge represents the 'how' of the knowledge. It represents knowledge of different processes that need to be applied during problem-solving (Anderson *et al.,* 2001:53). For example, in solving stoichiometric calculations, learners need to follow certain procedures after understanding the problem, in spite of possessing factual and conceptual knowledge.

2.6.1.5 Inquiry-based teaching

Inquiry-based teaching was developed to promote learner-centred teaching and it is considered an important prerequisite for effective teaching and learning to take place. The fundamental concept in inquiry-based learning is personal discovery by learners. According to Ismail and Elias (2006:14), while learners are learning through inquiry, they are guided to ask relevant questions and to come up with the appropriate answers through critical thinking. Through inquiry-based learning, learners acquire in-depth knowledge of their subject matter, structure their knowledge so that it is readily accessible, transferable and applicable, and, with little effort, acquire new information related to what they already know. In-depth knowledge will be gained, as the learning starts by posing questions and developing hypotheses about concepts. Learners investigate the hypotheses and end with conclusions and evaluations. Learning through inquiry supports constructivist-based learning (Rutten, Van der Veen & Van

Joolingen, 2015:1227). These researchers propose the POE model – predict, observe and evaluate – for inquiry-based learning. A teacher using the POE model will guide the learners to make predictions about a certain concept, and do observations through investigation. The observations done will be evaluated, and conclusions reached. The conclusion will determine whether their prediction was correct or not. This way of learning helps learners construct their own knowledge.

2.6.2 Learning

Research indicates that, for learning to happen, learners need experiences of their own, and they have to organise these experiences and connect them, to cause a relatively permanent change in their knowledge or behaviour (Woolfolk-Hoy, 2004:178). Physical sciences – a subject with extensive quantitative component – have cognitive prerequisites for learners, so that they can do scientific and analytical thinking. The teacher needs to develop concepts and principles for any learning outcome, to support a certain cognitive level of thinking by learners. Later, learners must also be able to practice what they have learned (Dhurumraj, 2013:2).

2.6.2.1 Science learning from various perspectives

After teaching physical sciences for years, I understand that learners learn science in different ways and, hence, physical sciences learning cannot be achieved through a ‘one size fits all’ way of thinking. I also understood that common practices, such as a teacher explaining the content and the learner duplicating what was taught for tests or examinations, does not help learners to learn science with understanding. Thousands of research studies have been conducted in classrooms, and have found that learners, even adults, do not achieve science learning as it is supposed to be with this method (Anderson, 2007:5; Anderson, 2013: 22). Researchers point out that learners do not learn what teachers try to teach them and, as a result, a gap exists in the achievement of learning. Therefore, the current study found it necessary to understand how learners learn, why learners fail to learn and what the needs are to achieve learning.

2.6.2.2 Conceptual change research for learning

Based on studies by Piaget about how learners make sense of the world and how they think, conceptual change research emerged. According to conceptual change research, learners come to class with different understandings about science concepts, which shape their perceptions and interpretations of science. Anderson (2007:11-12) explain the characteristics of conceptual change research as follows:

- To study and account for a wide range of science phenomena in nature, scientists have developed powerful models. These scientific models and model-based reasoning helps us understand science better. Hence, researchers propose that science education must provide learners with access to these scientific models, so that learners can be included in the theoretical dialogue that scientists have with nature.
- Learners and students come with alternate frameworks, naïve conceptions, or even misconceptions regarding scientific phenomena. These ideas are less powerful than scientific theories, and learners need access to new experiences with the material world that are different from their own ideas. Thus, the new experience they gain will help them to achieve a more powerful understanding of scientific phenomena. This is a very complex process of conceptual change. In the current study, the researcher wanted to determine whether the new experience of learning stoichiometric chemistry using computer simulation brought a conceptual change and better understanding of topics.
- Making use of written tests and interviews before and after instruction to construct an argument of how learners and students learn, is another characteristic of understanding how conceptual change can happen. In the current study, the researcher used a pre-test, a post-test and interviews to determine whether a conceptual change happened during the teaching of stoichiometric chemistry.
- The method used for instructional intervention is also characteristic of conceptual change research. Traditional methods were found to be inadequate and, hence, instructional methods or situations that introduce conceptual conflict are needed. In this way, learners or students can see the contrast between their conceptions, and alternative scientific conceptions, with their

superior power and perceptions. Based on this understanding, the current study focused on whether using computer simulation to teach stoichiometric chemistry could cause an improvement in the conceptualisation of the topic.

According to Anderson (2007:12), conceptual change research could explain why learners fail to learn what they were taught, that is, because teaching science could not address the alternative conceptual frameworks that had shaped their perceptions and interpretations that they already had. For conceptual change to happen, learners need to change their conceptions about a phenomenon or principle by restructuring and or integrating the new information gained into their existing schemata (Nomvuyo, 2018:19).

2.6.2.3 Sociocultural research for learning

While conceptual change research is based on Piaget’s emphasis on how learners learn by interacting with the material world, sociocultural research focuses on Vygotsky’s approach, which is that that learners learn by participating in activities with other people. The characteristics of sociocultural tradition, as explained by Anderson (2007:18–19), is explained below.

- Sociocultural research focuses on the scientist’s interaction or dialogues with people. According to this research, scientists are participants of communities of practice, and share social values, norms and patterns of activity. Through science education, learners are able to control the linguistic and cultural resources that they need to participate in the community.
- Students are participants in multiple communities of practice, each with their own language, values and practices. Students learn science when they can adopt scientific languages, values and norms for scientific practices, like inquiry-based learning and application of scientific concepts.
- Understanding interaction between learners, to analyse the learners’ culture, language and practices, also plays an important role in sociocultural research.
- The question of how learners and teachers communicate meaningfully across linguistic and cultural differences needs to be considered. So, sociocultural researchers focus on how learners master the language and culturally

embedded practices. As a result, scientific discourses and knowledge need to be discussed and combined for learning (Anderson, 2013:20).

Therefore, in answer to the question, why do learners fail to learn, sociocultural research says that students must, first, deal with hidden cultural conflicts and conceptual conflicts. It summarises that social interaction and social foundations can determine the successful acquisition of knowledge.

2.6.2.4 Critical tradition research for learning

While researchers of conceptual change and sociocultural tradition give hidden conceptual conflicts and cultural conflicts as the reasons for students' difficulty to learn, critical tradition researchers are concerned with the ways in which these conflicts are shaped. The characteristics of critical traditional research explained by Anderson (2007:23-24) are summarised below.

- Critical tradition researchers report that science is inherently ideological and institutional, and advantaged and dominant classes of people decide on what the truth must be.
- Critical tradition researchers understand science education as a form of indoctrination: students accept the knowledge that serves the interests of the powerful, as true. Therefore, researchers recommend that students/learners criticize the relationship between communities and other powerful interests.
- Critical tradition researchers recommend acquiring unbiased, impartial knowledge from intersubjectively shared theoretical perspectives and life experiences.

Critical tradition research challenges science educators to think about their own roles in maintaining injustice and inequality in schools. Critical tradition research has analytical tools to expose the culture of power in institutions, and propose how science education must take place, and what knowledge learners must be taught. Critical traditional researchers point out that the achievement gap will persist, as science education serves the interests of those who benefit from their preferred access to and control over scientific knowledge (Anderson, 2013:24; Anderson 2007:23–24).

The various traditions of learning discussed above discusses the nature of grounded knowledge and give a collective, deep and richer insight into the science of learning when brought together, rather than considering each tradition alone (Anderson, 2007:26).

2.6.2.5 Cognitive load and learning

A discussion of chemistry and stoichiometric chemistry, dealing with abstract concepts and the resulting difficulties with learning it, was given in Chapter 1 (see 1.1.) The subject's abstract concepts increase the cognitive load of the learners and reduce learners' motivation to learn these concepts. The cognitive load theory of Sweller (1988) explains how people learn. According to this theory, the part of our mind that processes information can only deal with limited amount of information at a time. The theory explains the cognitive load of a person as comprising three types (Sweller 2010:124-126):

- Intrinsic cognitive load: Caused by the inherent difficulty of the material itself, which can also be influenced by prior knowledge of the topic.
- Extraneous cognitive load: Caused by presenting the material in a way that does not promote learning.
- Germane cognitive load: Caused by elements that aid information processing and contribute to the development of schemas.

To reduce intrinsic cognitive load, the subject content needs to be sequenced into subtasks, to avoid learners being overwhelmed too early on when introducing a new and abstract topic. In the current study, to reduce the intrinsic cognitive load, the content of stoichiometric chemistry was sequenced into subtasks and learners were taught the steps for solving stoichiometric calculations. Extraneous cognitive load can be reduced by changing the way instruction is conducted. This was addressed by the method of teaching the teachers used for the two groups: One group was taught according to the lecture method (direct teaching), and the other group was taught by using simulation. In the case of germane cognitive load, learners learn a new topic by referencing a schema or mental model of pre-existing knowledge. So, when the knowledge is not presented clearly, learners experience high cognitive load in their working memory, and they will have to spend more time solving the instructions, than acquiring new schema information (Sweller, 2010:124-126).

2.6.2.6 Conceptions of learning and conceptualisation

To improve the learners' conceptual understanding in physical science, we need to understand how they learn science. Researchers have explored students' conceptions of learning and suggest that learners treat learning science as memorising, preparing for tests, calculating, practising tutorial problems, increasing knowledge, applying, understanding and seeing in a new way (Chiou, Lee & Tsai, 2013:3). Learning is a sequential process involving the above conceptions of learning, and the individual first treats learning as memorising. During exposure to learning, the learning experiences help the learner to conceptualise the learning as applying and understanding, and lastly, seeing it in a new way. Conceptualisation occurs when learners, beyond learning facts and skills to uncover concepts, can transfer their learning to new situations (Chiou *et al*., 2013:3; Marschall & French, 2018:2). These researchers assert that the first three conceptions of learning stated above refer to a passive way of learning, which involves copying and reproducing the learning material. The last four conceptions of learning in the sequence results in active learning processes that transform what the learner has perceived from the learning material into a meaningful whole and enable the learner to make connections between concepts. This could help in deep learning of a concept. Intentionally designing the learning activities helps learners to move between the factual and conceptual levels of thinking, and helps them construct understanding, facilitate the transfer of knowledge in new situations and build a sense of agency – this will result in deep learning (Marschall & French, 2018:3). The current study sought to determine whether designing lessons incorporating simulation had an effect on the conceptualisation of stoichiometric chemistry.

2.6.2.7 Metacognition and learning

Metacognition refers to a learner's awareness of his or her own learning and learning in general. The active learning process happens when learners construct their own knowledge by applying cognitive skills, which include remembering, understanding, applying, analysing, evaluating and creating (Anderson *et al*.,2001:63). Metacognitive knowledge, which is knowledge about one’s own cognition, plays an important role in helping learners construct their own meaningful learning. As learners learn, they need to be made aware of and responsible for their own knowledge and thought. When they are aware of their own knowledge and cognition, learners will act on this awareness, and then tend to learn better (Anderson *et al.,* 2001: 55). Therefore, when learning has taken place, learners will be able to appreciate the role of science in society, and this will cause changes in their behaviour (Koti, 2016:20,36). When learning occurs in this way, it will change the learners’ impression that physical sciences is difficult and will motivate them to continue learning physical sciences at secondary and tertiary levels. As solving stoichiometric problems is difficult metacognition is necessary in solving stoichiometric chemistry problems involving the visualization of the macroscopic, microscopic and symbolic levels. According to researchers, learning stoichiometric chemistry involves acquiring skills in writing chemical formula, chemical equations and mathematical skills. Investigations on stimulating chemistry students to generate complex questions enabled with a metacognitive strategy showed that the strategy enabled the students to be aware of their cognitive process and to self-regulate it according to the learning task. It was also found that science students model their teachers in relation to the cognitive and metacognitive skills that are demonstrated to them during the teaching process. (Sujak & Daniel,2018:85). The study done by the researchers showed that students succeeded in solving stoichiometric problems when metacognitive strategies are infused in the teaching process. The metacognitve strategies helped the students to convert their visualisation from macroscopic to microscopic and to symbolic levels (Sujak & Daniel, 2018:93).

2.7. POOR PERFORMANCE OF LEARNERS IN PHYSICAL SCIENCES

In the South African curriculum, natural sciences, which is a combination of physical sciences, life sciences and earth sciences, is a compulsory subject in Grades 8 and 9. However, in Grade 10, learners can choose whether they wish to study physical sciences as a subject. After having worked as a physical sciences teacher in both previously disadvantaged township schools and former Model C schools, I have observed a decline in the number of learners choosing physical sciences as a subject in Grade 10. I have also noticed that many learners drop the subject after Grade 10. The reason they give for abandoning the subject is that physical sciences is difficult. Poor performance in physical sciences and the low enrolment of students in science subjects at tertiary institutions have been reported as posing a threat to South Africa's development and economy (Ngema, 2016:1). Learners' poor performance in science in South Africa, compared to other countries, in the international benchmark tests is reported by Trends in Mathematics and Science Studies (TIMSS). The report points out that South African learners perform far below the international mean (Arends, Winnaar & Mosimege, 2017; Mji & Makgato, 2006). Investigations have identified several causes of poor performance, among which poverty of the learners, availability of resources and poor infrastructure at schools, poor learning culture, and inexperienced and underqualified teachers. Three causes facing South African schools will be explained in the next sections.

2.7.1 Teachers and their teaching methods

As the knowledge gained by learners is influenced by the perceptions of science teachers and teachers' content knowledge, schools with underqualified teachers are likely to experience learners performing poorly in the subject (Mji & Makgato, 2006:254; Ngema, 2016:28) Teaching approaches, and the ability of teachers to create a learner-centred approach were discussed in Sections 2.6.1.1 and 2.6.1.2. A teacher must possess knowledge about content, knowledge about teaching and knowledge about learning, and apply all these types of knowledge, known as PCK, together to achieve effective teaching (Killen, 2015:31). If teachers do not make use of their PCK or fail to apply appropriate teaching approaches and methods to transfer knowledge, learners struggle to conceptualise topics, and it leads to them dropping physical sciences in Grade 11 or opting not to take it as a subject in Grade 10 (Mji & Makgato, 2006:260; Semeon, 2014:2). Therefore, teachers need to have the correct approach, and the necessary PCK for teaching science, to prevent learners developing a negative attitude to learning physical sciences. These precautions can, to some extent, prevent poor performance.

2.7.2 Resources

Schools' poor infrastructure, and shortages of resources, such as textbooks and laboratory equipment, lead to a lack of interest in both learners and teachers, and prevent effective learning taking place (Karue & Amukowa, 2013:105; Mji & Makgato, 2006:260). To achieve effective learning in physical sciences, learners need to be exposed to practical experiments and demonstrations, to reinforce the scientific concepts that they have been taught, and to help them remember the content. However, many schools lack these resources (Dhurumraj, 2013:14).

2.7.3 Language of learning

Another reason that has been reported as being a hurdle to learning physical sciences, is the language of learning. A subject taught in learners' second language makes deducing the meaning of the science concepts difficult, assert Mtsi & Maphosa (2016: 60), Koti (2016), Kurwa (2016) and Setati (2011). This could be the reason why some learners perform well in physical science when Afrikaans is the language of instruction at school and their home language (Simelane, 2019:24). The only two languages in which learners can be taught and may write physical sciences in the South African curriculum are English and Afrikaans. English is a second language for the majority of learners in South Africa. When physical sciences are taught in English, learners' lack of proficiency in the language makes it difficult for the learners to communicate their understanding correctly (Ngema, 2016:119). Some learners complain that it is difficult to understand some of the concepts in physical sciences due to the language barrier (Mji & Makgato, 2006:261). Thus, language becomes a challenge for learners' performance in physical sciences. Teachers are advised to reduce the complexity of the concepts by giving proper explanations and practical demonstrations and activities, thereby ensuring better learning experiences. (Ferreira, 2011:103; Mokiwa & Msila, 2013:58). For the current study, it was investigated whether using simulations would reduce the complexity of the concepts when the teacher explains the concepts while the learners visualise the microscopic form of the reactants and products and engage in activities.

In addition to these three major reasons for poor motivation and poor performance, content overload, failure to complete the syllabus, learner absenteeism, the socioeconomic background of learners, and large classes are also reported as reasons for the poor performance of learners in physical sciences (Basson & Kriek, 2012:116; Dhurumraj, 2013:19-20; Mji & Makgato, 2006:261; Ngema, 2016:120–121; Simelane, 2019:17).

2.8. CHEMISTRY AS A BRANCH OF SCIENCE

The current topic of study, stoichiometric chemistry, falls under chemistry. This section will provide a brief explanation of the importance of studying chemistry as a branch of science. Chemistry is the study of all matter around us. Everything on earth is made up of tiny particles called atoms, and this confirms that chemistry is one of the core enabling sciences. In order to study biology and earth sciences, learners need to have a basic knowledge of chemistry (Dahsah & Coll, 2007:573; Edomwonyi-Otu & Avaa, 2011:2). According to Sevian and Bulte (2015:55), chemistry is a field of study in which students can practice their chemical knowledge by evaluating benefits, costs and risks associated with products and processes, and make informed decisions. Chemistry explains the whys and hows of the chemical phenomena that exist around us. As chemistry deals with the structure of matter around us, it enables us to understand what happens around us, which makes it one of the most important branches of science (Sirhan, 2007:2). Photosynthesis, which is the basis of life on earth, how cooking food changes it, how fireworks work, how iron and other metals corrode, and many other examples show the importance of chemistry in our lives. Chemistry has, therefore, developed as a discipline in natural sciences to meet the needs of man, and also to explain and predict the behaviour and happenings in nature by making use of theoretical models (Ross, 2016:1). Chemistry is a subject that also involves experimentation, by making use of chemical resources and equipment in laboratories. Conducting experiments is a means of enhancing the learning of chemistry, as the results obtained through experimentation are more memorable than when facts are taught through mere explanation (Ibrahim, Surif, Pei Hui & Yaakub, 2014:4946).

2.9. TEACHING AND LEARNING CHEMISTRY

The teaching and learning of physical sciences, in general, were discussed earlier (see 2.6.1 & 2.6.2). Physical sciences in the South African curriculum consists of physics and chemistry, as Paper 1 and Paper 2 at the secondary school level. Stoichiometric chemistry is a topic that is dealt in Grades 10–12 under chemistry. As the current study dealt with the conceptualisation of stoichiometric chemistry, the first secondary research question was about the value and importance of teaching and learning chemistry in the South African context (see 1.4.2.).

2.9.1 Value and importance of chemistry

Chemistry has been identified as an important science subject. Its importance for the scientific and technological development of some nations is reported by Edomwonyi-Otu and Avaa (2011:1) (also see 1.1). These researchers point out that the purpose of chemistry education is to maintain the economic wealth of modern societies. Researchers confirm that chemistry is at the heart of the economy of any developed or emerging country, as it is the foundation of modern agriculture and pharmaceutical industries and provides the basic materials for many other producing industries (Eilks *et al*., 2017:97). At the same time, it needs to be acknowledged that many underdeveloped countries still need to realise the importance of chemistry in the development and economic growth of their countries (Burger, 2019:1). In many countries, including South Africa, chemistry is recognised as a subject that promotes the development of individuals and the nation, hence, it is an important subject at schools in South Africa. It is a prerequisite subject for enrolling for any science-related courses at tertiary institutions.

Research conducted in Nigeria by Okoye (2009:561) reports that good performance in science has high value in society, as it is considered to be a stepping-stone for entering prestigious occupations. Hence, chemistry learners can dream of a better future with tremendous opportunities if they aim to pursue a career in chemistry. Furthermore, chemistry education provides the country with scientifically literate citizens who are free of false beliefs and superstitions. Moreover, it helps to promote understanding and appreciation of the sustainable use of the environment, thereby promoting healthy lifestyles (Kurwa, 2016:1), which is essential for the African context.

Despite the negative impact that chemicals have on our environment, chemistry is economically and ecologically sustaining the developing world (Eilks & Hofstein, 2015:2). This is because chemical science plays a vital role in improving materials' security and efficient use, through reusing, recycling, reducing and replacing the necessity to use expensive or critical resources. The relevance of chemistry education was studied by Eilks and Hofstein (2015:5), and they summarise their findings as follows. Chemistry education becomes relevant in students' lives when the learning has positive consequences. Chemistry education fulfils actual needs pertaining to students' interests or educational requirements, and anticipation of future needs of their lives. Chemistry is also vital to our society, because of its impact upon the knowledge necessary to achieve and maintain good health. For example, the pharmaceutical chemistry contributes a great deal to the field of medicine and to maintaining good health, in spite of some people misusing the resulting products.

By providing appropriate learning experiences in chemistry, learners can broaden their skills and knowledge, which helps to increase productivity, thereby reducing poverty and unemployment among the youth of a nation. Chemistry can, thus, play a major role in solving many challenges faced by African nations, and in developing the continent (Lerman, 2014:80). Chemistry permeates several branches of industry, including agriculture, biotechnology, engineering, environment and medicine. It serves as the foundation for understanding biochemistry, molecular genetics, physics, geology and physiology. The mole concept in chemistry plays an important role in analytical techniques, such as proteomics, enzyme assays, spectrophotometry and photochemistry (Arya & Kumar, 2018:9). In South Africa, agricultural industries and the integrated energy and chemical company known as Sasol contribute to the economy of the country and provide employment opportunities. Economic activity in modern-day South Africa focuses on mining, as South Africa is rich in minerals, and relies heavily on the mining industry for economic development. This means chemists have many job opportunities in the mining industry (Mtero, 2017:191). The chemical sector is an upstream sector of mining, manufacturing and agricultural industries, and the growth of the chemicals sector in South Africa has led to a need for knowledgeable and skilled people (Burger, 2019:1).

2.9.2 Difficulties related to learning chemistry

Researchers report that poor performance in chemistry by learners and students is due to difficulties they experience in learning the subject (see 1.2.1). It has been found that learners perform poorly in chemistry (see also 2.7) due to the following reasons: teachers' incompetency in delivering concepts appropriately; lack of laboratory and other facilities; teachers' and learners' attitudes towards the subject; constraints on providing learners with adequate time to practise; lack of teacher professionalism and morale and environmental constraints (Edomwonyi-Otu & Avaa, 2011; Kurwa, 2016; Mammino, 2014; Ross, 2016; Simelane 2019:13). In addition to these reasons, Broman *et al.* (2011:44) report that misconceptions and problems with models and modelling often make learning chemistry difficult. They conducted a study that identified which areas in chemistry secondary school learners find easy or difficult. They report that topics relating to atoms and molecules are the least interesting areas for learners, which results in few students studying chemistry at the tertiary level. The mole concept and reaction stoichiometry – the topic of the current study – are two domains in chemistry that learners tend to find problematic. Learners in South Africa who continue their study of chemistry at the tertiary level generally perform poorly, despite these topics being covered in the secondary school curriculum (Malcolm, Rollnick & Mavhunga, 2014:135).

Mammino (2014:41) reports on the challenges faced by learners and students in learning general chemistry:

> *the challenges are largely related to the nature of chemistry as a science characterised by fundamental interplays: interplay between microscopic and macroscopic descriptions and interplay between qualitative and quantitative methods.*

These interplays pose substantial learning challenges, due to their inherent complexity. The qualitative and quantitative interplay is extensive in chemistry, and they play essential roles in conceptual understanding and in applications in stoichiometric calculations.

Ross (2016:24) reports on a study done at a South African university, which found that students lack motivation, self-discipline, concentration and interest in chemistry, resulting in a negative attitude towards its learning. Any learner or student studying chemistry must be able to meaningfully communicate abstract ideas by thinking about them at the macroscopic, molecular and symbolic levels. However, science teaching in South Africa occurs at the symbolic level only, due to a lack of resources, few well-equipped laboratories, and the application of inaccurate models. These drawbacks become a challenge for teachers, who should make use of appropriate teaching methods. Teaching methods that are inappropriate for the level of the learners is a major reason for learners fearing the subject (Mihindo *et al*., 2017:66).

2.10. STOICHIOMETRIC CHEMISTRY: QUANTITATIVE ASPECTS OF CHEMISTRY

As mentioned in Section 2.4, in the South African school curriculum, physical sciences consist of physics and chemistry. The chemistry part comprises three sections, namely, matter and materials, chemical change, and chemical systems. The focus topic of the research, stoichiometric chemistry, falls under chemical change. The topic of stoichiometric chemistry is an important topic in the secondary school curriculum of South Africa, as it deals with the quantitative aspects of chemistry (Malcolm *et al*., 2018:134) (see also 1.2.1). Researchers report that both teachers and learners find it a difficult section of chemistry. Conservation of matter and chemical change are two important concepts in the study of stoichiometric chemistry. Conservation of matter is the basis of any study of chemical change. According to the law of conservation of matter, as discovered by Antoine Lavoisier, matter is neither created nor destroyed. Therefore, one should understand that any reactant that is involved in a chemical change will be conserved by its quantity. The stoichiometry of the reaction and the balancing of the equation are based on this concept, which will be explained in detail in the following sections.

2.10.1 Brief overview on stoichiometry and the mole concept

The term stoichiometry was introduced by the German chemist Jeremias Richter in 1792 to measure ratios by the mass of chemical elements when they combine. The term stoichiometry is derived from the Greek word *stoicheion* (meaning element) and *metron* (meaning measure) (Upahi & Olorundae, 2012:181). Mole is the term used in chemistry to express the amount of a substance that is fundamental to introductory chemistry. It was firstly introduced by Ostwald in the beginning of the 20th century. The symbol for mole is *n*. In Latin, the word mole means big mass, and adding the suffix cula to mole, converts the word to the term *molecula,* meaning small or tiny. The term molar was first introduced by the German chemist Hofmann, and was derived from moles, which means large mass – the opposite of the term molecular mass. The terms molar and molecular stand in place of the terms microscopic and macroscopic. Later on, the term mole began to be widely used without any discussion of the nature of the quantity it referred to (Pekdağ & Azizoğlu, 2013:117). Ostwald wanted to treat mole as a macroscopic term that could be used to discuss the laws of stoichiometry. In 1971, the International Union of Pure and Applied Chemistry, the International Union of Pure and Applied Physics and the International Organization for Standardisation recommended adding mole as the basic unit of the amount of substance into the International System of Units (SI). They described mole as the amount of substance of a system that contains as many elementary entities, as there are in atoms of 0.012 kg of carbon-12 with the symbol mol (Pekdağ & Azizoğlu, 2013:118).

Figure 2.1 is based on the study done by Malcom *et al*., (2014:5) on stoichiometric chemistry and shows the important terms that need to be conceptualised when using the mole concept.

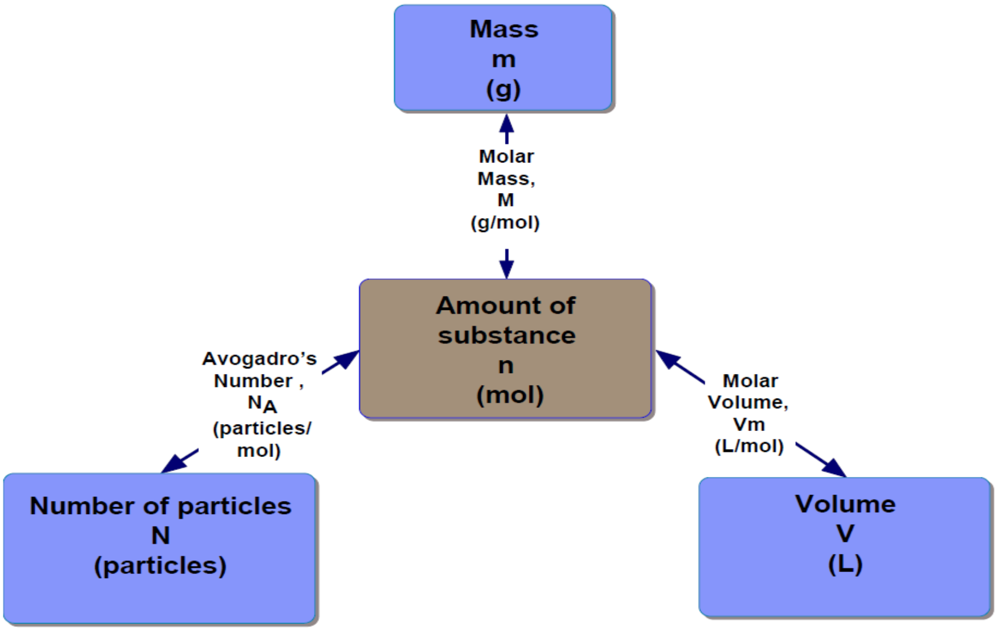


Figure 2.1: The moles and the other terms that represents quantity of a substance

The terms given in the blue blocks in Figure 2.1 are the different quantities in which substances are expressed when dealing with stoichiometric calculations. Each of them has a relationship with the amount of substances, mol. Calculations based on the mole concept use certain basic formulae. These formulae connect the mol (n) – the central block in the Figure 2.1 – with the mass (m) of the substance, molar mass (M) or atomic mass, number of particles (N) and volume (V) of the substance with gases involved. These formulae need to be applied in calculations when the amount of substances needs to be converted between mol and other quantities, such as mass, volume and number of particles. One mole of a substance can be equated to a certain mass of each substance in grams, number of particles and volume, and these interconversions are the basics of stoichiometric calculations.

Figure 2.2 shows the relationship of the mole with mass, molar mass, number of particles and volume (Fang *et al*., 2016:186).

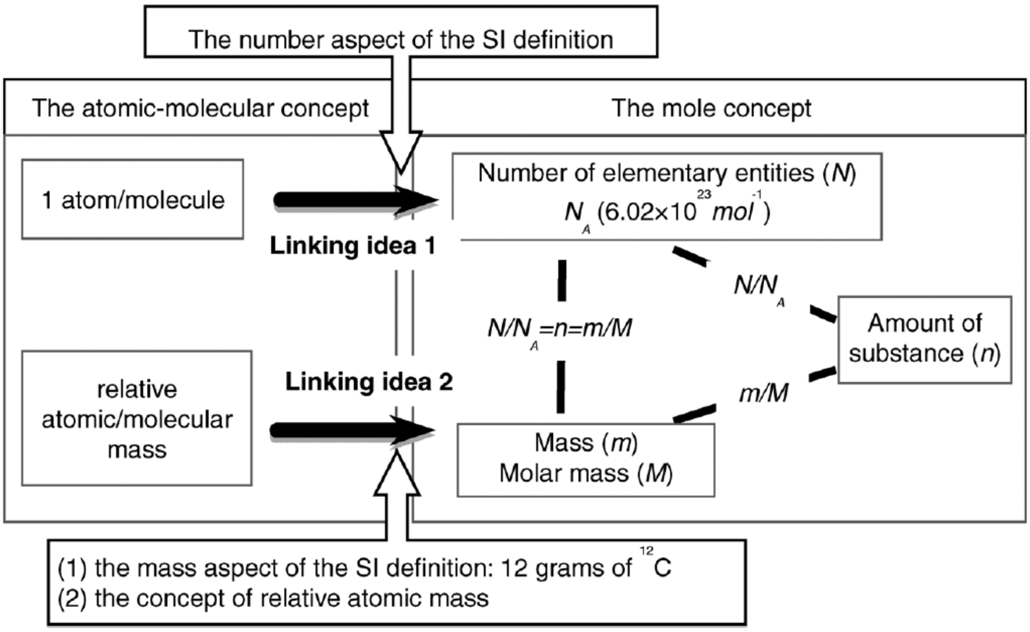


Figure 2.2: Concept map showing relationship of moles with other quantities

The concept map in Figure 2.2 can be explained as follows.

For a better understanding of the mole, the atomic molecular concept is incorporated with the mole, and the two are connected by the two linking ideas, as shown in the concept map. The meaning of the mole can be understood through two aspects, either through the number aspect, or through the mass aspect. The number aspect can be explained further with an example. If there are two moles of Ne-20, then the substance will consist of 2 x 6.02 x 10^{23} Ne-20 atoms. (Ne-20 refers to the element neon with atomic mass 20.) This is because one mole of any substance will consist of 6.02 x 10^{23} elementary entities. The mass concept, expressed in grams, can be explained by the relationship between the atomic mass/molar mass and the associated mass in grams. One mole of any substance will have a mass equal to its atomic mass or molecular mass or formula mass – it is called molar mass, with the unit grams per mole ($gmol^{-1}$). If there are 2 moles of Ne-20, the total mass will be 2 x 20, which is equal to 40 grams. These two aspects apply to the atomic-molecular concept. This explanation leads us to the key emphasis, that the number aspect deals with the substance composed of atoms or molecules, and the mass aspect deals with relative atomic mass or molecular mass or formula unit mass. The relationship between the amount of substance (n), number of elementary entities (N), and mass (m) or molar mass (M), are linked by the three formulae.

$$n = \frac{N}{N_A} \text{ and } n = \frac{m}{M} \text{ and } \frac{N}{N_A} = n = \frac{m}{M} \quad \text{(combining the first two)}$$

Linking idea 1 and linking idea 2 in the concept map connect the atomic-molecular concept with the mole concept. Linking idea 1 is the number aspect for the SI-accepted definition of the mole. Linking idea 2 shows the connection between molar mass and relative atomic mass, which can be used to explain the numerical identity between them.

There is a problem-solving approach that teachers can use to teach learners to calculate moles and their interconversions with mass, number of particles, volume for gases and concentration for solutions (Arya & Kumar, 2018:8), which can be summarised as follows:

- Write down the data provided and look for what needs to be calculated.
- Select the appropriate formula that connects moles with what needs to be calculated.
- Calculate molecular mass (M) if not given, and if needed.
- Substitute what is given and then find the unknown by changing the subject of the formula.

For further learning on the topic, learners need to determine the quantity of a reactant or product in a chemical reaction – this fall under the quantitative aspects of chemistry, and is the reason why stoichiometric chemistry is the branch of chemistry that studies the quantitative aspects of chemical reactions, which involves problem-solving in relation to the relationships between the number of moles of reactants and products (Hanson, 2016:2; Okanlawon, 2010:28). The conceptualisation of stoichiometric chemistry enables students to efficiently solve numerical problems related to chemical reactions, concentrations, amounts of substances, titrations and chemical equilibrium (Hanson, 2016:1). These concepts are fundamental to quantitative chemistry. Failing to understand and connect these concepts creates conceptual problems for learners.

For solving problems in stoichiometry, the learner needs to do calculations on molar mass of compounds, write balanced chemical equations, apply the mole concept, determine the limiting reagent, mass percentage and percentage yield, use ratios in balanced equations, and find the empirical and molecular formula (Gulacar, 2007:4). According to my experience of teaching stoichiometric chemistry at high schools a few years back, learners must possess certain basic knowledge if they are to do the above calculations and interpret balanced equations. However, many learners lack this understanding. As fundamental knowledge I teach that every chemical reaction takes place in certain proportions, which is obtained from a balanced equation – this also explains the relationships between the reactants and products in a chemical reaction. When analysing a balanced equation, the coefficients indicated before the chemical formula show the amount of reactants reacted, and the products formed, according to certain proportions or ratios. These coefficients represent the ratio in which reactants react and products form. When doing calculations, the coefficients can be interpreted as the mole ratio of the reactants and products.

In the South African curriculum, the study of stoichiometric chemistry starts in Grade 10, as the quantitative aspects of chemical change, with balancing chemical equations, calculating molar mass, mole concept, determining empirical formulae, molecular formula and mass-mole ratio calculations as the main content. More complex calculations with limiting reagent/reactant, percentage yield and percentage purity are covered in Grade 11. According to Gauchon and Méheut (2007:362), a thorough understanding of stoichiometry requires an understanding of limiting reagent and excess reactants in a chemical reaction, which means it is particularly important that Grade 11 learners conceptualise what a limiting reagent is and how it affects the quantity of the product formed. The limiting reagent is the substance that is completely used up first in a reaction, and the amount of products formed depends on the amount of this reactant. The ratio of the limiting reactant and the product needs to be considered to calculate the amount of product formed.

Reaction stoichiometry also involves problem-solving in relation to theoretical yield and actual yield. Theoretical yield is the maximum amount of product formed when all the limiting reagent has reacted according to the balanced equation without any loss. However, in reality, most reactions do not happen perfectly. So, when performing an experiment for a chemical reaction, the amount of product formed will be less than the theoretical calculations, and it is called the actual yield. Calculations with percentage purity of a sample is another part of reaction stoichiometry. This calculation becomes important when an impure sample is made use of in a reaction. The percentage purity of the impure sample can be determined by reaction with a pure compound as in an acid-base titration. In Grade 12, all the topics of chemistry need to be integrated with stoichiometric calculations, as recommended in the technical report of the DBE (see 1.2.1).

2.10.2 Conceptualisation of stoichiometric chemistry

According to Upahi and Olorundare (2012:181),

> *stoichiometric chemistry basically involves relating the mass of a substance to atoms, molecules or formula units; converting the result of the composition analysis into a chemical formula; and applying the quantitative information held within them.*

Stoichiometric chemistry lays the foundation in chemistry, and its level of conceptualisation affects understanding of the advanced concepts; failure to grasp this foundation makes chemistry a difficult subject. Failure to understand and connect the concepts in quantitative chemistry creates conceptual problems for learners at the school level, and for students at the tertiary level (see 2.6.2.2). If students do not fully understand the fundamental concepts in chemistry, it will affect their understanding of the more advanced concepts that build upon the fundamental concepts (Osman & Sukor, 2013:433; Woldeamanuel *et al.*, 2014:32).

It is important to have a better understanding of the various challenges facing the teaching and learning of stoichiometric chemistry, including the teaching of stoichiometric chemistry, misconceptions related to the understanding and interpretation of stoichiometric chemistry, and the difficulties students experience in understanding the concept.

2.10.2.1 Misconceptions and difficulties related to learning stoichiometric chemistry

Despite the relevance of stoichiometric chemistry, studies report that learners find stoichiometric calculations difficult. Literature also reports evidence of learners' and students' misconceptions about and failure to understand stoichiometric chemistry. Bridges (2015), Fach *et al.* (2007), Gauchon and Meheut (2007), Opara (2014) and Upahi and Olorundare (2012) have reported on learners' failure to understand the concepts in stoichiometric chemistry. However, little research has been done on improving the conceptualisation of stoichiometric chemistry.

Becuse learners do not conceptualise in stoichiometry, they lack the confidence and ability to master chemistry (Bridges, 2015:15). Malcolm *et al*. (2018:135) argue that learners find it difficult to perform well in stoichiometric calculations, due to their lack of conceptual understanding of the mole concept, their failure to construct and balance chemical equations from a reaction given, lack of mathematics skills, and finding it difficult to interpret word problems into steps that they can proceed with to solve a problem based on the quantitative aspects of a reaction.

Many learners think that mole is an abbreviated form of the term molecule, and some use the terms atom, molecule, element and compound interchangeably, without knowing the differences between these terms (Ndlovu, 2017:11). Yaayin and Ayoberd (2018:21) report that some students associate the mole with number of particles, while others associate it with mass in grams, even though there is an internationally accepted definition for mole. Hanson (2016:2) reports that, even at the university level, students confuse different chemical quantities, like mass, molar mass, molar volume and mole. For example, molar volume is used for substances in gaseous form to calculate moles or volume of the gas occupied by a certain mole of the substance; however, due to learners' lack of understanding, they use the relationship between moles and molar volume to do calculations with solids and liquids (Ndlovu, 2017:12). I noticed the same misconception among learners during my years of teaching stoichiometric chemistry at schools and at the tertiary level. When learners are given the volume of a certain liquid, they convert it into moles by making use of the formula connecting moles, molar volume and volume of gas at standard temperature and pressure. It has also been noticed that learners cannot identify the coefficients in the balanced equations as reaction ratios in stoichiometric problems. According to the law of conservation of mass, all reactions take place according to a certain proportion or ratio, which can be obtained from the balanced equation for the reaction. Furthermore, learners are uncertain about the conservation of mass in relation to chemical formulae (Chandrasegaran *et al*., 2009:15).

The ability to understand and use the mole ratio is at the heart of stoichiometry, but students lack this skill (Chandrasegaran *et al.,* 2009:14). Ndlovu (2017:13) reports that learners are unable to perform calculations for not only the mole concept, but also to construct balanced equations, and use and apply their algebraic skills to interpret a word problem into procedural steps that lead to the correct answer. Learners normally use algorithmic statistics when solving problems, rather than applying their conceptual understanding. Doing so will not help them to improve their comprehension and critical thinking skills (Van der Westhuizen, 2015:37). If learners do not develop conceptual understanding at school level, it affects their learning of advanced calculations at the tertiary level.

The skills needed to interpret the ratios in the balanced equation can be explained by considering a balanced equation for a reaction between hydrochloric acid and sodium carbonate:

$$2\ HCl + Na_2CO_3 \rightarrow 2NaCl + CO_2 + H_2O$$

The coefficients can be interpreted as indicating that, for every two mols of HCl, only one mol of Na_2CO_3 will be needed. So, for any mols of HCl given, only half the mol of Na_2CO_3 will be needed. This is a basic concept in stoichiometric chemistry that learners need to understand. The same understanding applies to the products too. When the amount of the reactant or product is given, the calculations need to be done according to the mole ratio that is given as the coefficients in the balanced equation. Learners need to master using mole ratio in balanced equations to solve stoichiometric problems. However, many learners and students find it a challenge (Okanlawon, 2010:28; Omwirhiren, 2015:2). Hanson (2016:2) reports that learners could not link the microscopic and macroscopic levels of chemistry, which aggravated their weakness in the conceptual understanding of stoichiometry.

Understanding the limiting reagents, or the excess reactants, is important for solving stoichiometric calculations. Chemical reactions are normally presented as if all reactants are used up in producing products, even though, in most cases, this is not true. Most learners' conception is that, if both reactants in a chemical reaction were in the same state, then both reactants would be completely used up (Chandrasegaran et al., 2009:14, 18). The learners also have the misconception that the limiting reagent is the reactant with the lowest mole ratio in the balanced equation, or the substance present in the least amount (Gauchon & Méheut, 2007:364; Marais & Combrinck, 2009; Malcolm *et al*., 2014:25). This misconception makes it difficult or impossible to solve a problem. Learners must understand that, if the number of moles of reactants in the balanced equation are not equal, then one of the reactants would be used up, while the other reactant/reactants might remain. Learners find it quite difficult to understand that the used-up reactant would be the limiting reagentt in the presence of excess reactants (Van der Westhuizen, 2015:36). Learners rationalise that the limiting reactant would be the one that is present in the reaction with the lowest quantity of mass, and not the mole, reports Hanson (2016:2). In a study conducted by Hanson (2016), students were given a stoichiometric problem and asked to balance the equation, determine the amount of each reactant and determine the limiting reagent for the reaction. The study reveals that students could not determine the limiting reagent in the problem when one substance was added in excess. Even if they identified the limiting reagent, they did not make use of the amount of the limiting reagent to find the amount of the excess reactant that will be used up, or the amount of product(s) that will be formed.

These difficulties arise because few students understand stoichiometric entities, in general (Van der Westhuizen, 2015:37). In addition to the above misconceptions, it is reported that learners do not consider that, when aqueous solutions are diluted, the volume and the concentration of the solution changes, but the number of moles remains the same (Malcolm *et al*., 2014:26). When learning stoichiometric chemistry, a learner is required to make the transition between macro and micro levels of matter, which are very small to measure by physical means. Learners find this difficult to do, and when the basic concepts are not thoroughly embedded, complex problems become even more difficult (Marais & Combrinck, 2009:88).

As a physical science teacher, I observed that few learners really understand how to solve problems in stoichiometric chemistry. On analysing how they performed a calculation, I realised that the main challenge facing solving such questions is learners' lack of fundamental knowledge and skills for balancing equations, interpreting mole ratio or mass ratio of the limiting reagent with the product, or incorrect understanding of a limiting reagent.

2.10.2.2 Alternative conceptions in stoichiometric chemistry

As learners do not conceptualise the concepts behind stoichiometric problem-solving, they make use of algorithmic methods, and teachers even encourage them to do so. They may reach a correct answer by just memorising a formula, manipulating the formula and substituting values (Schmidt & Jignéus, 2003:306). Researchers report that, when they start learning stoichiometric chemistry, learners find it easy to solve problems that contain direct calculations based on the mole concept; however, when they have to solve complex questions that include ratios in balanced equations, the struggle starts (Arasasingham, Taagepera, Potter & Lonjers, 2004; Boujaoude & Barakat, 2000; Frazer & Servant, 1987; Huddle & Pillay, 1996; Schmidt, 1994).

From the above discussions we can conclude that conceptual scientific knowledge, procedural mathemats knowledge and language skills need to be applied to solve stoichiometric problems successfully. In chemistry, some of the concepts can be acquired by rote learning or algorithmic learning, but to gain mastery in stoichiometric chemistry, learners need to have conceptual understanding. The overuse of algorithmic strategies, without applying reasoning in the process, is evident in many learners (Fach *et al*., 2007:15). The researchers report that learners apply algorithms in traditional problems, but cannot solve unfamiliar problems, as they lack conceptual understanding. If learners can conceptualise stoichiometric relations in terms of ratios, it can improve their understanding and make problem-solving easier for them. The challenge is that learners cannot apply the mathematical concepts of proportions, ratios or percentages in stoichiometric calculations. They usually use algorithms to perform stoichiometric calculations. Algorithmic learning becomes possible when similar problems are given, but when learners are confronted by a stoichiometric calculation that involves many steps, they will not know how to solve it (Marais & Combrinck, 2009:89). For example, calculating the number of moles present in a given mass of a compound can be done by memorising a formula and substituting values into the formula. This type of calculation is very direct, and most learners will find it easier to do. However, stoichiometric chemistry is a topic that needs deep conceptual understanding for complex problem-solving.

2.10.2.3 Problem-solving in stoichiometric chemistry

A general discussion about problem-solving was presented in 2.6.1.4. This section will discuss the problem-solving in stoichiometric chemistry specifically. Learners' understanding of mole, chemical equations and formulae play an important role in stoichiometric calculations. Learners' problem-solving abilities for stoichiometric calculations depend on cognitive variables, like prior knowledge, critical thinking abilities and skills (Gulacar, 2007:4). A learner who lacks in cognition of these aspects will not be able to do calculations relating to, for example, limiting reagents, or percentage purity in a sample, or stoichiometric calculations based on acid-base reactions. In the South African context, learners in Grade 10 need to understand the mathematical concepts in stoichiometric chemistry and apply them in reactions. This knowledge will help them to apply it in complex stoichiometric problems in Grade 11 and in Grade 12, when they learn more complex concepts in rate of reaction, chemical equilibrium and acids and bases. Mole calculations and problem-solving in stoichiometric chemistry is difficult for learners at schools and students at tertiary institutions; hence, many students shy away from studying chemistry (Lerman, 2014; Ross, 2016).

The review above can be summarised by stating that the following are the basic skills learners need to develop to conceptualise stoichiometric chemistry:

- Recognise unbalanced equations and balance them;
- Interpret the mass/mole relationships of reactants and products;
- Classify and understand the types of chemical reaction;

- Explain excess and limiting reagents and identify them;
- Calculate theoretical yield, actual yield of chemical reactions; and
- Calculate percentage purity of a chemical compound in a sample.

Omwirhiren (2015:1) reports the following as prominent areas that lead to general failure of learners to construct a meaningful understanding of stoichiometric chemistry:

- Inconsistency between the instructional approaches as described in the textbook and by the teacher;
- Confusing vocabulary used to explain the mole concept;
- Learners' inability to apply mathematics in problem-solving in stoichiometry;
- Inadequate cognitive ability in learners; and
- Lack of practice in problem-solving.

Teachers need to assist learners to conceptualise stoichiometric chemistry through instruction in the classroom. To gain conceptual scientific knowledge and procedural knowledge for problem-solving in stoichiometric chemistry, a teacher's instructional approach plays a major role (Malcolm *et al*., 2018:135) (see also 2.6.14).. The study by Malcom *et al.* (2018) illuminates the significance of teaching for conceptual understanding in science education, by using ways of instruction other than the traditional lecture method (direct teaching).

2.10.2.4 Teaching stoichiometric chemistry

As stoichiometric chemistry is a complex topic in chemistry, learners require a series of skills, basic conceptual knowledge of chemistry and knowledge of basic calculations in mathematics to master it. The content of stoichiometric chemistry and the misconceptions of students and learners were discussed Sections 2.10.1, 2.10.2 and 2.10.2.1). Reaction stoichiometry is considered to be an important part of applying the concepts in a reaction. Being a chemistry teacher previously in grades 10-12, I understand that topics like conservation of mass, balanced equations, volumetric analysis and dilution need to be considered as important subsections that must be taught in physical sciences from Grades 10–12. Learners face a number of new terms that sound similar, or related concepts in stoichiometric chemistry, such as moles, mass, molar mass, which means teachers need to give beginners in stoichiometry a chance to review these definitions while solving stoichiometric calculations. This approach is recommended by researchers as an appropriate way to address this problem, as misconceptions arise when definitions and connections of terms and concepts are misunderstood (Fach *et al.*, 2007:29).

Hanson (2016:2) list three big ideas that need to be taught effectively to ensure that learners can conceptualise stoichiometric chemistry. These are mole concept, limiting reagent and concentration of solutions. When teaching stoichiometric concepts, it is recommended that teachers teach the mole and the related concepts until the learners clearly understand them, before engaging learners in problem-solving. The main aim of teaching stoichiometry should be to develop conceptualisation of the concepts in stoichiometry, so that learners can use it to solve problems. Teachers must also ensure that learners understand and can interpret abstract events into concrete representations (Hanson, 2016; Malcolm *et al*., 2018; Pekdağ & Azizoğlu, 2013).

A common pattern that is used to teach stoichiometric calculations, suggested by Gulacur (2007:69), is shown in Figure 2.3.

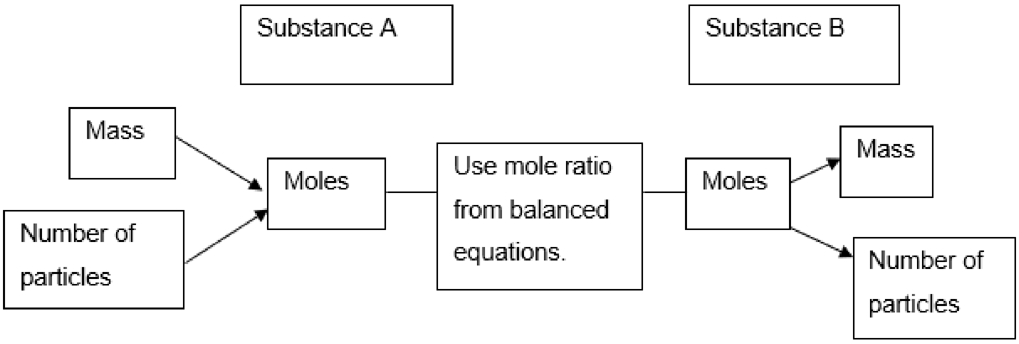


Figure 2.3: Flow diagram of calculations based on moles

To answer questions based on stoichiometric calculations, the flow diagram in Figure 2.3 suggests that, if data regarding substance A is given and learners have to solve problems for substance B, they must make use of the molar ratio from balanced equations. To solve this question, learners must know to use their proportional reasoning abilities. This type of question is a very basic one that deals with the foundations of stoichiometric chemistry in Grade 10 in the South African physical sciences curriculum.

Pekdağ and Azizoğlu (2013:118) suggest that one way to solve the 'mole problem' is to focus on language usage, nomenclature and semantics. The terms relative mass of elements, atoms, compounds and molecules, should be avoided, as they are inconsistent with everyday usage. In terms of nomenclature, instead of using atomic mass, molecular mass and formula mass of different entities like atoms, molecule and ionic compounds, the term formula mass should be used consistently for all the entities. The term, amount of substance, is not used by teachers and, hence, learners do not see mole as its SI unit for amount of substance (Pekdağ & Azizoğlu, 2013:124). The learners would, hence, have the tendency to identify amount of substance as mass or volume. In South Africa, English is the second language of the majority of learners, and they are familiar with using amount for mass or volume, which could be problematic when learning stoichiometric chemistry. To avoid this problem, teachers can share the meaning of 'amount of substance' in chemistry with learners. Pekdağ and Azizoğlu (2013:124) recommended teaching models that refer to semantics, using mass-volume quantities and using number of particles. In stoichiometric chemistry, semantic mistakes can be avoided by changing the way terms are used. For example, by asking learners, 'how many moles are present in 30 g of water', which omits the macroscopic level of representation, a teacher can ask, 'what is the amount of substance in 30 g of water in the gas form or liquid form' (Malcolm *et al.,* 2014: 6).

2.10.2.5 Learning stoichiometric chemistry

A study done on the conception of stoichiometric chemistry of secondary school learners recommends that learning chemistry needs conceptualisation and visualisation skills, along with mathematical and problem-solving skills. Teachers must make sure that learners have a good foundation of balancing chemical equations and using mole ratio to do calculations with excess and limiting reagents. For teaching the concepts, teachers can use innovative pedagogic plans, so that learners are exposed to microscopic, macroscopic and symbolic representations (Jaranilla, Prudente & Perez, 2017:50).

Students also make mistakes during problem-solving of stoichiometric calculations due to comprehension error. This is because students do not understand how to approach a given problem from the concept. This type of error can be minimised if teachers, while teaching, emphasize simplifying the concepts as they appear.

Researchers recommend that teachers avoid emphasizing algorithmic skills for problem-solving, without giving proper explanations for the concept or principle. Teachers can encourage learners to concentrate on one point at a time, and proceed stepwise in a logical fashion, and encourage groupwork with frequent activity-based demonstrations (Omwirhiren, 2015:7).

Other literature that was reviewed reports varied perspectives on teaching the mole concept. One suggestion is to identify the critical components of the topic, to provide the key for teachers to improve classroom instruction (Fang *et al.,* 2016:201). Omwirhiren (2015:5) recommends that, when learning the mole concept and other complex stoichiometric calculations, the teaching-learning process encourages learners to concentrate on one point at a time, and then to proceed step-wise in a logical manner. Malcolm *et al.* (2018:145) agree that lessons on stoichiometry need to be conducted as a series of lessons that will help to consolidate ideas. Omwirhiren (2015:5) also suggests the need to investigate an appropriate, student-friendly pedagogical approach to enhance performance on problems relating to the mole concept. Sunyono *et al.* (2015:40) recommend using a learning model based on multiple representations for learning stoichiometric chemistry, while Opara (2014) suggests collaborative learning to improve students' learning of stoichiometry.

2.11. SUMMARY

In order to understand the value and importance of teaching and learning chemistry in the South African context, this chapter reports on a non-empirical study that was conducted. In the South African curriculum, at the secondary school level, physical sciences consist of physics and chemistry, hence, a review of physical sciences as a sub-discipline of science formed part of the chapter (see 2.4). Learning science helps people to understand the nature and structure of the physical and natural world. The nature of science has certain characteristics, and a learner and teacher also need to understand the nature of science during the process of learning science (see 2.2). As a result, learning science helps to develop values, resulting in changes in individual behaviour. This process contributes to creating citizens who act responsibly towards the environment, society and themselves (see 2.3). In addition to the importance of science generally, physical sciences play an important role in the development of countries, and the value of including physical sciences as a choice subject in the South African curriculum was explained.

During the teaching process, it is important that teachers shift their approach between the executive, facilitator and liberationist approaches, in order to improve the conceptualisation of a topic according to the subject being taught. When teaching physical sciences, the approach, together with various strategies, such as direct instruction and demonstration, inductive and deductive reasoning, and problem-solving were explained as important for conceptualising the topic (see 2.6.1). Performance of learners in physical sciences, teaching methods, resources needed for teaching and the language of teaching and learning were also discussed (see 2.7). The main focus of the chapter was the teaching and learning of chemistry and, particularly, stoichiometric chemistry. Therefore, a literature review on the importance of chemistry was done. It was explained that chemistry makes a valuable contribution to the economic and healthy growth of a country. The need to learn chemistry to enter a variety of professions was explained (see 2.9.1) This study, on stoichiometric chemistry, found that conceptualisation of the mole concept is important at school level, not only for good performance in chemistry, but also for studying other tertiary-level subjects, like biochemistry and pharmaceutical chemistry. The content of stoichiometric chemistry, which includes the mole concept, the use of balanced equations, the need to understand the limiting reagent and excess reactants, was discussed. To understand why stoichiometric chemistry is regarded as a difficult subject, misconceptions that learners have about the mole concept and other related concepts were reviewed (see 2.10.2.1). The suggestions and recommendations made by researchers on the teaching of stoichiometric chemistry were reviewed. Some researchers identified a need to visualise microscopic and macroscopic representations while learning the topic. Studies that were reviewed indicate that teachers are expected to use appropriate approaches, strategies, methods and resources for teaching, to ensure that learning is effective (see 2.10.2.4).

The effectiveness of using computer simulation to teach various abstract concepts in physics and chemistry was discussed briefly in Chapter 1 (see 1.2.2). As the focus of this study was to determine the effectiveness of using computer simulation in the conceptualisation of stoichiometric chemistry, a literature review of ICT integration and the use of computer simulation to teach different science concepts will be presented in Chapter 3.

CHAPTER 3:

COMPUTER SIMULATION IN THE TEACHING AND LEARNING OF CHEMISTRY

3.1. INTRODUCTION

The famous comedian Groucho Marx said, “If you are not having fun, you are doing something wrong”,[1] and the sentiment can also be applied to a classroom situation. If the learners are not having fun while being taught, they will not have fun and enjoy learning. Chemistry instructors may also improve learners/students' learning by inspiring their interest in their way of teaching that promotes learning (Wu & Foos, 2010:3). The aim of the research was to study the effect of computer simulation on the conceptualisation of stoichiometric chemistry. In this chapter, a literature review on ICT and its application and merits in education will be explored. This will be followed by a discussion on the importance of TPACK and activity theory, which served as the theoretical framework. As the focus of the study was on the effect of using computer simulation, a literature review on simulation, in general, and the use of simulation for teaching will also be presented in this chapter. Then, a review on PhET simulations and simulations in PhET to teach and learn the main concepts in stoichiometric chemistry will be given.

3.2. ICT IN EDUCATION

Much research has been conducted over the years to introduce more effective teaching and learning practices. Using ICT is one of these innovations, and presently we are living in the information and communication age. ICT refers to technologies that provide access to information with the help of telecommunication (Ratheeswari, 2018:45). ICT in education can be any educational technology, whether hardware or software, that is applied in the educational process (Ugwu & Nnaekwe, 2019:12). ICT has the potential to provide teachers and students with exciting and effective opportunities in teaching and learning. Integrating ICT into education helps to

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[1] https://www.goodreads.com/quotes/136001-if-you-re-not-having-fun-you-re-doing-something-wrong

transform education, resulting in economic advancement and social development, as reported by Cha, Park and Seo (2020:16). These days, ICT has impacted our daily lives and, hence, knowledge relating to using ICT to teach has become more important. Ugwu and Nnaekwe (2019:10) argue that computers and communications technology provide ways for teachers and learners to integrate, enhance and interact with each other over a wide range of ways to achieve learning objectives. Hence, the curriculum of most subjects now requires the integration of ICT. According to Bindu (2016:24), the importance of ICT, as a pivotal tool to spread quality education, has been recognised by education institutions worldwide. According to Rabah (2015:24), technology is a powerful and flexible tool for learning, and it can be used to motivate and aid students to learn better, so that they can meet global challenges.

3.2.1 Application of ICT in education

The application of ICT in education has been divided into two main categories: ICT for education, and ICT in education. ICT for education focuses on developing ICT as a support for teaching and learning purposes, while ICT in education refers to using the basic elements of ICTs in the process of teaching and learning, to achieve better communication between teachers and students (Bindu, 2016:24; Kundu, 2018:57; Mdlongwa, 2012:4). As part of ICT for education, integrating digital content into lesson plans, using technology, like certain software or simulation, to teach different content areas, and using ICT for formative and summative assessments, were introduced into the school system (Meyer & Gent, 2016:27).

The initiative taken to ensure strategic alignment for integrating ICT into the education system in South Africa falls under the category of ICT in education. The use of ICT for the administration of schools in South Africa and providing in-service training and intervention to develop the skills, confidence and the desire of the teachers to integrate ICT into their teaching, falls under ICT in education (Meyer & Gent, 2016:1). ICT in education is not only useful for teachers and administration staff. When learners use ICT for a research project or for presenting an assignment using PowerPoint, they start interacting with a culture of personal information management, independent learning, teamwork, research and communication skills. learning, teamwork, research and communication skills. These skills have great value in today's global workforce.

ICT for education enables learners to become creators of knowledge in their own right (Mdlongwa, 2012:4).

The current Covid-19 pandemic in 2020 has put the world education system in check after the closure of schools universally and remote education by using ICT during the pandemic became important to continue providing education in many countries (König, Jäger-Biela & Glutsch, 2020:610). Vélez, Rodríguez and Gámez (2020:1269) reports that Torrecillas (2020) researched the challenges of online teaching in the face of the Covid-19 pandemic, and found that the modality of e-learning – making modifications in teaching-learning strategies logically based on ICT tools – was chosen as suitable for addressing the difficult times caused by the pandemic. From the above discussion it can be understood that application of ICT plays an important role in teaching and learning

3.2.2 Merits of ICT in education

Among the merits of ICT in the education field are its ability to enhance the teaching and learning process, the quality of education, the learning environment, learning motivation and scholastic performance (Bindu, 2016:25–27; Noor-Ul-Amin, 2013:2–7). Previously, teachers' resources were limited to textbooks for teaching in class, and direct instruction and scaffolding were the most popular ways of teaching. From a science teacher's point of view, the introduction of ICT into classes helps teachers to make use of simulation, video lessons and slides with images as additional resources. To learn chemistry, learners need to experience certain microscopic and macroscopic concepts visually, instead of the teacher just explaining about it with the aid of textbooks. Using simulations and videos helps learners to visualise these concepts. In a teacher-centred environment, using simulation and other technology resources improves teacher-learner interaction and helps learners to be actively involved in learning. ICT is considered to be an effective tool in the constructivist approach of learning, and helps to improve the learning environment, so that it is more learner-centred and motivates learners to actively participate in lessons (Bindu, 2016:25).

Researchers assert that ICT-supported education acts as a catalyst to promote and drive the acquisition of leaner knowledge, and enables learners to be more responsible in their own learning. As a result, learners are empowered for lifelong learning (Kotoka, 2013:13; Mdlongwa, 2012:4).

The development of ICT has spread its uses worldwide and, now, it has become a necessary tool for teaching and learning in schools and tertiary institutions all over the world, especially during the Covid-19 pandemic. The rapid development of technology has made it possible to change the learning environment, so that teachers can use various digital tools and resources to support teaching and learning, and guide learners and students to become its diversified users (König *et al.*,2020:610).

The use of ICT globally reveals its positive impact on learner achievement. Globally, it has been acknowledged that the use of computer simulation supports a variety of cognitive learning styles, facilitates higher-order thinking and develops problem-solving skills. Using ICT as an instructional tool bridges the gap between real life and abstract knowledge (Sedega, Mishiwo, Fletcher, Kofi & Awudetsey, 2017:49). The rapid development of technology has also made creative changes to the way we interact with society and, now, computer technology has become an important source of generating and spreading information (Suleman, Hussain, Din & Iqbal, 2017:9–10).

With the help of ICT, teachers are exposed to countless techniques and strategies to boost teaching and learning (Jordan, 2011:420). As a result, schools consider computers, printers, scanners, digital cameras and data projectors as essential requirements for enhancing teaching and learning (Hsu & Kuan, 2013:27). These facilities helped to introduce e-learning and blended learning in schools and tertiary institutions. The process of e-learning makes use of an internet network to deliver knowledge. The teacher can interact with the learners and facilitate learning from any part of the world. Blended learning combines face-to-face classroom practice with e-learning solutions (Ratheeswari, 2018:45). These ways of learning help teaching in a constructivist approach and it creates an atmosphere for a learner-centred learning environment. It was reported that digitalisation in schools also closes the gap between students' conventional learning and development at school and hence they gain experiences and skills that the youth need to enter the information economy. Advanced technological tools and digital resources help them to solve problems creatively and innovatively (König *et al.*,2020:610).

Research findings also show that ICT can be used in three ways to improve students' acquisition of basic skills, by blending learning with multimedia and curriculum objectives. In the first place, the computer can be used as a tutor, where the computer adapts to the students' needs by selecting instructional resources and maintaining academic records. Secondly, the computer can be used as a tutee, where the computer receives and executes instructions, in the form of a programming language, from the student. Thirdly, the computer can be used as a tool for doing calculations, creating graphical displays, animations and simulations, and gaming (Nkemakolam *et al*., 2018:285).

3.2.3 Computer technology and teaching and learning

From the discussion (see 3.2.1 & 3.2.2), it is clear that technology for the sake of itself is unlikely to have a lasting impact on teaching and learning. Research has shown that technology can only have an impact on teaching and learning if it supports the teaching and learning process (Meyer & Gent, 2016:3). Meyer and Gent (2016:3) refer to four models (see Table 3.1) that outline the roles technology could play to enhance teaching and learning.

Table 3.1: Models for the role of technology on teaching and learning

Model	Focus	Elements
Bloom's taxonomy	When planning to integrate technology in the lesson, classifies objectives in learning and structures activities in the curriculum	When engaging with technology, provides a progression, from recalling of facts to producing new and original work in the learning process
TPACK framework	Emphasizes the key knowledge elements to make use of technology in teaching	An overlap of technology, pedagogy and content knowledge in the teaching and learning process
NIMB framework	Integrates a number of models so that ICT can be used in the process of teaching and learning	Progression of learning according to Bloom's taxonomy through the effects of notions of learning, ICT in education

Model	Focus	Elements
		and models of learning design
UNESCO framework	Outlines the various dimensions of competencies that a teacher needs to have in ICT for the teaching process	Describes how teachers can develop their ability to improve their technological literacy, create knowledge and deepen their knowledge

Notes: NIMB: Notions of learning, ICT in education, model for learning design, and Bloom's modified taxonomy framework; UNESCO: United Nations Educational Scientific and Cultural Organization

Three models – TPACK, NIMB and UNESCO – focus on how ICT can be used to provide support in the progression of learning and relevance of ICT in the process of teaching and learning, while Bloom's taxonomy guides any lesson that is presented with or without the use of ICT. Meyer and Gent (2016:5) assert that random access to ICTs in classrooms does not necessarily result in successful learning. Therefore, effective integration of technology into teaching and learning must take place, by making use of appropriate tools at appropriate times and for appropriate content. This will help to enhance the progression of learning, that is, remembering, understanding, applying, evaluating and creating, by creating value in the learners' education. It was reported that the pedagogic expertise of using technology effectively by interactive whole-class teaching facilitates conceptual change (see 2.6.2.2) by engaging the learners through public expressions, leading to a critical scrutiny of their own conceptions (Hennessy *et al.,* 2007:149).

3.3. TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE

As the study was on the effect of computer simulation on the conceptualisation of stoichiometric chemistry, TPACK was important in the study. As technology integration is rooted in curriculum content and content-related learning processes, TPACK supports content-based technology integration (Harris & Hofer, 2011:212). In TPACK, the teachers' curriculum content knowledge, general pedagogy, technology and the context that influences teaching and learning, are integrated. TPACK is the extension of PCK (Shulman, 1987), which explains the specialised knowledge that teachers must have to deliver an effective learning experience. According to Koehler and Mishra (2009:63), TPACK is informed by four intersections of knowledge types, as shown in Figure 3.1.

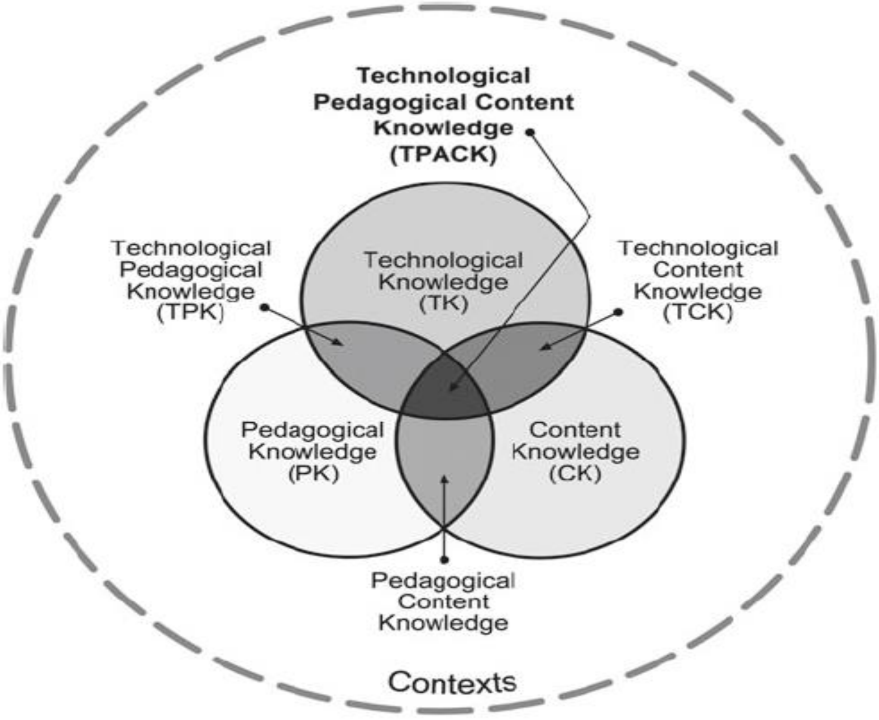

Figure 3.1: The TPACK framework and its knowledge components

Figure 3.1 depicts

- PCK, as explained by Shulman, which is the teachers' knowledge of how to teach specific content in the curriculum;
- Technological content knowledge, which explains how to select technologies to support the teaching of specific content best;
- Technological pedagogical knowledge, which is the use of particular technologies in teaching; and
- TPACK, which refers to teaching specific content using technologies that suits and supports the content and context best, to provide an effective learning experience.

In this model, there are four main sections or types of knowledge that teachers need to acquire; there are six components of teachers' knowledge, which are content knowledge, pedagogical knowledge, technological knowledge, technological pedagogical knowledge and technological pedagogical content knowledge, as explained by Koehler and Mishra (2009:63-66):

- To deliver content effectively, the teachers’ knowledge about the subject content (content knowledge), is important, and it differs in each subject. The content knowledge that a science teacher has is different from that of a history teacher or a language teacher.
- A teacher with adequate content knowledge must also have deep pedagogical knowledge about the methods and processes needed to deliver the content knowledge, so that the teaching meets the purpose, aims and values of education.
- The teacher must then, through the PCK, combine the content knowledge and pedagogical knowledge and transform the subject matter by interpreting it, and finding multiple ways to represent it so that it covers teaching, learning, curriculum, assessment and reporting.
- The technological content knowledge and the technological pedagogical knowledge together comprise the TPCK. A teacher with technological knowledge will be able to perform various tasks using information and communication technology. Technological content knowledge enables the teacher to change the subject matter by the application of particular technologies. The teacher will also know what specific technologies are best to address the subject matter, and how the content dictates or even changes the technology according to the needs of the learners.
- Technological pedagogical knowledge helps the teacher to understand how teaching and learning can change when a specific technology is used in a particular way. TPACK is the emergent form of knowledge, which results from the interaction of the content, pedagogy and technology knowledge. By integrating their knowledge of technology, pedagogy and content, teachers can apply TPACK to make the teaching and learning effective. To teach successfully with TPACK, a teacher has to create, maintain and re-establish a dynamic equilibrium among all the components mentioned above.

In this study, TPACK was considered instrumental. To integrate ICT in teaching, the teacher's TPACK explicitly makes the connection with a teacher's conceptualisation of educational technology for teaching subject matter (Harris & Hofer, 2011:224; Khan, 2011:215). However, to enhance learning, a teacher with TPACK needs to involve learners in activities while making use of computer technology to teach. Activities done by learners in relation to specific content, and their learning, are interdependent. While accepting that the teacher's TPACK is important, the learners' activities, infused in computer simulation, played an equally important role in this study. Activity theory describes the theoretical framework of this study.

3.4. ACTIVITY THEORY, THE THEORETICAL FRAMEWORK OF THE STUDY

Activity theory provides a broad theoretical framework for a context of computer-supported activities (Hardman, 2005:258; Kaptelinin, Kuutti & Bannon, 1995:2; Karanasios, 2014:1; Nardi, 1996:2). Activity theory describes the structure and development of activities executed by making use of computers. In the current study, a simulation was used to teach stoichiometric chemistry and learners were involved in activities based on the simulation to achieve an outcome. Hence, activity theory is appropriate as the theoretical framework for the study. Making use of visual representations can create a learning environment in which learners are able to interact with abstract concepts (Naidoo, 2017:2). Therefore, the intentional design of the learning activities with simulations for the current study, done by interaction, can create conceptual understanding (see 2.6.2.2).

Activity theory originated as a theoretical perspective on human–computer interaction in 1920 by the Russian psychologists Vygotsky, Rubinshtein, Leont'ev and others. It was later expanded by Engeström in 1987. The application of activity theory in studies based on human–computer interaction has taken place since the late 1980s and early 1990s. Researchers point out that framing human–computer interaction with purposeful activities helps to understand how technology supports humans (Kaptelinin & Nardi, 2018:2). Activity theory calls for a shift, from more teacher-centred activities to the types of activities where learners are responsible for their own learning (Froyd & Simpson, 2010:3).

Activity theory was used as the theoretical framework for the current study to account for the systems that link stoichiometric chemistry, learning and different social milieus that include the people, physical and social conditions of the environment in which actions take place. This theory is based on the assumption that all human actions are mediated by tools and cannot be separated from the social milieu in which action is carried out (Naidoo, 2017:3). Activity theory goes hand in hand with the constructivist theory of learning of Lev Vygotsky (1978), according to which learners construct their own knowledge through various activities that they are taken through. The activities and the interaction of learners with each other help learners to create a meaningful experience by constructing their own knowledge (Kotoka, 2013:23). The work of Vygotsky emphasizes the social part of constructivism, where the importance is on the social cognitive aspects of learning. The cognitive development of a learner is affected by the social and cultural background of the learner. While learners learn through social interaction, the teacher's role is to provide an environment suitable for learning through social interaction. Hence, learning happens through the mediation of community and culture (Amineh & Asl, 2015:10; Hodson & Hodson,1998:33; Malia & Kambleb, 2020:2).

Since the early 1990s, activity theory has been a visible landscape for studies related to human–computer interaction. The basic principles of activity theory consist of a hierarchical structure of activity, object-orientedness, internalisation/externalisation, tool mediation and development (Kaptelinin & Nardi, 1997:2). According to the principles of activity theory, activity and learning are interactive and interdependent. In the hierarchical structure, the activity is directed at an object, with specific goals directing the action. The goal is to achieve the objective, which consists of conscious and different actions. Regarding object-orientedness, Kaptelinin and Nardi (1997:2) point out that, even though human beings live in a reality that is objective, it also has socially or culturally defined properties. They argue that, in activity theory, the subject makes use of mental simulations and imaginations as a means of internalising the object. In this way, a subject transforms external activity to internal ones. Afterwards, externalisation transforms internal activities into external ones. In terms of tool mediation, activity theory emphasizes that human activities are mediated by tools, and by making use of tools, social knowledge is accumulated and transmitted. Lastly, the active participation of the subject in monitoring developmental changes also form part of activity theory.

According to the activity theory model used for the study, within the context of the study, the subject was the teachers teaching stoichiometric chemistry, the instruments were the simulations and the other teaching tools for stoichiometric chemistry, and the object or objective was the development of the various concepts in stoichiometric chemistry. In the context of the study, the tools used varied for each teacher teaching the learners. One teacher used computer simulation in addition to the whiteboard and textbook, while the second teacher used a whiteboard and representations on the whiteboard as tools. The community in the activity system refers to the group of individuals who share a common objective to achieve. The communities in the study are the learners in the two classes (experimental group and control group), and their respective teachers. The subject belongs to a community that is governed by rules and divisions of roles (labour). During interaction, members of each community collaborated with each other to achieve the outcome of the activity system, which was the conceptualisation of stoichiometric chemistry (Naidoo, 2017:4).

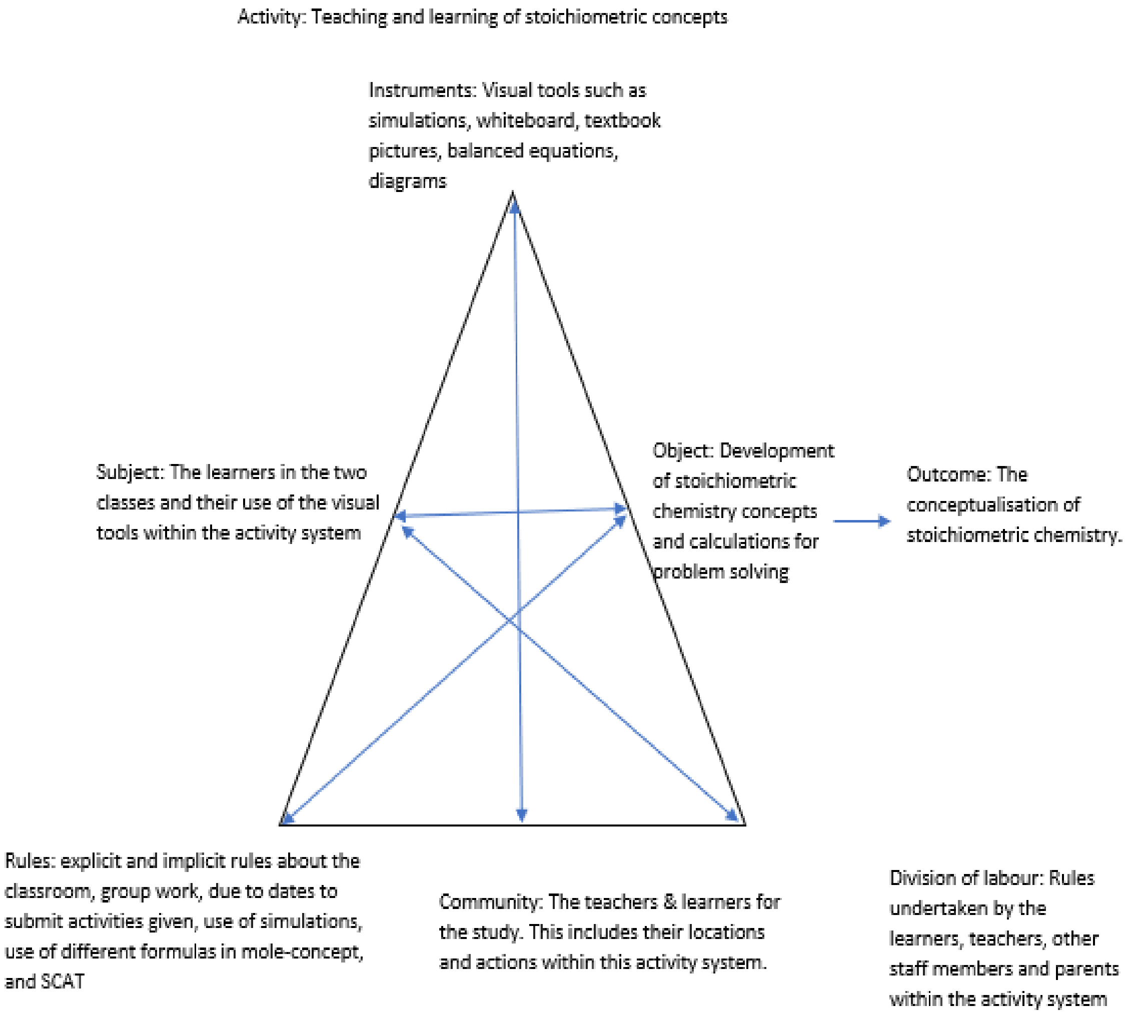

Figure 3.2: Adapted activity theory model of Engeström

Figure 3.2 emerged from this study, and was adapted from the activity theory model of Engeström (Naidoo, 2017). In Chapter 1, I discussed how computer simulation can help learners to visualise abstract concepts, and to attain development in learning (see 1.2.2). I also discussed the difficulty learners face in conceptualising stoichiometric chemistry (see 2.10.2.1). Hence, the study aimed to determine the effect of computer simulation on learners' conceptualisation of stoichiometric chemistry within the framework of activity theory. The activity system under the microscope in this study is the act of teaching and learning stoichiometric chemistry with and without computer simulation. As the learners work and solve problems together within the activity system, they develop a new set of values and notions.

3.5. ICT IN AND FOR EDUCATION IN AFRICA

Since South Africa is part of Africa, the development of ICT in Africa needs to be reviewed. ICT has been in use in education in Africa since the 1980s and has developed to include the evolution of technology that has produced innovations such as the internet of things and artificial intelligence (Amory, Rahiman & Mhlanga, 2015; Arowolo, 2009; Gillwald, Mothobi & Rademan, 2018). E-learning websites in Africa report that the Discovery Channel Global Education Partnership (DCGEP) introduced video and technology into South African classrooms in 1998. The aim of the project was to develop learning content in the physical sciences, cultures, geography, health, biology and other subjects, in close collaboration with the communities with which the DCGEP works (Kotoka, 2013:37). ICT use in education is at a dynamic stage in Africa, and many governments have developed national ICT policies and national information and communication infrastructure plans to support their socio-economic development efforts by introducing ICT in education. Increased investment in ICT in the education sector in Africa was spurred by a realisation of the need to establish a competitive advantage (Meyer & Gent, 2016:4). These researchers report that ICT helps teachers to be instructional managers who guide students through individualised learning pathways, by identifying relevant learning resources, creating collaborative learning opportunities and providing insight and support, both in class and outside the contact time (Meyer & Gent, 2016:5).

An improvement in learning with the use of ICT has also been reported from various parts of Africa, which shows the need to integrate ICT in teaching and learning. A study done on the effect of computer-aided instruction on teaching biology in Nigeria found that it had positive results (Julius, 2018:6). An experimental study in Kenya on the effect of computer-based simulation reports that students in the experimental group, who were taught biology using simulation, attained significantly higher scores than those in the control group, who were taught without simulation (Mihindo *et al.,* 2017:73).

About a decade ago, traditional teaching methods were still in use in South Africa, and the challenges that these schools faced regarding using ICT as a means of enhancing teaching led to South Africa failing to close the so-called digital divide (Mdlongwa, 2012:2). ICT is considered to be a means to eliminate the digital divide between nations, regions and even social classes. Internationally, communities and societies are instituting efforts to ensure equity and inclusive education by making use of ICT (Cha *et al*., 2020:1). The digital divide is the gap between those individuals who benefit from the use of digital technology, and those who do not. By making use of ICT in schools, the effectiveness and productivity of both learning and teaching in South African schools could be improved, thereby reducing the digital divide (Mdlongwa, 2012:2). Integrating ICT in the teaching and learning process has had a positive impact on the education field in South Africa. It has led to the development of a policy regarding the use of ICT in education to improve teaching and learning in schools (Meyer & Gent, 2016:12).

South African schools started using computers in the early 1980s – mainly private schools and well-resourced government schools, and for administrative purposes only. In the past years, ICT has become more integral to the lives of South African learners. The CAPS curriculum expects learners to have access to information through the World Wide Web (Mireku, 2016:9), which enhances learner-centred teaching and learning. The DBE also reflects in the Action Plan 2019 – Towards Schooling in 2030, according to which e-education and ICT play an important role in providing quality education; it expects that ICT-integrated learning will be operational in schools by 2025 (DBE, 2015b:9). The action plan highlights the need for teachers to be computer literate, so that ICT can be integrated in the teaching and learning process. When teachers become computer literate and integrate ICT for teaching, it will ensure that learners have access to a wide range of media and computers, which can enrich their learning.

3.6. MERITS OF USING ICT TO TEACH

The merits of ICT, generally, in education and the integration of technology for teaching and learning were discussed previously (see 3.2.2 & 3.2.3). Today's learners and students are immersed in technology, and use computers, smartphones and digital media from a very early age. Hence, they like to utilise media and technology in everything that they do. Therefore, researchers support the integration of technology into learning environments and teaching contexts (Cha *et al.,* 2020:1). Studies done across the globe have reported the merits of using ICT to teach and have confirmed that ICT can help to improve student learning by offering better instructional techniques (Bindu, 2016:25). Including ICT in teaching helps learners and students to be active in learning and enables them to interact with each other (Masilela, 2019:1). Contradicting this claim, there is no conclusive research to prove that students perform better if ICT is used to teach. However, researchers suggest that there is a general belief among practicing teachers and other academics that, when ICT is used in education, it creates an overall positive learning environment (Kundu & Dey, 2018:342). In the past, teachers depended mainly on textbooks and the subject content was taught using the lecture method. This approach compromised the conceptualisation of the content in many classrooms (see 1.2.1). According to Mugo (2016), the tools available in ICT have opened up new pedagogical approaches to teaching and learning, which enable teachers to achieve better teaching and learning outcomes. In addition to this advantage, integrating ICT in education boosts learner motivation and involvement by providing opportunities to gain basic learning skills. As a result, ICT strengthens the quality of education (Mugo, 2016:16).

The integration of ICT in education has brought changes in the teaching and learning environment. When using ICT in the education process, there is more emphasis on the concept of learning than on teaching. Moreover, ICT integration in a classroom grabs the attention of students, resulting in higher engagement of students in the lesson, globalisation of 21st century education, and enhancement of the learning process (Rabah, 2015:26). The use of ICT in the school curriculum allows learners to construct their own knowledge and enhances the development of teaching instruction by teachers (Mdlongwa, 2012:4). This is confirmed by Ugwu and Nnaekwe (2019:15–16), who claim that, in an ICT integrated environment, the role of the teacher shifts from knowledge transmitter to facilitator and, thus, learners become knowledge seekers by finding, synthesising and sharing their knowledge with others. The researchers report that, when they use ICT in education, a passive, dependent and solitary learner who tends to reproduce knowledge, changes into an active, autonomous and collaborative learner who produces knowledge. This is because educational technology serves as a constructivist device that helps students to express their knowledge, and to examine, exploit and process information relating to abstract concepts. Mihindo *et al*. (2017:66) claim that computer-assisted instruction (CAI) and computer-based simulation (CBS) have enhanced the learning of difficult concepts. According to the researchers, CAI programmes are categorised into drill and practise, simulations or hypermedia, while CBS presents certain dynamic and complex concepts that are difficult to teach using words, equations or experiments. Kundu and Dey (2018:343) support this idea, by saying that any combination of the above can be an appropriate computer intervention in the learning process. In this manner, learners can collect the information in science by interacting with resources, such as images and videos, and encourage communication and collaboration. Mihindo *et al.* (2017:66) conducted a study on the effects of a CBS teaching approach on students' achievement in learning chemistry in secondary schools. They found that, for teaching science subjects using regular teaching methods, students understand the subject only at knowledge level and, as a result, they just memorise the concepts without grasping their real meaning. In contrast, the CBS teaching approach was found to be more effective for enhancing student achievement than regular teaching methods. Bindu (2016:27) reports that students who used computer-based learning scored higher than students who learned without computers, as ICT-integrated learning helps students to grasp the concepts better and to retain it for a longer period of time.

Researchers have identified a variety of benefits of ICT in promoting the quality of education, among which enriching and deepening skills, accelerating, motivating and engaging learners to help relate school experience to work practices, and creating economic viability (Mireku, 2016:11). Moreover, ICT use offers opportunities to liberate learners in the classroom, while teachers can provide individual attention to learners. Fu (2013:113-114) summarised the benefits of using ICT in education, which was found to:

- Assist students in assessing digital information efficiently and effectively;
- Support student-centred and self-centred learning;
- Produce a creative learning environment;
- Promote collaborative learning in a distance-learning environment;
- Offer more opportunities to develop critical thinking skills;
- Improve teaching and learning quality; and
- Support teaching by facilitating access to course content.

Even if ICT cannot replace normal classroom teaching, it could help to promote a deeper understanding of the principles and concepts of science and could be used to provide authentic, interesting and successful educational activities. (Bindu, 2016:25; Nkemakolam *et al.*, 2018:285).

3.7. LIMITATIONS OF AND BARRIERS TO USING ICT

One of the biggest concerns of educators around the world is preparing the present generation of learners for the future. ICT plays an important role in the education system, by making them ready to face the future (Kundu & Dey, 2018:342). However, there are some limitations and barriers related to implementing ICT in education. The important ones will be discussed in this section.

Regarding the challenges related to providing ICT resources to schools and using it for classroom instruction, researchers report that setting up information technology-based management information systems are expensive, as the hardware and software required are costly. Staff also need to be trained regularly, and they may resist it, due to fear of change and due to the fear that they may not be able to cope with new technology (Amuko, Miheso & Ndeuthi, 2015:2; Kundu, 2018:349; Mdlongwa, 2012:4). Even though teachers are trained to use ICT, the majority use it in a limited manner, as there is insufficient planning for integrating ICT into the curriculum (Lisene & Jita, 2018:47).

Integrating ICT into teaching and learning is a complex process and there are several barriers that hinder the integration. One important barrier that has been identified is that more time is needed when ICT is used in teaching, compared to teaching using the traditional lecture method. This is mainly due to insufficient and good quality training on how to integrate ICT in teaching. A second barrier is the incompetence of teachers, and their lack of confidence to use ICT in class. The teachers' resistance to changing their pedagogical approach according to the new developments in technology is another barrier (Bingimlas, 2009:237). In such situations, the TPACK of teachers can reduce their resistance to using ICT in teaching (see 3.3). Rabah (2015:27) points out that, due to teachers' lack of confidence, they have to be supported by being provided with training, and this training must not be restricted to three to four times a year, but rather be continuous according to developments in technology. Researchers found that a lack of accessible resources, inadequate training opportunities, lack of confidence and self-efficacy by teachers, paucity of time, insufficient knowledge on how to integrate ICT in lessons and how to interact with students when using ICT to teach, technical issues, poor administrative and management support, poor fit with the curriculum, and insufficient support from different stakeholders were barriers to the successful integration of ICT in education (Alkahtani, 2016:32; Cha *et al*., 2020:3; Kundu, 2018:349; Mugo, 2016:19; Padayachee, 2017:36; Rabah, 2015:27).

3.8. COMPUTER SIMULATIONS

As a tool, the computer can be used to help with calculations, graphical displays, animation, simulations and gaming. Advances in technology have introduced a variety of tools to enhance learning, and one of these is the use of computer simulation reports (Guy & Jackson, 2015:2). Computer simulations are now widely used in different fields, and especially in the field of education. The word simulations has been explained by several researchers, and a few definitions are given below.

According to Eckhard, Urhahne, Conrad and Harms (2013:106), a computer simulation provides a model of a natural or artificial system or process that humans can interact with. Clark, Nelson, Senguta and Angelo (2009:4) explain simulation as computational models of real or hypothesised situations of natural phenomena, within which the user can explore, manipulate and modify parameters. Simulation is different from other forms of media, for instance, a diagram in a textbook, as it helps to provide a dynamic visualisation with which the user can interact, while textbooks only provide static visualisation (Plass, Homer & Hayward, 2009:32). Nkemakolam *et al.* (2018:285) explain computer simulations as computer-generated versions of various phenomena in the real world, which provide an authentic environment, context and situation for task-based learning. These simulations allow learners to view events, processes and activities that are not available in their school contexts. Julius (2018:41) explains simulations as an interactive program based on graphics, where learners can visualise a process and explore the effect of changing parameters on the operation system.

In all the above explanations it can be noted that computer simulations help to visualise a concept by interacting with the concepts presented in the simulations. Considering the way ICT is advancing, the researchers quoted all recommend using computer simulations, as it is the most powerful educational tool and provides authentic practise while learning, feedback about performance, and motivation to learn further without any physical danger or constraints.

3.8.1 Using computer simulations in contexts with a range of learner ability

In a classroom, there will be learners with a range of abilities, and dealing with such a variety of learners has always posed a challenge for teachers. A class will comprise slow learners, and gifted learners who learn quickly. Any technique or method of teaching that is conducive to teaching and learning and that would help slow learners, so that learning is easier, should be welcomed. Researchers have identified teaching with simulation as one example. As simulations help learners visualise abstract representations, less able learners will benefit (Hennessy *et al*., 2007:149). Their study on using simulations for dealing with an abstract topic in science indicates that learners could repeat the experiments as often as needed, which cannot be done in a practical session. This confirms the benefit of using simulations for slow learners, so that they can learn at their own pace.

Another important benefit that is reported by Ceberio, Almudi and Franco (2016:592) and Anderson and Wall (2016:162) is that each simulation focuses on a single concept, and does not involve unnecessary details and gives the user a simple and controllable way of learning. Moreover, for meaningful learning to happen while learning a concept, learners need to construct their own knowledge. Simulations enable learners to interact with the computer representations, and provide a learner-centred environment. Therefore, learners will be able to explore systems, manipulate variables and test hypotheses, which will help them to construct their own knowledge (Widiyatmoko, 2018:38). Simulations can help slow, average and gifted learners to interact with each other in a constructivist manner, and do activities by sharing their knowledge and understanding (Bindu, 2016:25; Nkemakolam *et al*., 2018:285). Activity theory, which is the theoretical framework of the study, endorses a social constructivist manner of learning, whereby learners engage in activities that emanate from the simulation, interact with each other, and construct their own knowledge (see 3.4).

3.8.2 Computer simulations for reducing learners' cognitive load

The cognitive load theory and how people learn was explained in Chapter 2 (see 2.6.2.5). In the current study, learners had studied the basics of stoichiometric chemistry in Grade 10. Later, a teacher can reiterate this prior knowledge and can use simulation to teach new concepts. Doing so could help reduce germane cognitive load. Moreover, there is a limit to how much information learners can process in a certain time. Unless concepts are broken down into simplified versions and instructions are given in an appropriate manner, learners can experience cognitive overload (Reedy, 2015:356). It is reported by Kaheru and Kriek (2016:77) and Sokolowski (2013:36) that simulations are designed to reduce cognitive load to some extent. The researchers report that interactive and dynamic simulations facilitate active engagement in the learning process, as simulations can present dynamic representations of complex processes that are difficult to visualise and, hence, reduce the cognitive load.

3.8.3 Advantages of computer simulations

Research in the early 2000s found that computer simulation has advantages when it is used as a tool in teaching and learning. Jimoyiannis and Komis (2001) and Huffman, Goldberg and Michlin (2003) found that simulations have a positive effect on students' results. Jimoyiannis and Komis (2001:185) report that simulations are open learning environments that provide learners with the opportunity to

- Develop their understanding of phenomena through hypothesising and testing ideas;
- Develop an understanding of relationships between the physical concepts, variables and phenomena;
- Express their representations and mental models about the physical world; and
- Investigate phenomena that are difficult to experience in a classroom or laboratory setting.

They conclude that the use of simulations during the teaching and learning could help students to dispel misconceptions and can improve their comprehension of difficult concepts. This finding was confirmed by research conducted by Stephens and Clement (2015:138). They found that, by making use of simulations, the difficult concepts are understood better, as it helps students “make their thinking visible” and “customize their own modelling tool”. It is reported by Clark *et al.* (2009:4) that simulations allow learners to explore scientific phenomena under certain mechanisms, like hitting a ball or projectile motion, which they normally experience in real situations, and also other phenomena that are inaccessible, like the microscopic properties of matter, cell biology and electrical conduction. Simulations allow the learners to view and interact with theoretical entities that are very difficult to represent in a textbook, but which are critical for understanding (Plass *et al*., 2012:395). The concept of stoichiometry, which was the subject content focus of this study, is a good example of this claim. When studying stoichiometry, learners need to understand that a certain number of molecules or moles of reactants react to change into products according to a ratio. Simulations helps them to visualise these concepts at the molecular level by using animations and simplified models (Widiyatmoko, 2018:38).

Bindu (2016:26) points out that simulations contributes to an authentic learning environment, and helps learners understand complex concepts, and it acts as impetus for active learning and high order thinking. Moreover, simulations provides a better learning environment for presenting information, testing, evaluating and providing feedback, thereby individualising learning (Tareef, 2014:275). Other research studies show that using computer simulations to explain scientific phenomena makes the students’ conceptual understanding easier to achieve, than when traditional methods are used for teaching (Chao, Chiu, DeJaegher & Pan, 2016; Sarabando, Cravino & Soares, 2014; Stern, Barnea & Shauli, 2008; Zacharia, 2007). Rutten *et al*. (2012) reviewed articles on simulations and reported positive consequences for situations where simulation was used to replace or enhance traditional lectures. Using simulations also creates a positive environment, thereby motivating learners, increasing their attention span by making use of the experimental tools and materials, and encouraging learners to actively participate in activities (Hursen & Asikoy, 2015:88; Ulukök & Sari, 2016:467). These findings support those of Bozkurt and Ilik (2010), namely that groups that studied with the aid of computer simulations were more successful than those who studied with traditional methods.

Simulations can be adapted according to the abilities and preferences of learners, and helps to develop their creativity, problem-solving skills, identity and self-reliance.

Rutten *et al*. (2015:1242) report the following advantages of a learning environment with computer simulations. Students can

- Methodically explore hypothetical situations;
- Perform practical tasks as many times as necessary, and solve problems without stress in a realistic environment;
- Change parameters and time-scales of events;
- Gain interest in the task, as they can interact with the simplified version of the task.

Widiyatmoko (2018:39) summarises the advantages of simulations as follows:

- Simulations help to improve learners', students' and pre-service teachers' understanding of difficult science concepts;
- The animation in simulations makes abstract concepts more accessible and visible for learning;
- Simulations animate dynamic changes in scientific processes that are difficult to understand from the representations in textbooks;
- Simulations help students to visualise certain phenomena that might be difficult to depict and help students to generate their own mental models; and
- Simulations assist to increase learner engagement with science by allowing them to experience and interact with an environment similar to the real world.

The quoted research on using computer simulations to learn asserts that the use of simulations has a positive impact on students' ability to predict and explain phenomena. The advantages listed encourage teachers to use simulations, and motivate them to make use of it in the teaching process.

3.8.4 Disadvantages of computer simulations

Although there are many positive impacts and advantages of using computer simulations in teaching and learning, the disadvantages also need to be reflected on. In addition to the fact that computer simulations are expensive, and that disadvantaged schools may not have access to computers in classrooms, not every teacher will be able to update their knowledge on ICT for teaching. Frederking (2005:386) and Shellman and Turan (2006:22) raised concern about the positive impact of learning with simulations; they claim that simulations lack a high standard of rigour. Another concern is that simulations perpetuate continuous guessing and, hence, the performance of learners taught with computer simulations cannot be valid or reliable (Teach & Patel, 2007:81).

Researchers report that simulations can be used instead of conducting practical experiments – a topic that will be discussed in Section 3.9.2. However, Greca and Freira (2014:301) assert that the same experiments conducted in the laboratory and with simulations are not comparable, as simulations lack materiality. Therefore, virtual experiments have an inferior epistemological status compared to real, practical experiments. Kotoka (2013:17) raises the concern that learners may not do enough hands-on activities, which are important skills they need to gain. Guy and Lownes-Jackson (2015:98) report that simulation can hinder learners' growth in interpersonal skills, as they have minimum interaction with teachers when they use simulation to learn. Widiyatmoko (2018:39) summarises the disadvantages of simulations as follows:

- In a real environment, learners can gain experience by, for example, feeling or tasting, but when using simulations, this will not be possible;
- Learners will not be exposed to quick thinking required by problem-based scenarios when learning using simulation. This is because simulation provides flexibility in time for thinking;
- Learners do not get hands-on experience when using simulation, as they do when they perform practical experiments in a laboratory; and
- As the simulations show outcomes that are preprogrammed, they can only be manipulated to a certain extent.

3.9. TEACHING WITH COMPUTER SIMULATIONS

It was discussed in Chapter 2 (see 2.10.1 and 2.10.2) that learners have difficulties learning stoichiometric chemistry, and that the misconceptions generated while learning created problems for solving problems related to moles. The need of teachers practicing the three approaches of teaching according to the needs of the learners were also discussed (see 2.6.1.1). The need of reformed teaching was identified by researchers and an observational instrument, RTOP was developed to assess the degree to which the teacher creates a conducive learning environment for achieving the goals of effective teaching (Sawada *et al*., 2002:251) (see also 1.7.3). One of the aims in an effective teaching and learning classroom is addressing difficulties that arise while learning, and correcting misconceptions or developing alternative conceptions. Even early studies report that simulations can produce a significant conceptual change in learners who have misconceptions or alternative conceptions on topics (Zietsman & Hewson, 1986:29). Jimoyiannis and Komis (2001:201) assert that simulations play an important role in bridging the gap between learners' prior knowledge and learning of new physical concepts. This will help them to get a better scientific understanding, by reformulating their misconceptions. Figure 3.3 is a flow diagram that shows how the conceptual change happens gradually (Jimoyiannis & Komis, 2001:201).

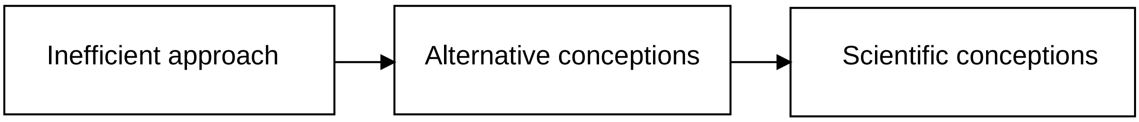

Figure 3.3: Simulation changes misconception changes to scientific conceptions

When inefficient approaches are used for teaching stoichiometric chemistry, they will create misconceptions and alternative conceptions in learners. As a result, there is a need for alternative teaching strategies, like performing experiments and/or using simulations while teaching. Once an appropriate strategy has been used, learners will be able to gradually experience a conceptual change, which leads to scientific conceptions. Using computer simulations with hands-on activities will facilitate testing one's own understanding, and will rectify misconceptions (Kunnath & Kriek, 2018:330). Moreover, it will also help learners to express their ideas about a given domain, or speculate on how to solve a problem (Smetana & Bell, 2013:482). The aims discussed above also formed part of the criteria in the observation schedule (RTOP) to assess the degree of effective classroom teaching. The current study used the observation schedule to observe the lessons conducted by the teachers and whether teaching using simulations could be seen as reformed teaching. Further discussion about the use of this observation schedule from RTOP will be done in Chapter 4 (see 4.7.2.1) and Chapter 5 (see 5.3.2).

3.9.1 Using computer simulations to promote inquiry-based teaching

Inquiry-based teaching was discussed in Chapter 2 (see 2.6.1.5). Researchers report that teaching with simulations promotes inquiry-based teaching, and helps learners to construct their own learning. Potane and Bayeta (2018:4) state that computer simulations, when integrated with guided inquiry activities, are effective, as it encourages students to construct their own understanding. Rutten *et al*. (2015:1226, 1241) are of the opinion that computer simulations offer an excellent opportunity to learners to conduct scientific inquiry and to improve their scientific literacy, and motivates students to have a positive attitude towards learning. They assert that teacher-led classroom discussion, supplemented by computer simulations, guide learners through the important aspects of the research process, and through the different stages of inquiry learning.

Using simulations helps teachers and learners to be more flexible in relation to an authentic scientific inquiry, as it serves as scaffold for learners to solve complex tasks that are often inherent in authentic inquiry (Kunnath, 2017:52). Hence, it could be interpreted that using computer simulations helps not only to aid student learning, but also allows inquiries that are analogous to authentic science practice. Therefore, computer simulations help to scaffold authentic science inquiry and promotes understanding of science practices.

3.9.2 Using computer simulations to conduct experiments

An important use of simulations is in conducting experiments that cannot be conducted practically. According to my experience as a physical science teacher in high schools in the Northern Cape province of South Africa, various problems are encountered when experiments need to be conducted. Not all schools have the facilities to conduct experiments, as they lack laboratories and expensive equipment. Some experiments may be dangerous to carry out, like experiments with chemicals that relate to studying chemistry concepts. Therefore, learners need to be given an alternative method to understand these concepts. One method is to make use of computer simulations. Simulations offer a visual representation of physical and chemical phenomena and experiments that cannot be carried out in a classroom situation. It is reported that some experiments are difficult to set up and hard for students to understand in a real laboratory and, therefore, it can be made simpler by using simulations (Bozkurt & Ilik, 2010:4588).

Research conducted on the effect of using simulations instead of traditional laboratory experiments reports that the learners who were exposed to simulation performed better than those who were exposed to the experimental laboratory experience (Anderson & Wall, 2016:172). Advantages of using computer simulations instead of conducting experiments have also been reported by Rutten *et al.* (2015:1225), as well as Tashdere (2015:777). According to these researchers, to conduct a practical experiment, teachers need to spend time setting up the equipment, testing whether the practical will yield results and, later, they have to supervise the learners and intervene while the learners perform the experiment. These preparations require a lot of time, and the teaching time needs to be utilised optimally, as there is no special time allocated for conducting experiments. By simulating experiments, a lot of time can be saved, as the experiment is set up virtually, hence, teachers can dedicate more time to teaching learners. Another advantage is that learners themselves can manipulate the variables of the experiment while performing it with a simulation, for example, changing the independent variable or other parameters and observing the impact immediately, which is different from when a student does hands-on experiments. In a hands-on experiment, the student's goal is to reproduce a preordained result as quickly as possible, without making a mistake. The stress of getting a correct result can be avoided when doing experiments with simulations (Wieman, Adams & Perkins, 2008:682).

3.9.3 Computer simulations in the teaching and learning of chemistry

The use of ICT has proved to be advantageous to education, as it has the potential to improve the quality of education without limits (Alkahtani, 2016:40). Udo and Etiubon (2011) conducted a study using a pre-test–post-test experimental design to determine the effectiveness of computer simulation on student achievement in a chemistry course, compared to guided discovery and traditional expository teaching methods. A sample of 89 students were randomly assigned to three treatment groups and all groups were taught the same concepts under chemical combination. Group 1 was taught using a computer-based science simulation, group 2 was taught using guided-discovery method, and group 3 was taught using the traditional instructor-centred expository approach. The authors conclude that the computer-based science simulation had a greater enhancing effect on students' performance than the traditional expository method, but was comparable with guided-discovery approach. An earlier study by Udo (2010) yielded similar results.

Several other studies were also done on the impact of computer simulations on teaching and learning chemistry. Correia, Koehler, Thompson and Phye (2019:193) integrated simulations to facilitate learners' conceptual understanding of gas behaviour on the sub-microscopic level, which proved to have benefits for its conceptualisation. The simulation used for the above study allowed the learners to change variables and verify gas behaviour, which they had already studied, and it helped learners to understand gas behaviour on the sub-microscopic level. Develaki (2019:10) reports that computer simulations can be incorporated into different kinds of teaching, thereby promoting students' understanding of science concepts, developing their inquiry skills, and enhancing teacher education and their professional growth by recreating real-world perspectives, which, in normal classroom situations, would not be possible. Reports that the use of computer simulations to teach electrolysis yielded positive results in enhancing learners' understanding of the concepts (Nxumalo-Dlamini & Gaigher, 2019:330).

According to Bailey (2007:13), making use of interactive simulations in a classroom engages students in inquiry-based learning much more readily, as they can make predictions about various processes in a chemical system and then examine the results immediately. The researcher reports that computer simulations could increase the students' learning and comprehension of microscopic events in gases, and their ability to comprehend how these microscopic events are related to macroscopic events.

In another study, by Liu (2005:187), on making use of computer simulations, molecular animations helped students to connect chemical reactions to chemical equations when using symbols and signs. A study by Bayrak and Bayram (2010:234) aimed to enable students to study acids and bases by making use of computer animations and simulations. The result of the study is that teaching the topic of acids and bases with the support of computer simulations had a positive effect on the students' achievement. When computer simulations are used to teach chemical equilibrium, it presents dynamic equilibrium at molecular level and thereby increases students' conceptualisation of the content, and prevents misconceptions developing (Sarıçayır *et al.,* 2006:134). A study by Özmen (2008:435), on the conceptual understanding of chemical bonding when integrating its teaching with computer simulation, reports a positive effect on student achievement and attitude towards chemistry. The researchers assert that CAI, including making use of simulations, needs to be integrated with other teaching methods, so that student learning of chemistry concepts can be enhanced. Lisene and Jita (2018:49) argue that various research studies highlight the positive results of using simulations and hence the education system and teachers must take advantage of simulation to teach concepts in science. Simulation is an effective and realistic way of enhancing contemporary teaching and learning practices in schools. Therefore, it can be integrated with different teaching approaches, and could help to improve the achievement of learning outcomes (Develaki, 2019:19).

A variety of simulations are available online to teach and learn the various concepts in chemistry. The focus of the current study was to determine the effect of using simulation to teach stoichiometric chemistry. Hence, the simulations that can be used to teach and learn quantitative aspects of a chemical change will be discussed in this section.

The American Chemical Society website[2] discusses virtual chemistry and simulations and provides information regarding different simulation options for teaching chemistry. When using this website, learners make use of a virtual chemistry laboratory and simulations, which provide additional ways to learn chemistry. The American Chemical Society recommends a variety of simulations to teach and learn different topics in chemistry, among which the following:

- PhET interactive simulations;
- Chemistry solutions;
- Featured simulations;

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[2] https://www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/simulations.html

- Chem Collective;
- CK-12 chemistry simulations;
- Virtual chemistry experiments; and
- General chemistry interactive simulations.

In the South African context, using online simulation for classroom teaching is a challenge. The majority of schools lack internet access for teaching and learning. PhET interactive simulations, once downloaded, can be used offline and it can be copied to another computer without internet access. In addition to the challenge of being only available offline, the effectiveness of these simulations (except PhET interactive simulations) could not be verified through literature review. The literature review done on the PhET found that learners could construct their own knowledge by engaging in exploration by using its interactive simulations (Paulson, Adams & Perkins, 2009:2). Therefore, PhET simulations blend with activity theory, which is the theoretical framework of the study.

3.9.4 PhET simulations

A group of researchers from the University of Colorado in the United States of America conducted research on how students learn, the difficulties they face to conceptualise different concepts, and misconceptions about physics that are created while learning. This research led to the development of PhET in 2002, which consists of interactive simulations for physics. Later, it incorporated simulations for other disciplines, such as earth science, biology, chemistry and mathematics. For each discipline there are meaningful, highly interactive research-based computer simulations available at no cost. It makes learning easier by making use of graphics, click-and-drag manipulation controls and other aids (Kunnath, 2017:52). Podolefsky, Perkins and Adams (2009), Bandoy, Pulido and Sauquillo (2015), Kunnath (2017), Tavares, Perkins, Kauzmann and Velez, (2019), Potane and Bayeta (2018) and Wieman, Adams, Loeblein and Perkins (2015), all report that PhET simulations have been accepted globally due to the way it is presented, its versatility and free availability on the internet. PhET simulations are also reported to be effective when integrated with guided inquiry activities, as mentioned in Section 3.9.1.

According to Tavares *et al.* (2019:2), engagement of students with PhET simulations helps them to address science goals, such as exploring, generating questions, making predictions, testing ideas, designing experiments and monitoring one's own understanding. PhET simulations are designed with activities, such that it enhances learning results by providing opportunities for student engagement, thereby addressing the above-mentioned science goals. Research done by Devalaki (2019:3) reports on the impact of simulations on science teaching, and its use of innovative didactic approaches that can enhance learning. A study conducted by Potane and Bayeta (2018:5) confirmed these findings, by reporting that PhET interactive simulations are an alternative teaching approach that has the potential to enhance and facilitate the teaching–learning experience. They made use of PhET simulations to teach the concept of electricity, by manipulating the different variables referred to in the simulations. It helped learners to understand the concepts up to the molecular level, where the learners were able to see the flow of electrons in the entire circuit. The researchers assert that the PhET simulations directly promoted the visual comprehension of science concepts and, hence, improved the mastery of science process skills, compared to students who did not use computers to learn at all. The students in the study of Potane and Bayeta claimed that PhET simulations provided them with an enjoyable learning experience, promoted quick learning, and ignited their interest in learning, which helped to boost the students' academic achievement. These results confirm that of a study by Bell and Smetana (2008:24), who report that computer simulation can be effective for developing process skills and content knowledge, and enhances achievement of more complicated goals and conceptual change in science.

Moreover, a survey done by Bandoy *et al.* (2015:2–3) reports that PhET simulations help learners learn basic facts and acquire knowledge in physics, are effective in helping them grasp content, test hypotheses, understand learning concepts, gain problem solving skills, build confidence, develop independence and improve test scores – in effect, it led to the conceptualisation of the subject content. By integrating simulations, the subject physics, which had been seen as boring and irrelevant due to abstract concepts, turned out to be interesting, fun and important. Therefore, the researchers encourage educators and students to make use of PhET simulations for teaching and learning. A teacher can select an appropriate teaching approach by integrating the learning strategies and media that will be used for effective teaching and learning. For this study, the target of the approach must be to engage the students in activities and to improve their conceptual mastery – in accordance with activity theory, the theoretical framework of the study. This will enable learners to construct their own knowledge. Research reports that PhET simulations, when integrated in teaching and learning, could enhance conceptualisation of the subject content. According to Wiemann *et al*. (2008:682), a student explores an educationally effective simulation in the same way as a scientist approaches research. For a scientist, research is an enjoyable opportunity to explore concepts, and to challenge, correct and add to understanding of how the world works. Similarly, a student who works with a well-designed simulation explores and discovers new ideas about science. When something unexpected happens while exploring a concept using simulations, the student can question the understanding and change the parameters in the simulation to explore and improve the understanding. Activity theory supports this type of learning, where learners interact with each other while engaging in activities of the simulation to achieve an outcome (see 3.4).

Another study, conducted by Sari *et al.* (2018:6), explored the effect of PhET simulations on the learning of the solubility equilibrium. They applied the virtual lab media from PhET to teach students the concepts of salt solubility equilibrium. They found that it helped students to activate long-term memory and, eventually, improved the achievement of the learning outcomes and the students' conceptual mastery of the topic.

Research was done by Astutik and Prahani (2018) on the practicality and effectiveness of the collaborative creativity learning (CCL) model by using PhET simulations to increase students' scientific creativity. According to Astutik and Prahani (2018:410), the CCL model enhances scientific creativity based on motivational theory, cognitive psychology theory, social constructivism learning theory and positive dependence through collaboration. The model was proved to be feasible for improving students' scientific creativity in the discipline of natural science, with some shortcomings in assisting students who have little imagination. The researchers conducted the study by integrating PhET simulations in the CCL model and proved that the integration was effective for optimising the creativity of junior high school students in Indonesia (Astutik & Prahani, 2018:420).

3.9.4.1 PhET simulations for teaching and learning stoichiometric chemistry

In this section, a discussion on the simulations available on PhET for teaching stoichiometric chemistry will be discussed. Two main simulations for the content related to the topic of stoichiometric chemistry will be explored:

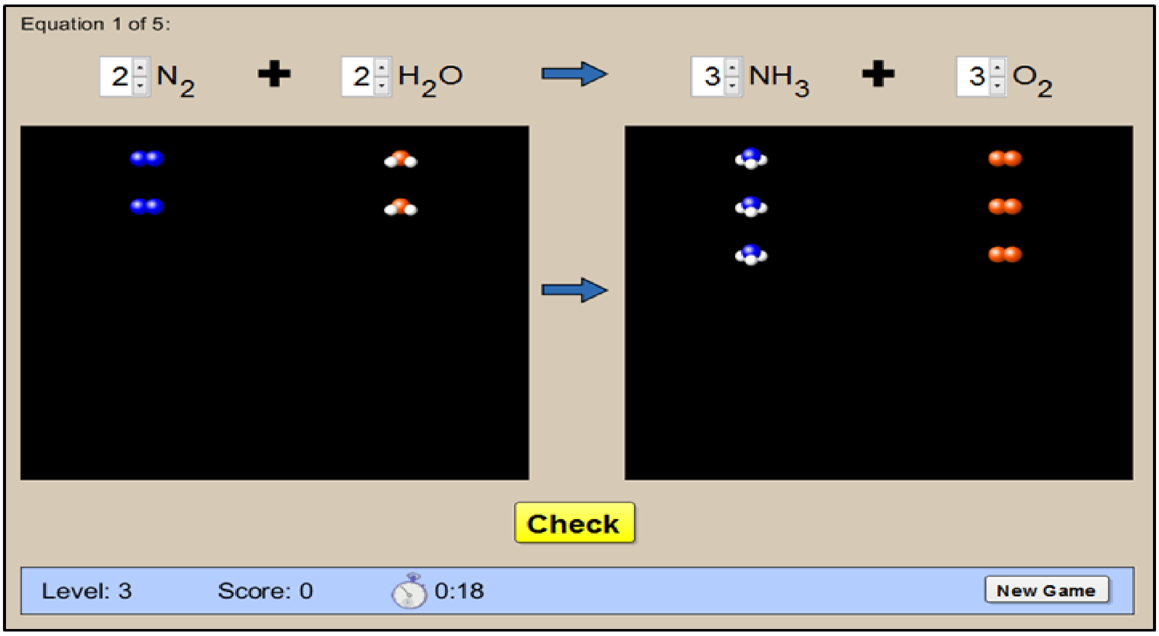
- Balancing of chemical equations
- Reactants, products and leftovers

3.9.4.1.1 PHET simulations for balancing chemical equations

To study the concepts related to the quantitative aspects of chemical change, one must have the foundational skill of balancing chemical equations. If learners cannot balance an equation, it can affect their learning and practice of chemistry. Moreover, it can affect the calculations related to reactions (Carpenter, Moore & Perkins, 2016:1150). Balancing of chemical equations is fundamental to manipulating quantitative aspects of chemistry (Omwirhiren, 2015:5). The practice of teaching balancing chemical equations is generally done in the traditional way of direct instruction, and later on, teachers give learners the opportunity practise with different examples. When teaching how to balance equations, teachers normally give learners a definition, but often fail to help learners with a non-algorithmic approach, with activities based on balancing (Carpenter *et al.,* 2016:1151). PhET simulations provide an alternative way to help learners conceptualise balancing equations. It helps learners to balance chemical equations without explicit instruction, and the representations used in the simulation contribute to developing learners' balancing practices.

In the PhET simulations, the topic of balancing equations – the first step in stoichiometric chemistry learning – provides an introduction, where learners have to compare the total number of atoms and molecules on both sides of different, unbalanced equations. Then, there are other game screens, where learners complete activities at different levels with varying difficulty. In all these games, the learner is supported by guided-inquiry activity, offered through both symbolic and pictorial representations. When learners have done the activities, they can click on the check button to verify their answers. If their answers are not correct, they can always go back and redo the balancing. This approach, of game-like activities with different difficulty levels, and the option to check the accuracy of answers, helps learners to improve their understanding of balancing equations (Carpenter *et al.,* 2016:1150). This understanding could, in turn, promote conceptualisation. Once learners learn how to balance an equation, the coefficients in the balanced equations need to be interpreted to solve the problems in stoichiometric calculations.

According to Carpenter *et al*. (2016:1151), the advantage of simulations is that the atoms and molecules are displayed concurrently in symbolic and molecular-scale pictorial representations of the atoms and molecules in the chemical equation. Figure 3.4 shows an example of how the simulation appears on the game screen for the reaction between nitrogen and water to produce ammonia and oxygen, which was downloaded from the PhET simulations. In this screen, the equation with the coefficients given is not balanced. Learners can change the coefficients by looking into the molecular representations on both sides until the equation is balanced.


Equation 1 of 5:

$2\ N_2 + 2\ H_2O \rightarrow 3\ NH_3 + 3\ O_2$

Level: 3

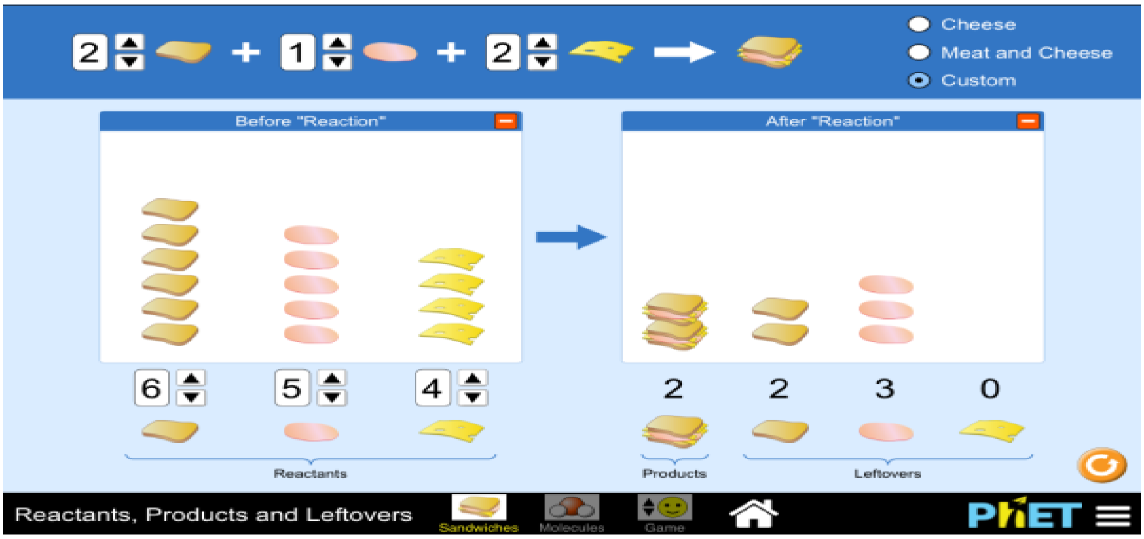
Score: 0

0:18

Figure 3.4: Game screen on PhET simulations to balance equations: Molecular scale representation

Carpenter *et al*. (2016) explain that, by analysing the number of atoms of each element on either side, the learners can understand how many atoms of each element is needed to balance the element on either side. In the above example, on the left-hand side of the equation, with the respective coefficients, there are four nitrogen atoms, four hydrogen atoms and two oxygen atoms. However, on the right-hand side, there are three nitrogen atoms, nine hydrogen atoms and six oxygen atoms. This shows that the number of atoms for each element are not balanced on either side. The molecular scale representation in the simulation helps the learners to manipulate the coefficients of the reactants and products and balance the equation correctly.

Another type of game for practising balancing equations in the PhET simulations uses different ingredients to make a sandwich. The research done by Bílek, Nodzyńska, Kopek-Putała and Zimak-Piekarczyk (2018) on the use of the sandwich simulation reports as follows. The first part of the simulation starts with learners creating their own sandwiches with bread, cheese and ham, and they can check how much of each ingredient is needed to create different numbers of sandwiches, and how many sandwiches can be made with the given amount of ingredients. Later, they compare the method of creating sandwiches to the method of balancing chemical equations. Bílek *et al.* (2018:791) report that this sandwich method of balancing equations is successful for conceptualising balancing of equations. A screenshot of the PhET simulations for the sandwich game is shown below as Figure 3.5. According to the game screen given below, two bread slices, one slice of ham and two cheese slices are needed to make a sandwich. In the game there are six bread slices, five ham slices and four cheese slices. Using the simulation, learners can be asked to make their own sandwiches (consisting of bread, cheese and ham). Then, they can refer to the number of each ingredient needed to create one sandwich and how many sandwiches can be made with the given amount of ingredients. Then, they can compare the process of creating sandwiches to the process of balancing chemical reaction equations.



○ Cheese
○ Meat and Cheese
● Custom

Figure 3.5: Game screen on PhET simulations: Sandwich method

From the above game, according to Bílek *et al*. (2018:784), playing with the simulation helps learners to create their own sandwiches with bread, cheese and ham, and to calculate how much of each ingredient is needed to create different numbers of sandwiches. After each game, the learners can check their results and then try again if they were wrong. Once the learners have had enough practice in making sandwiches, they can go back to molecular representations for balancing equations. This will help them to compare the process of balancing chemical reaction equations with the process of creating sandwiches Figure 3.6 shows the game for balancing chemical equations using molecular representation in the PhET simulations used by the researchers to conduct the research with learners. The figure shows the reaction between hydrogen and oxygen to form water, in which two molecules of hydrogen gas combine with one molecule of oxygen gas to produce two molecules of water. It is given as the balanced equation at the top of the game screen. The balanced equation represents the simplest whole number ratio in which the hydrogen and oxygen reacts to form water, according to the law of conservation of mass (see 2.6.1.3 & 2.10.2.1). The game gives three molecules of hydrogen and two molecules of water. The learners can use the balanced equation to find out how many water molecules can be formed with the given molecules of hydrogen and oxygen, and the number of molecules of oxygen and hydrogen left (leftovers), if any, after the reaction.

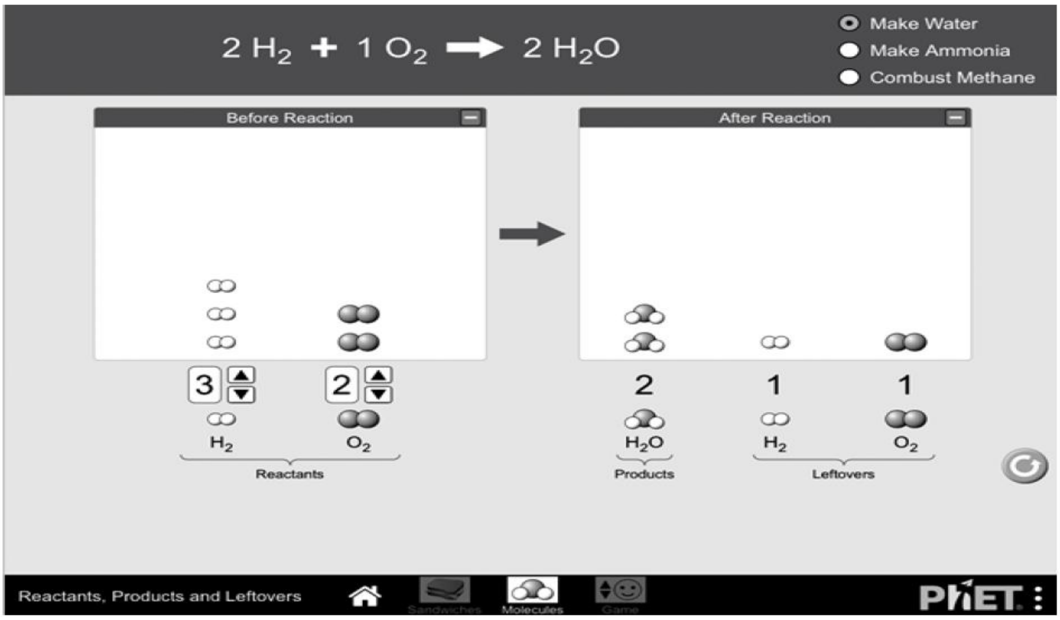


Figure 3.6: Game screen on PhET simulations: Symbolic and molecular scale representation

Bílek *et al.* (2018) report that, throughout the activity, the simulation supported the learners with balancing, with symbolic and molecular scale pictorial representations of the atoms and molecules in the chemical equation. The representations in the simulations also help to avoid terminology mismatches, so that students can accurately convey their intended meaning. Using the common phenomenon of making sandwiches as the starting point, and then moving to a more abstract activity, of matching the number of molecules in a reaction, is recommended in the PhET simulations, as it gives good results in the conceptualisation of balancing equations in the study (Bilek *et al.,* 2018).

3.9.4.1.2 Simulations of reactants, products and leftovers

Once learners conceptualise the balancing of chemical equations, the next step that teachers can take is to introduce the mole concept. The mathematical chemistry of the mole concept was discussed in Section 2.10.1. According to Malcolm *et al.* (2018:135), due to the mathematical application of mole, teachers consider the mole concept to be the most difficult concept for learners to grasp and, hence, while teaching, the teachers use algorithms instead of developing conceptual understanding. As a result, learners who do direct calculations using algorithms by substituting in formulae connecting the mole with other quantities such as mass, number of atoms, volume and concentration struggle to solve complex problems. According to Omwirhiren (2015:3), this is an area where very few students and learners are successful and, hence, those who do not fully understand the mole concept experience difficulties in problem-solving, and in other calculations based on stoichiometry. Complex problems are those that require that, when a reaction is given, one has to calculate the mole or mass of the product when the mole or mass of the reactant is given, and vice versa. It was discussed in Chapter 2 (see 2.10.1) that, in addition to just applying the formulae in the mole concept, learners must first understand the ratios in which the reactants react and products are formed (Yaayin & Ayoberd, 2018:21). They also have to identify the limiting reagent and the excess reactant, which requires understanding of the ratios, that is, knowing what the coefficients of the reactants and products in the balanced equation are (see 2.10.2.).

When learners are faced with a complex stoichiometric calculation, they must first interpret it correctly. A common error that occurs is a comprehension error, as pointed out by Omwirhiren (2015:4), because learners do not approach the question from the concept – this is a result of the way the teacher explained how to simplify the concept. According to Van der Westhuizen (2015:21), learners' long-term memory is inadequate and, due to the comprehension error, they find it challenging to find the link between the current problem they have to solve and the knowledge that has been stored in their long-term memory. Yaayin and Ayoberd (2018:21) report that the mole concept and its application become more difficult to conceptualise due to the perceptions and attitudes that students have towards it. Perception plays an important role in awareness and acceptance of the stimuli of selection, organisation and interpretation, while attitude comprises feelings, belief and action. Yaayin and Ayoberd (2018:21) recommend that any teaching method that can positively influence students' perceptions and attitudes regarding the mole concept is worth exploring, which supports my motivation in this study to determine the effectiveness of computer simulation for teaching stoichiometric chemistry.

While exploring the different simulations, I noticed that, in the PhET simulations, the topics of reactants, products and leftovers provided simulations which simplify the concept, thereby influencing the students' perceptions and attitudes and, hence, could reduce the comprehension error. Therefore, the PhET simulations were chosen as a tool to find out whether its use can enhance the conceptualisation of the mole concept and its complex calculations. An explanation of how the PhET simulations simulate the concept of reactants, products and leftovers are given below.

The simulations first make use of bread, ham and cheese for making sandwiches and, then, help learners to understand the ratio in which reactants (in this instance, slices of bread, ham and cheese) react and products (sandwiches) form. The same game could be used to conceptualise balancing equations (see 3.9.4.1.1) Learners know that, to make a sandwich with bread, cheese and ham, each two slices of bread need a slice of cheese and a slice of ham. The simulation takes the form of a game, and the learner can increase or decrease each ingredient needed to make a sandwich and find out how many sandwiches can be made and how much of the ingredients is left over. This game can help them to acquire foundational knowledge in a concrete and familiar context (Perkins, Lancaster, Loeblein, Parson & Podolefsky, 2010:1). When using the game to teach, the teacher can help learners to understand that, like the ratio of using each ingredient for making a sandwich, there is a ratio at which each reactant reacts and forms product(s). Figure 3.7 shows an example of making sandwiches in the PhET simulation, which has the end goal of studying reactants, products and leftovers.

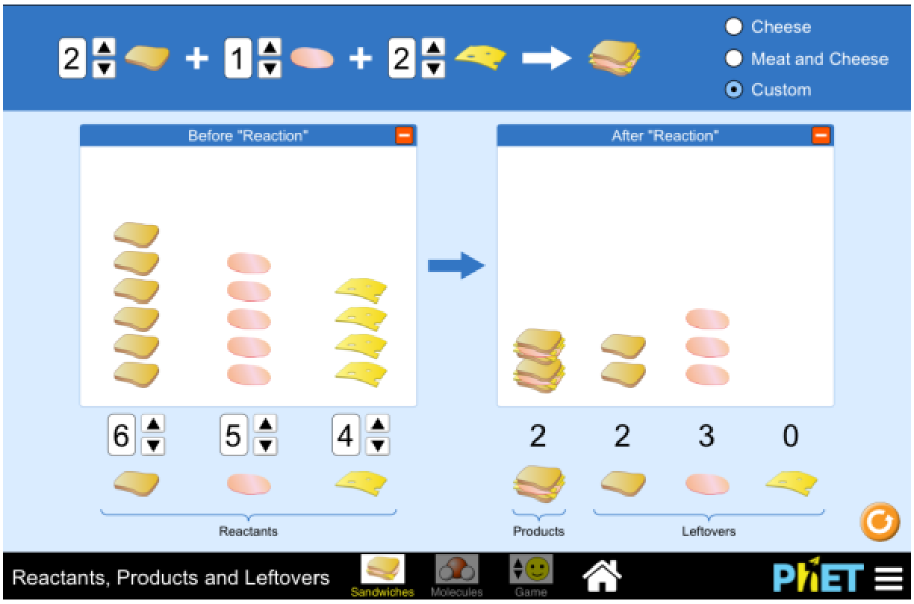
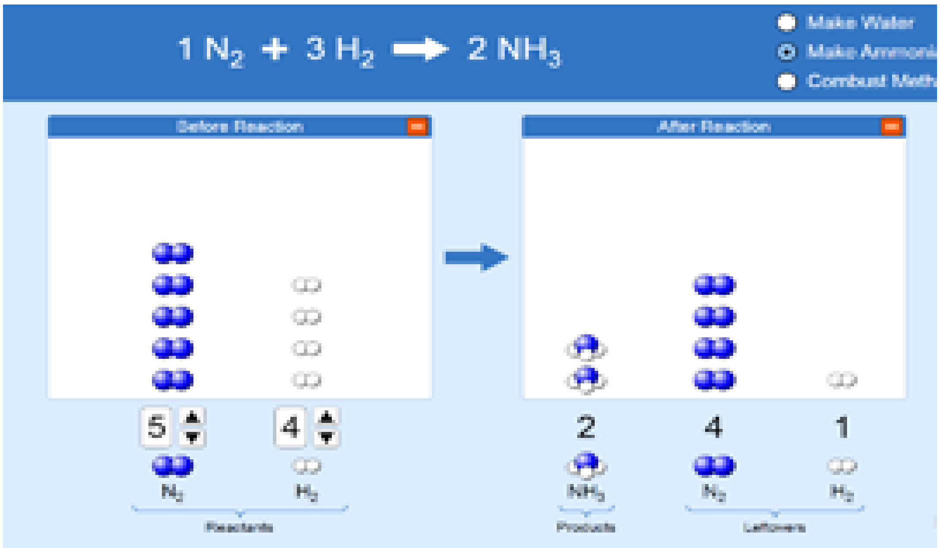


Figure 3.7: Sandwich method to explain the ratio of reactants, products and leftovers

By using a sandwich as an example, learners can connect the bread, ham and cheese slices to reactants and understand in what ratio the products are formed and what remains as leftovers. The game provides multiple opportunities for teachers and learners to customise and manipulate the amount of each ingredient that must be present in one sandwich and, hence, use the ingredients like an equation in a reaction. Learners make use of real-world, authentic examples for learning chemical reactions and eliminating misconceptions (Bílek *et al.*, 2018:791).

The developers of the PhET simulation claim that the simulation reactants, products and leftovers are designed to address learners' difficulty in translating between the chemical equation and a molecular view of the reaction. While working with the simulation, learners make use of folder-like tabs that scaffold from simpler to complex calculations, first with sandwiches and later with chemical reactions. Adjustments to the number of reactants immediately and dynamically change the molecular view representations of products and leftovers (Podolefsky *et al.*, 2010:2). Figure 3.8 is a screenshot of an example of the molecular view of a reaction in the PhET simulation for learning about reactants, products and leftovers.



$1\,N_2 + 3\,H_2 \rightarrow 2\,NH_3$

Figure 3.8: PhET simulation: Molecular view

Figure 3.8 displays a game that shows representations of each molecule of the reactant that was available for a reaction, products formed and leftovers. The balanced equation for the reaction is given at the top of the game screen. By changing the coefficients that represent the number of molecules of each reactant that could be used for a reaction, learners can view the number of molecules of the products and the leftovers by referring to the balanced equation given at the top of the game screen.

In the final game tab, the difficulty level increases and learners can challenge, test and refine their understanding. Interviews with students established that the game provides a critical feature for engaging students in developing a robust understanding of limiting reagents (Hansen, 2014:88). Therefore, the simulations recommends the achievement of the following learning goals:

- Predicting the amounts of products and leftovers after reaction, using the concept of limiting reagents;
- Predicting the initial amounts of reactants, given the amount of products and leftovers and using the concept of limiting reagent;
- Translating from symbolic to molecular representations of matter; and
- Explaining how subscripts and coefficients are used to solve limiting reagent problems.

3.10. SUMMARY

The second secondary research question asked, what influence does computer simulations have on learning when it is integrated with the teaching of chemistry? This chapter was an attempt to answer the above question. A general overview of ICT in education was given, and various researchers' views on the importance of using information and computer technology to enhance learning were reported. The review found that ICT plays an important role in providing quality education (see 3.2). The review also showed that, when computer simulations were used to teach complex and difficult concepts in chemistry, learning results showed a positive influence. The literature review that was conducted revealed that simulations, despite its disadvantages, enhanced learning in the different topics in chemistry (see 3.9.3). The effectiveness of integrating ICT in their teaching depends on the TPACK of the teacher. The importance of the teacher's TPACK was also discussed before (see 3.3). Activity theory, as the theoretical framework for the study was discussed, and an explanation given on the adapted activity theory model and how it supported the study (see 3.4). As the research topic is the effect of computer simulations on the conceptualisation of stoichiometric chemistry, simulations in the form of games that

PhET provide for the teaching and learning of the topic were explored. The review explained that simulations have a variety of exploration techniques for learners to engage in activities and games for learning a concept. PhET simulations were compared to other simulations during the study. PhET simulations have simulations and games based on stoichiometric chemistry, and the way it could be used for the conceptualisation of the topic was explored (see 3.9.4). It was found that the games in PhET simulations guide the learners in an innovative way to conceptualise balancing of chemical equations, and to use ratios in the balanced equation to determine the limiting reagents and excess reactants and, finally, to solve complex stoichiometric problems (see 3.9.4.1). Hence, PhET simulations were chosen as the appropriate simulation to be used to study the effect of computer simulation on the conceptualisation of stoichiometric chemistry.

In the empirical research of this study, activity theory was used as the theoretical framework to study learners’ use of PhET simulations to engage in activities based on stoichiometric chemistry. The empirical research design for the study will be discussed in Chapter 4.

CHAPTER 4:
EMPIRICAL RESEARCH DESIGN

4.1. INTRODUCTION

In Chapter 2, the teaching and learning of physical sciences and the difficulty experienced by learners in learning chemistry, which is considered as an abstract field, were explored. The value and importance of learning chemistry, in general, and stoichiometric chemistry, in particular, in the South African context were also discussed in Chapter 2. The literature review conducted regarding the concepts and content of stoichiometric chemistry and its teaching and learning explained that learners had many misconceptions about the quantitative aspects of chemical change, and this results in poor conceptualisation of the topic.

In Chapter 3, ICT and computer simulation in general, and how the integration of computer simulation influences the learning of chemistry, were explored and discussed. The use of PhET simulation (see 3.9.4) in general, and how simulating the mole concept and complex stoichiometric calculations can be used for teaching and learning were explained in the later sections of this chapter.

Chapters 2 and 3, thus, helped to answer the first and second secondary research questions of the study. In research, it is essential to explain why a specific method(s) was chosen for a study, and the entire research strategy needs to be described. The purpose of this chapter was to unfold the research methodology of the study. Topics that will be discussed include the appropriateness of the choice of the research method, the specific research design, and how using this design could answer the research questions. The explanation of how the paradigm could justify the selected research design, the population and sample used for the study, the data collection methods, instruments used, their validity and reliability, and how the analysis was done, will be explained. The ethical issues will also be discussed in this chapter.

4.2. RESEARCH QUESTIONS

The primary and secondary research questions for the study are given below.

4.2.1 Primary research question

The primary research question is as follows:

> What is the effect of computer simulation on Grade 11 learners' conceptualisation of stoichiometric chemistry?

The following secondary questions guided the investigation to answering the primary research question.

4.2.2 Secondary research questions

1) What are the value and importance of teaching and learning chemistry in the South African context?
2) What influence does computer simulation have on learning when it is integrated with the teaching of chemistry?
3) How effective is the use of computer simulation in the teaching of stoichiometric chemistry concepts?
4) What recommendations can be made regarding the effect of computer simulation on the teaching and learning of stoichiometric chemistry for improving its conceptualisation in the Further Education and Training (FET) phase at schools?

The first and second secondary research questions were addressed through a literature review, reported on in Chapters 2 and 3 respectively. To answer the third question, a mixed methods research study was conducted. The data collection was done using quantitative and qualitative methods. The data analysis and discussions were used to answer question 3. The last secondary research question will flow from the findings of the first three research questions and will be addressed in the last chapter of this study.

The search for answers to the secondary questions listed above contributed to answering the primary research question.

4.3. RESEARCH METHODOLOGY

While conducting this research, the process of collecting and rationally analysing the data in search of answers to the research questions was not a neutral process. According to De Vos *et al.* (2011:143), a research methodology relates to the researcher's perspective on the purposes of a particular study. This chapter describes the choices that were made regarding the topic to be studied with the selected population, which research methods were most suitable and chosen, how observations were made and how the study was conducted (Babbie, 2007:112; Monette, Sullivan & DeJong, 2008:9). During the research, I kept in mind that methodology not only explains the choice of data collection method, but also provides a theoretical justification for the methods used and the kind of knowledge one can generate from a study (Case & Light, 2011:205). Pragmatism was the paradigm for the study (see 1.6) and it is discussed further in Section 4.5.

4.4. RESEARCH DESIGN

This section will discuss the plan, structure and strategy of investigation that was used. It will communicate to the world the proposed study design, how information was collected from respondents, how the respondents were selected, how the information collected was analysed and how the findings were communicated (Kumar, 2018:95). Therefore, the research design focused on identifying and developing procedures and logistical arrangements for the study, and ensuring validity, objectivity and accuracy of the procedures. A mixed methods design was used for the study.

4.4.1 A mixed methods research design

Explanations by different researchers about mixed methods design will be given in this section. The mixed methods design builds on both quantitative and qualitative approaches. By making use of mixed methods, a researcher combines quantitative and qualitative strategies in one study by collecting numerical and textual data concurrently or in sequence, to find answers to the research questions (Maree, 2016:312). Researchers define mixed methods research in more or less the same manner. According to Tashakkori and Teddlie (2003:711), mixed methods research can be defined as a research design that uses both qualitative and quantitative approaches to answer the research questions, to determine research methods, data collection and analysis, and, finally, to draw conclusions. Within the mixed methods, the quantitative and qualitative methods complement each other and allows for a more complete analysis of the research problem, hence, gaining in-depth understanding. A mixed methods design is a procedure for collecting, analysing and mixing quantitative and qualitative data in one study during a particular stage of the research process, in order to understand the research problem completely (Maree, 2016:313). Creswell (2014:32) adds that a mixed methods research is an approach to inquiry that involves a procedure for collecting, analysing and integrating both quantitative and qualitative data by making use of philosophical assumptions and theoretical frameworks.

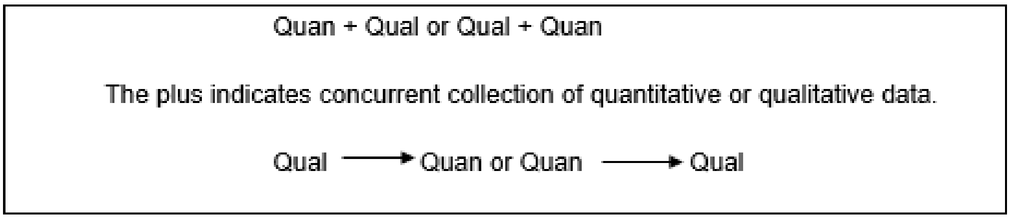
4.4.2 Rationale for choosing a mixed methods approach for the study

The literature about the mixed methods approach quoted above (see 4.4.1) shows that combining qualitative and quantitative approaches by purposefully mixing the methods for data collection, data analysis, and interpretation of the evidence leads to a more complete understanding of a research problem than either approach alone (Shorten & Smith, 2017:74). The motivations given by researchers about using mixed methods helped me conduct the study using mixed methods. It was decided that the most effective way to answer the secondary research question 3 would be through the pre-test post-test experimental design, which is quantitative in nature, observation of lessons, and the test response analysis, which are qualitative in nature, to provide data for interpreting. The questionnaire, which included both quantitative and qualitative sections, and the interviews added to the explanation of the results.

4.4.3 Advantages of a mixed methods design

According to Alharbi (2014:76), an advantage of using different methods to gather data is that it enables a researcher to effectively triangulate the data. Triangulation involves checking and verifying results by two or more methods, to give more confident and stronger results. Shorten and Smith (2017:75) report on the strengths of mixed methods, and consider it to be an appropriate design for obtaining a better understanding of connections and contradictions between qualitative and quantitative data. This approach provided me, as the researcher, with opportunities to explore all methods possible for answering the questions, which, in turn, enriched the evidence collected during the process. Bergman (2008:12), Creswell and Plano Clark (2017:4) and Teddlie and Tashakkori (2010:8) assert that mixed methods research has more scientific value than using qualitative and quantitative methods alone in a study. In mixed methods research, the mixing helps to expand the researcher's understanding, instead of requiring a search for corroboration across the different approaches used. A mixed methods approach helps to gather information from divergent views and perspectives, and alerts the researchers that the issue can be more multifaceted than initially understood (De Vos *et al.,* 2011:436).

After collecting and analysing the data, the different findings from the quantitative and qualitative methods can be compared and contrasted by triangulation. Schoonenboom and Johnson (2017:4) assert that, when various methods are used, triangulation helps to obtain convergence, corroboration and correspondence from the different methods. Doing so helps to obtain a variety of information on the same issue by strengthening each method and overcoming deficiencies of the other (Honorene, 2017:92). Ginyigazi (2018:47) reports that triangulating data offers an advantage when a research involves qualitative and quantitative methods, as it tests the consistency of the findings using different instruments – in this research, pre-test and post-test, observation of lessons, test response analysis, interviews and questionnaire. These helped to determine the extent to which the results obtained agreed or disagreed with each other and, hence, enabled me to achieve more complete and well-validated conclusions for the study (De Vos *et al.,* 2011:442). A notation system that was used by early mixed methods researchers to convey the aspects of the research process implemented is shown in Figure 4.1 (Maree, 2016:316). This notation system uses labels for quantitative (quan) and qualitative (qual), and indicates the timing of data collection and analysis.



Quan + Qual or Qual + Quan

The plus indicates concurrent collection of quantitative or qualitative data.

Qual → Quan or Quan → Qual

Figure 4.1: Notation system for mixed methods research

Mixed methods research provides a way to harness strengths that offset the weaknesses of both quantitative and qualitative research (Creswell & Plano Clark, 2017:53):

- Quantitative research alone is considered to be weak, as the respondents are not directly heard by the researcher and, hence, the understanding of the context and setting in which the respondents talk, will be weak. Also, personal biases and interpretations of the quantitative researcher are seldom discussed and, hence, the qualitative research makes up for this weakness.
- A qualitative method for research is seen as deficient because of the personal interpretations made by the researcher and its ensuing bias. Also, there is difficulty in generalising findings to a large group, because of the limited number participants studied, which is not a weakness in quantitative research.
- The strength of one approach makes up for the weakness of the other and, hence, by mixing both quantitative and qualitative research and data, the researcher gains in breadth and depth of understanding and corroboration, while offsetting the weaknesses inherent in using each approach by itself.
- Using mixed methods research provides broader evidence for the study of the research problem, than when qualitative or quantitative research is done alone.
- Pragmatism, which is the paradigm of this research, is supportive and provides the means to conduct mixed methods research (see 4.5).
- A mixed methods researcher can use relevant methods, skills and thinking to address a research problem.

The literature discussion above supports the rationale behind the use of a mixed methods design for the study. The mixed methods research model for the current study is shown in Figure 4.2.

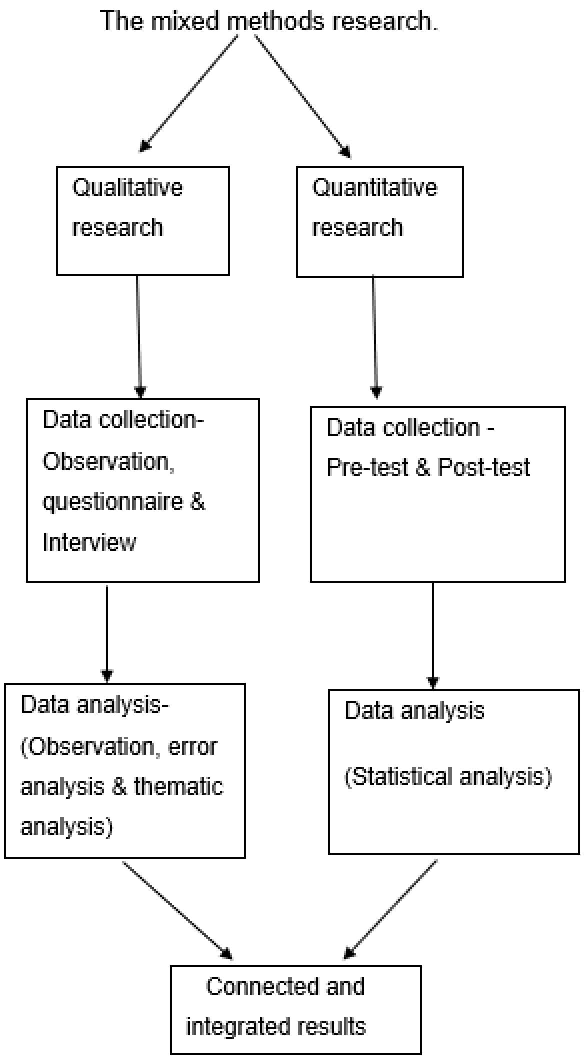


Figure 4.2: Mixed methods research model for the study

4.4.4 Basic designs in mixed methods research

In a mixed methods study, data collection can be conducted concurrently or sequentially. It is important that the researcher identifies the most suitable mixed methods for the study. There are basically three designs that are most frequently used by researchers, namely the exploratory sequential design, the convergent parallel design and the explanatory sequential design (Maree, 2016:319).

4.4.4.1 Exploratory sequential mixed methods design

The exploratory sequential design is used when a researcher collects the qualitative data and explores it first, and then collects data quantitatively. In this design, the first phase of the research is the qualitative phase, during which themes are identified and theories are generated, which is followed by the subsequent quantitative examination of the initial qualitative results (Maree, 2016:317). The exploratory sequential flow of the design is shown in Figure 4.3.

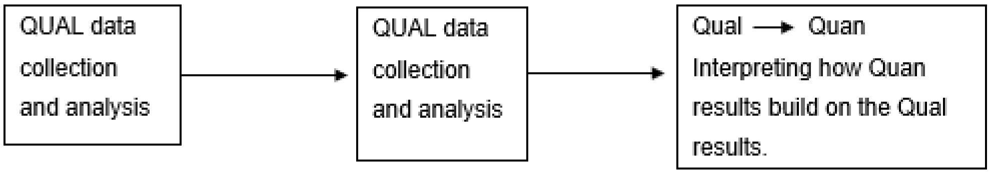


Figure 4.3: Exploratory sequential design

4.4.4.2 Convergent parallel mixed methods design

In the convergent parallel design, the researcher uses qualitative and quantitative techniques in parallel. In this design, the research questions are addressed by collecting and analysing both qualitative and quantitative data at the same time. Thereafter, the two sets of results are merged and the results are compared and interpreted. The parallel and convergent aspects of the design are shown in Figure 4.4.

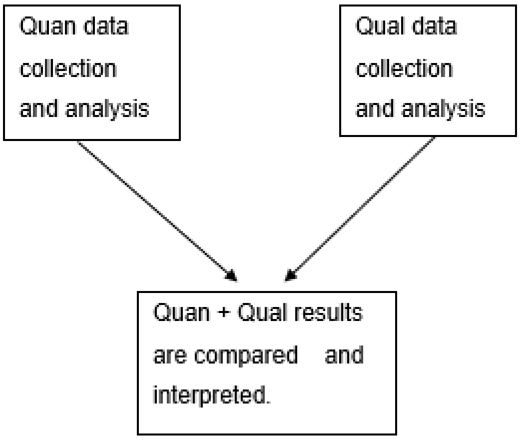


Figure 4.4: Convergent parallel mixed methods design

4.4.4.3 Explanatory sequential design

The explanatory sequential design is the most common and straightforward mixed methods design, whereby qualitative findings help to refine, explain and clarify the general picture presented by the quantitative results (Creswell & Creswell, 2017:196; Aguiton, Li, Worch, Zhou 2015:4; Maree, 2016:316). Researchers explain the design as starting with the collection and analysis of the quantitative data, followed by the collection and analysis of the qualitative data. In this design, researchers apply the two methods in separate phases and collect only one type of data at a time. In general, the qualitative data, which is collected in the second phase of the study, will help clarify and explain certain quantitative results of the first phase. Figure 4.5 shows the sequential flow of the quantitative and qualitative phases of the explanatory sequential design (De *Vos et al.*, 2011:442).

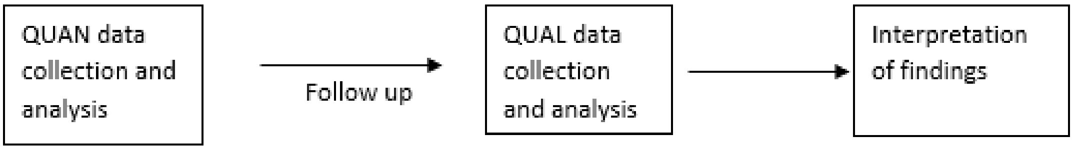


Figure 4.5: Explanatory sequential mixed methods design

The sequential experimental design was used for the study.

4.5. PRAGMATISM AS PARADIGM

All scientific research needs to be done within a specific paradigm, which is a framework based on people’s philosophies and assumptions about the social world and the nature of the knowledge they are searching for (De Vos *et al*., 2011:513). Pragmatism is the paradigm that was used in the study, as researchers consider it to the best philosophical foundation for justifying the use of mixed methods in a study (Brierley, 2017:143; Johnson, Onwuegbuzie & Turner, 2007:115; Teddlie & Tashakkori, 2006:13).

To justify the use of pragmatism as the paradigm for mixed methods research, its theoretical background needs to be understood. Pragmatism is an American methodological approach that was taken by William James (1842–1910), John Dewey (1859–1952), Charles Sanders Peirce (1839–1914) and Herbert Mead (1863–1931). *Pragma* is a Greek word that means action, and it simply means searching for the feasible, workable solutions to complex human problems (Parvaiz, Mufti & Wahab, 2016:68). Through the lens of pragmatism, researchers conduct studies on real-world issues and construct knowledge by means of a mixed methods approach (Maree, 2016:312). Pragmatism emphasizes answering the research questions by choosing the best strategies to address the research questions. Doing so opens doors to using multiple methods to conduct a study. Pragmatism, as discussed by mixed methods researchers, makes use of various approaches for collecting and analysing data, rather than using only one way (Creswell & Garrett, 2008:327). Parvaiz *et al*. (2016:76) report that, in pragmatism, the research problem is the concern, and the different data collection methods in mixed methods, like interviews, questionnaires, observation, articulation and analysis, all provide deep insight into the problem. The method draws information from both quantitative and qualitative assumptions during the research and it does not commit to any one philosophy or reality. Pragmatism emphasizes the flexibility of the choice of methods, in order to match the purpose of inquiry, which will be practical and useful (Creamer, 2017:45). Pragmatism supports a mixed methods study, where equal status is given to qualitative and quantitative aspects of the study, and pragmatism results in one answer to the research question (Schoonenboom & Johnson, 2017:7).

For this study, the quantitative and qualitative methods were mixed to explore objective and subjective knowledge (Wong & Cooper, 2016:48). In pragmatism, both inductive and deductive methods can be used, and for this study, the inductive approach was followed. This approach helped to discover patterns, consistencies and meanings in behaviour through analysis of the data collected from the pre-test and post-test, observation of lessons, test response analysis, questionnaire and interviews.

According to Goldkuhl (2012:12) and Greene and Hall (2010:123), pragmatism emphasizes constructive knowledge, which is gained through investigation of collected data, and which is used for action with a difference that results in change. For the current study, the knowledge gained from the data collected from the pre-test post-test experimental design, questionnaire and interviews was used to make recommendations for changes in the conceptualisation of stoichiometric chemistry.

Thus, for mixed methods research, pragmatism opens the door to multiple research methods with different forms of data collection and analysis. This is because pragmatism allows the researcher to be free of the practical constraints of other paradigms, thereby giving the researcher the freedom to use the various research methods that are appropriate for the study (Feilzer, 2010:8).

4.6. POPULATION AND SAMPLING

The population and sampling techniques that were used for the study are discussed in this section.

4.6.1 Population

In any mixed methods research, identifying the individuals from whom the data is to be collected is very important (Edmonds & Kennedy, 2016:19). The population of the study comprised learners in Grade 11 who had chosen physical sciences as a subject in the Northern Cape province. The study was conducted in the Northern Cape province, which had 117 schools offering physical sciences in the FET band. The topic of stoichiometric chemistry, which involves complex calculations, is recommended by the Grade 11 physical sciences curriculum in South Africa and, hence, the specific grade was chosen. In Chapter 1 (see 1.2.1), the performance of learners in physical sciences in the NSC November examination and the need to improve the conceptualisation of certain topics in Grades 10 and 11 were discussed. Being employed and living in the Northern Cape province, it was therefore convenient for me to conduct the research in this province.

4.6.2 Sample and sampling procedure

As the population of the study was from the Northern Cape province, the Frances Baard district, which had the greatest number of learners enrolled for physical sciences, was chosen for the study (see 1.7.2). The collection of data with the experimental pre-test post-test design required a control group and experimental group with learners taught by two different teachers of comparable qualifications and teaching experience. These control and experimental groups needed to consist of homogeneous Grade 11 classes that were comparable in performance, discipline and demographics. Hence, purposive sampling was used to select the sample for data collection: two Grade 11 classes at the same school in the Frances Baard district of Northern Cape province. This was the only school that met the above-mentioned requirements for the study. The motivation to use purposive sampling for the study was to increase the credibility of the results, to reduce variation and to simplify analysis (Palinkas *et al*., 2015:535). The selected school also had two Grade 11 classes that were taught by two different teachers which was a requirement for the study. The teachers had the same qualifications and same number of years of experience teaching physical sciences. In purposive sampling, the researcher chooses the sample with a specific purpose in mind. This sample consists of the most characteristic representative of the population that can serve the purpose of the study (De Vos *et al*., 2011:232; Edmonds & Kennedy, 2016:19; Maree, 2016:198).

The two Grade 11 class groups of the school were randomly assigned as the control and experimental groups. The control group consisted of 30 learners and the experimental group consisted of 32 learners. For the current study, the two groups were compared on a single measurement and, hence, a relatively small sample could be representative of the population (Maree, 2016:199).

All the learners in the control and experimental groups participated in the pre-test, lessons conducted by the teachers and in the post-test. Out of the total of 62 participants, only 61 learners completed the questionnaire. With purposive sampling, six learners from each group were selected for the interviews – they were the learners who had scored top, middle and lowest marks in the post-test (see 1.7.2). The same learners' scripts were used for test response analysis of the pre-test and post-test and the same learners' questionnaire responses were analysed.

4.7. DATA COLLECTION METHODS

Data collection is an important phase in the execution of research. Data collection is the systematic gathering and recording of information, with the aim of preserving and analysing the findings of a study and, hence, answering the research questions (Maree, 2016:37). The specific type of data collection and the procedures for data collection will be explained in this section.

First, the pre-test post-test experimental design was used to collect data. The lessons of both groups after the pre-test were observed, and the observations were recorded on an observation schedule. This was followed by the distribution of a structured questionnaire, which was self-administered by the participating learners. Thereafter, semi-structured interviews were conducted with the 12 selected learners individually. The test response analysis of the pre-test and post-test answer scripts of the 12 interviewees was also conducted. The above data was collected in order to answer the third secondary research question. The explanatory sequential design (see 4.4.4.3) used for this study is discussed below.

In this sequential explanatory study, the quantitative approach was applied first, to investigate the cause–effect relationship, and then the qualitative approach was applied to establish explanations and in-depth understanding of the quantitative results (Wong & Cooper, 2016:47). The two approaches are complementary, and were executed in a particular order in the research. The data of phase 1, which relates to the quantitative analytical results of the study, may not guarantee the cause–effect relationship, though the results of the analysis of the qualitative data in the second phase could confirm the cause–effect relationship (Wong & Cooper, 2016:55).

By making use of an explanatory sequential design, the quantitative data from the pre-test and post-test were collected first. The lesson observation was done for both groups after the pre-test, which was followed by the post-test. This was followed by participants completing the questionnaire. The questionnaire consisted of two sections: a larger and stronger qualitative section, and a smaller quantitative section. The small quantitative section was used as a guide to understand what needed to be asked in the interview. The interview schedule and the interviewees were finalised only after the post-test results analysis. After collection of data through the questionnaire, the semi-structured interviews with the selected learners were conducted. Therefore, the design was best suited for the study, as I wanted to understand the findings from the pre-test post-test results by obtaining richer, qualitative data. The cause–effect relationship, based on data from the pre-test post-test results, could be confirmed in the second qualitative phase. The test response analysis, open-ended questionnaire and the interviews provided the means to do that. Therefore, the data collected could provide a general understanding of the primary research question.

Table 4.1 provides a holistic presentation of the sequential explanatory design that was used for the study, which was adapted from Subedi (2016:574).

Table 4.1: Holistic presentation of the sequential explanatory design for the study

Phase	Procedure	Product
1. Quantitative data collection	Pre-test post-test experimental design and questionnaire section 2, questionnaire protocol	Numerical data
2. Qualitative data collection	Observation of lessons, questionnaire section 1, semi-structured interview with selected learners, questionnaire and interview protocol	Textual data
3. Quantitative data analysis	Descriptive and inferential analysis of pre-test post-test and questionnaire section 2	Meaningful measures of quantitative data
4. Qualitative data analysis	Lesson observation analysis of both groups, pre-test post-test response analysis, thematic analysis of questionnaire section 1 and interviews of the same learners	Qualitative explanation of results
5. Integration of quantitative and qualitative results	Explanation of quantitative and qualitative results and triangulation	Conclusions, recommendations and future research

4.7.1 Triangulation

Triangulation could require researchers to check the extent to which the findings from the quantitative data support the findings from the qualitative data, and vice versa (Maree, 2016:42). For the current study, the pre-test post-test (quantitative) findings were compared and contrasted with the findings of the qualitative questionnaire and interviews.

Figure 4.6 represents the research design as adapted from Wong and Cooper (2016:51) for the study, and shows the triangulation flow.

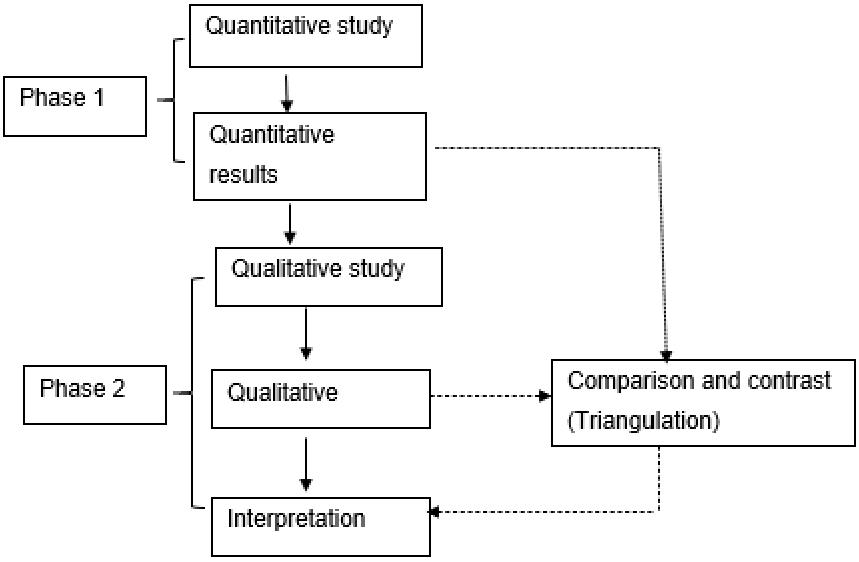


Figure 4.6: Triangulation flow of mixed methods design

Triangulation is also a means to justify the internal validity by comparing the qualitative interview and questionnaire (section 1) findings with the quantitative pre-test post-test results. Triangulation can be achieved by comparing and looking for convergence and complementarity of the findings from the quantitative phase and the qualitative phase (Wong & Cooper, 2016:55).

4.7.2 Instruments for data collection

The instruments that were used for data collection in the study will be discussed in this section.

4.7.2.1 Observation schedule

An observation schedule that had been adapted from the RTOP was used to observe the teachers while they were conducting lessons. RTOP is an instrument that was specially designed by the Evaluation Facilitation group of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) to measure reformed teaching, the idea of which is to prepare teachers to adopt a constructivist way of teaching (MacIsaac & Falconer, 2002:479) (see also 3.9). The observation schedule helped to implement the study within the theoretical framework of activity theory (see 3.4), as activity theory also gives importance to a constructivist way of teaching. The observation schedule contained criteria that could measure the characteristics and qualities of reformed teaching (see Appendix A). This way of constructing criteria – by carefully describing what behaviour of the teachers and learners needed to be observed – ensured validity of the observation that was conducted during the lesson (Ary *et al*., 2010:216). I used the observation schedule so that I could identify the methods and strategies used by the teachers while they were teaching their groups of learners. The same observation schedule was used for both groups, and it helped me to understand whether a constructive way of teaching was being applied and whether the use of computer simulations to teach the experimental group helped to reform teaching (see 3.9). Before observing the lessons, I made sure that I understood all the criteria in the observation schedule and how to record the observation. This ensured reliability of the observation (Ary *et al*., 2010:220). MacIsaac and Falconer (2002:479) recommend RTOP as a highly reliable instrument with strong predictive validity. The criteria in the RTOP were discussed with the teachers prior to the lessons, and I obtained their consent to observe their lessons. The anonymity of the observation was ensured.

4.7.2.2 Pre-test post-test experimental design

By means of the pre-test post-test experimental design, quantitative data was collected first. In this experimental design, there were two equivalent groups. The groups were first given a pre-test, followed by the intervention for the experimental group. In this study, the experimental group was exposed to an intervention using PhET simulations while the control group was taught according to the usual way of teaching at the school, which was the lecture method (direct teaching). This was followed by the post-test (Creswell & Creswell, 2018:273; Leavy, 2017:95; Leedy & Ormrod, 2014:223). This type of design is used to answer a specific kind of research question, specifically, the cause-and-effect question (Dimitrov & Rumrill, 2003:159; Leedy & Ormrod, 2014:223; Maree, 2016:166). As the two Grade 11 class groups in the school had been randomly assigned as experimental and control groups (see 4.6.2), doing so ensured that the groups were, in theory, probabilistically equivalent, and if there was any difference in their pre-tests, it would be due to chance (Edmonds & Kennedy, 2016:31).

4.7.2.2.1 Administration of pre-test and post-test

The pre-test was conducted for both control and experimental groups. The SCAT was used for the pre-test (see Appendices B & C). The content of the test will be explained later in this section. After the pre-test, one group was taught stoichiometric chemistry by using computer simulations, while the other was taught the same topic without using computer simulation. The tuition for the latter – the control group – was similar to the way chemistry was usually taught at this particular school, which was more direct teaching (lecture method, which is more teacher centred). After exposing the learners to the teaching of stoichiometric chemistry, both groups were exposed to the same post-test, to determine the effectiveness of the intervention and the direct teaching. A difference in performance in the post-test would explain the effectiveness of either the intervention or the direct teaching.

The control group learners were taught stoichiometric chemistry by the teacher explaining the content by writing on the board. In the case of the experimental group, the teacher taught the same topic of stoichiometric chemistry by making use of PhET computer simulations in addition to the explanations and use of white board as media. In this design, there was an independent and dependent variable. An independent variable is a variable that the researcher directly manipulates, and a dependent variable is one that is potentially influenced by the independent variable (Leedy & Ormrod, 2014:224). In this study, the independent variable was the method of teaching the topic in the two groups, while the dependent variable was the learners' performance in stoichiometric chemistry.

The pre- and post-test tests (SCAT) consisted of two main questions with sub-questions (see Appendices B & C). The questions were set from the learning area of quantitative aspects of chemical change. The questions were adapted from past question papers for Grade 11 and were moderated by three subject experts. The questions consisted of writing balanced equations, using balanced equations to determine the limiting and excess reactants, and calculating mass and volume of products formed.

The pre-test post-test design of the study is given in Table 4.2.

Table 4.2: Pre-test post-test design

Group	Pre-test	Intervention	Post-test
Control group	T	X_a	T
Experimental group	T	X_b	T

According to Table 4.7, the control group of the study was subjected to lessons by using the direct (lecture) method (X_a), according to the teacher’s choice. The experimental group was given the intervention using PhET computer simulation (X_b). T represents the SCAT as pre-test and post-test. Both pre-test and post-test was conducted with the same SCAT. After the pre-test, both control group and experimental group went through a set of lessons for two weeks. Both teachers followed the lesson according to the sequence given for conducting lessons.

4.7.2.2.2 Validity of the pre-test post-test experimental design

The internal and external validity of the design was ensured. Researchers suggest several explanations, of which a few are mentioned here. Validity is the extent to which any measuring instrument measures what it is intended to measure (Maree, 2016:169). Internal validity refers to the extent to which an investigation measures what it is supposed to measure, and external validity refers to the generalisability of the findings, which is also known as transferability (Alshenqeeti, 2014:43; Ary *et al*., 2010:501). The study becomes internally valid when factors that affect the internal link between the independent and dependent variables, which support alternative explanations for variations in the dependent variable, are considered (Dimitrov & Rumrill, 2003:159; Leavy, 2017:114; Leedy & Ormrod, 2014:226). Maree (2016:169) explains that, if the internal validity of an experiment is of a high degree, it means that there was sufficient control over the variables other than the intervention. It can be interpreted that the intervention alone was the reason for a change produced in the dependent variable. To ensure internal validity, all conditions for both experimental and control groups were the same, except that the experimental group had an intervention and the control group not. The two class groups were randomly assigned as control and experimental groups with their respective teachers. Both groups were given the same pre-test and post-test. As the same test was given for the pre-test and post-test, the instrumentation threat to internal validity was reduced. However, to avoid the possibility of learners using their knowledge of the pre-test in the post-test, it was ensured that a period of time had passed between the two tests (Creswell & Creswell, 2018:223).

The SCAT was moderated by three experts in physical sciences for validation, and corrections were made accordingly. External validity is the degree to which the treatment effect can be generalised across populations, settings, treatment variable for the design and the measurement instruments (Dimitrov & Rumrill, 2003:159; Leavy, 2017:114). With the small sample, external validity was not possible for the study, and generalisation to a larger population could not be done. However, it is reported that, in the first quantitative phase, inferential statistics, such as significance values in the pre-test and post-test, would indicate that the characteristics of the large population can be inferred from the characteristics of the sample in the study (Kabir, 2016:211; Maree, 2016:239; Wong & Cooper, 2016:55).

4.7.2.2.3 Reliability of the pre-test post-test experimental design

The reliability of the pre-test and post-test was also important in the study. Reliability refers to the consistency of the results obtained in identical situations, but in different circumstances (Maree, 2016:239). The reliability of the experimental design was checked by making use of Cronbach’s alpha. The Cronbach’s alpha evaluates the internal consistency of the instrument items (Creswell & Creswell, 2018:156; Kunnath, 2017:79; Tang & Abraham, 2015:31; Wong & Cooper, 2016:56). It is determined by measuring the extent to which the items in the test provide consistent information regarding the students' mastery of the domain. Researchers have accepted a set of values for the correlations between the items (Maree, 2016:239; Samuels, 2017:3). Table 4.3 shows the Cronbach alpha values for determining reliability.

Table 4.3: Reliability according to Cronbach's alpha values

Cronbach's alpha value	Reliability	Level of acceptance
0.70	Low	Acceptable
0.80	Moderate	Good
0.9	High	Excellent

Reliability estimates of 0.80 are regarded as acceptable in most applications. Cronbach's alpha was calculated using the reliability calculator designed by D. Siegle of Connecticut University, which is available online free of charge.[3] Cronbach's alpha of the experimental design for the study from the test results of both groups was calculated as 0,778, which shows close to moderate reliability and of a good level of acceptance.

4.7.2.3 Questionnaire

A questionnaire is probably the most commonly used instrument for data collection. The researcher collects data from respondents by requiring them to complete a set of questions and to respond to related prompts (Kabir, 2016:208). A questionnaire is "a document containing questions and or other types of items designed to solicit information appropriate for analysis" and the researcher can determine the extent to which respondents have a certain perspective (De Vos *et al*., 2011:186).

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[3] https://www.coursehero.com/file/16006365/Siegle-Reliability-Calculator-version-1/

4.7.2.3.1 Advantages of questionnaires

Kabir (2016:291) and Maree (2016:176) list the following advantages of using a questionnaire.

- The questionnaire can be completed by a large population in a short time and is a cost-effective way of data collection.
- The accuracy of the questionnaire can be checked by test administrators.
- Respondents can be reached across long distances and it is much cheaper than a telephonic interview and relatively easy to administer.
- The response rate could be increased if the questions in the questionnaire is developed and administered appropriately so that maximum respondents are able to complete the questionnaire.
- The results of the questionnaire can be quantified by the researcher, or by using computer software.
- The quantified data can be used to compare and contrast with the data obtained through other methods, and also to measure change.

For the current study, the first and third advantages were not applicable.

4.7.2.3.2 Questionnaire design

As a questionnaire is an instrument with which data can be generated, it needs to be designed appropriately according to certain basic rules. A questionnaire can be used as the only instrument for the research or can be one of several research instruments. The questionnaire used for this study (see Appendix D) was adapted from Kotoka (2013) and Kunnath (2017), and modified according to the pre-test and post-test results, and to comply with secondary research question 3.

Section A of the questionnaire dealt with demographic information of the learners who participated in the study. In this section, the learners had to indicate their age, home language, level achieved for physical sciences in the Grade 10 November examination, the discipline in physical sciences they enjoyed studying the most and their interest in proceeding with further studies in physical sciences . The adapted questionnaire was constructed by following the rules suggested by Kabir (2016:209).

Section B consisted of both qualitative and quantitative questions. According to the rules, I made sure that the statements in the qualitative section of the questionnaire would be interpreted in the same way by different respondents through pilot testing with colleagues and learners in Grade 11 from another school, and that, if the respondents had different opinions, they could express these opinions accordingly.

The questionnaire was constructed by avoiding negative or double negative statements and the questions were not biased. The questionnaire was brief, though it was long enough to collect all the relevant information, so that all concepts were adequately represented (De Vos *et al*., 2011:193). In the quantitative section, the learners indicated their responses on a Likert scale. This section of the questionnaire also helped me to construct the interview questions.

4.7.2.3.3 Administration of questionnaire

The questionnaire was administered to all the learners immediately after the post-test. After the post-test, each learner was assigned a code. For example, a learner in the control group has the code CGL1. Learners were asked to indicate their codes on the questionnaire instead of their names. This helped to ensure anonymity of the learners, and to link the questionnaires and interview analysis for particular learners. The learners, firstly, had to provide the demographic information in section A. Section B had two questions namely 1 and 2; question 1 had sub-questions. Question 1 consisted of six open-ended sub-questions. These questions investigated learners' understanding of stoichiometric chemistry, related calculations, and the method of teaching the lessons. In such open-ended questions, space is provided after the question, so that the respondent can insert a word, phrase or a description – the respondents formulate their own answers.

Questions 1.1, 1.2, 1.3 and 1.5 were based on the learners' conceptualisation of stoichiometric chemistry. The answers of the learners helped me to understand whether the intervention in the experimental group had any impact on their conceptualisation. Question 1.4 helped me to understand the confidence level of the learners after the lessons (see Appendix D). Question 1.6 helped me to understand the learners' experience of the lessons conducted in their respective groups, and to determine whether the intervention with simulation helped the learners to think differently about stoichiometric calculations as a result of better conceptualisation.

Question 2 contained closed questions, which consisted of a set of responses from which the respondent had to choose their response (Kabir, 2016:290). For the study, a Likert scale was used, and the respondent selected a ranked option from a list, indicating their degree of agreement or disagreement. This is the most commonly and widely used scale, and it provides an ordinal measure of a respondent's responses to a certain aspect (Maree, 2016:186; Marshall, 2005:133). After a respondent has answered a series of Likert scale questions, the total score for each respondent is calculated. This is done by assigning values 1 to 6 to the categories and then adding respondents' five values based on the responses (Maree, 2016:187). This section had questions on how well the teaching method used by the teacher had helped them to perform well in the topic. The data obtained from a closed question is easier to analyse than that obtained from an open question (Maree, 2016:180–81). The learners were given 45 minutes to respond to the questions in the questionnaire.

4.7.2.3.4 Validity of the questionnaire

To determine the validity of the questionnaire, I focused on face validity, content validity and construct validity of both qualitative and quantitative sections of the questionnaire. The face validity of the questionnaire was ensured by giving the questionnaire to experts in the field to scrutinise, so that the questionnaire measured what it was supposed to be measured (Killen, 2015:377). The content and construct validity of the questionnaire was ensured by using questions that completely covered the construct, based on how the teaching method that was used helped learners to conceptualise stoichiometric chemistry (Maree, 2016:240). The questionnaire was also pilot tested with colleagues and learners in Grade 11 at another school, to make sure that it measured what it was intended to measure (Leedy & Ormrod, 2014:198). Participants in the pilot test suggested simplifying the questions, and making them more straightforward, which was done.

4.7.2.3.5 Reliability of the questionnaire

Reliability refers to obtaining the same findings when the same instrument is administered at different times with the same respondents. Reliability is the extent to which the measuring instrument is repeatable with consistent results (Maree, 2016:238). Reliability focuses on quantitative data, though, for qualitative data, trustworthiness is of the utmost importance. Trustworthiness is a way that researchers persuade themselves and readers that their research findings are worthy of attention (Lincoln & Guba, 1985 in Nowell, Norris, White & Moules, 2017:3). Trustworthiness was ensured during each phase of the thematic analysis of the qualitative data. In pursuit of a trustworthy study, criteria such as credibility, transferability, dependability and confirmability were considered (Golafshani, 2003:601; Maree, 2016:123). These criteria lie parallel to validity and reliability in quantitative research (Nowell *et al.,* 2017:3). The criterion of trustworthiness will be explained below, thus, showing how a trustworthy thematic analysis was established for the current study.

The specific research design, sampling methods, data collection methods and triangulation ensured the credibility of the questionnaire (Maree, 2016:123). Credibility of the questionnaire was ensured by prolonged engagement with data, persistent observation during data collection and triangulation of the results. To provide transferability, I provide detailed descriptions of the data collected, and the process of coding and analysis, and I kept the anonymity of the participants. To achieve dependability, I ensured that the process was logical, traceable and clearly documented. For achieving confirmability, I demonstrate how the conclusions and interpretations were made from the data collected (Ary *et al*., 2010:501; Nowell *et al.,* 2017:3). Triangulation of the quantitative and qualitative results also helped to increase confirmability of the results. The findings of the study were shaped by the responses of the participants, and not by researcher bias, motivation, or interest (Maree, 2016:124-125). Cronbach's alpha reliability coefficient was used to determine the reliability of the quantitative section of the questionnaire. To ensure reliability with a small sample size, the Likert scale had six options, which reduced the risk of Cronbach's alpha inflation and misinterpretation. The individual items in the questionnaire were set to correspond sufficiently with the scale (Samuels, 2017:2). The same scale as in Table 4.3 was used here (see 4.7.2.2.3). The Cronbach's alpha was calculated to be 0.73, which was in the acceptable range (Samuels, 2017:3).

4.7.2.4 Interview

Interviewing is a powerful and predominant mode of qualitative data collection for eliciting narrative data, which could enable the researcher to gather an in-depth understanding of people's views. This method explores the construction and negotiation of meanings in a natural setting (Alshenqeeti, 2014:39; De Vos *et al.*, 2011:342). As a two-way conversation, interviews collect data about the ideas, beliefs, views, opinions and behaviours of the participants, to obtain descriptive data. The descriptive data helps the researcher to understand how the participants construct knowledge and social reality reports (Maree, 2016:93). Interviews can be structured, semi-structured or unstructured, and include individual, face-to-face interviews and face-to-face group interviewing (Kabir, 2016:211).

4.7.2.4.1 Semi-structured interviews

For this study, I conducted a semi-structured one-on-one interview. I constructed the questions for the interviews before conducting the interviews (see Appendix E). The quantitative section of the questionnaire helped to structure appropriate questions.

A semi-structured interview, which is a more flexible version of the structured interview, contains certain open-ended questions that are predetermined, but the interviewer can ask further probing questions for clarification purposes (Griffee, 2005:36). During the semi-structured interviews, I listened attentively to the responses of the interviewees, to identify any emerging lines of inquiry that were directly related to the phenomenon under study. This helped me to explore and probe these topics and to collection in-depth, reliable and comparable qualitative data (Kabir, 2016:212; Leedy & Ormrod, 2014:119; Maree, 2016:93). For this study, the use of semi-structured interviews as a data collection method provided me with a holistic view of the conceptualisation of stoichiometric chemistry after the intervention. This was made possible by analysing the words of the participants and reporting their detailed views. The interview method allows interviewees to speak in their own voices and express their own thoughts and feelings (Alshenqeeti, 2014:39). This helped me to gain a better understanding of how the lessons presented to both groups influenced the learners in answering the SCAT.

4.7.2.4.2 Administration of interviews

From the control group and experimental group respectively, six learners were recruited for the interview; these learners had scored top, middle and lowest marks for the post-test, giving a total of 12 interviewees. The 12 interviewees represented the range of scores obtained in the post-test and, hence, represented the sample of the study. Structuring questions for the interview based on the questionnaire helped me to get an in-depth understanding of why the learners marked a certain option on the scale provided by the questionnaire. The interview consisted mainly of questions related to the learners’ understanding of the quantitative aspects of chemical change, the importance of balancing a chemical equation for performing calculations in a chemical reaction, how well the respective lessons helped to conceptualise stoichiometric chemistry in Grade 11, and helped them to answer the post-test. The interview questions were sequenced logically and clarified during the interview. where necessary.

In the interview, I followed a paper-based interview guide with open-ended questions that could lead to discussions that diverged from the guide. Therefore, all interviews were recorded with the consent of the 12 interviewees. Later, the transcript of the recordings was analysed (Kabir, 2016:212; Maree, 2016:359). Recording aided data accuracy, because, if I had had to write down the responses from the interviewees, it would have been difficult to capture all the details and to focus on conducting the interview. The anonymity and confidentiality of the conversations were ensured.

4.7.2.4.3 Advantages of semi-structured interviews

Kabir (2016:213) and Maree (2016:351) explain the benefits of using semi-structured interviews as a data collection method. Preparing the questions for the interview ahead of time prepared me, as the interviewer, in advance to conduct the interview. Semi-structured interviews allow the respondents to express their own views in their own words and provide reliable and comparable qualitative data. Therefore, the interviews allowed the learners to express all their views in relation to the intervention and their conceptualisation of stoichiometric chemistry.

4.7.2.4.4 Validity of interviews

To ensure internal validity, the interview questions in the study related to the secondary research question, which wished to determine the effect of computer simulation on the conceptualisation of stoichiometric chemistry. To answer this question, the interview questions for the two groups were constructed to include questions that interrogate the effect the lessons and the intervention had on their conceptualisation of stoichiometric chemistry. Hence, I could make sure that the interview questions measured what they were supposed to measure. The quantitative section of the questionnaire was also a guide to ensure that the interview questions were valid. For external validity, instead of generalisation, extrapolation and comprehensive description and information could be provided (Ary *et al*., 2010:501). A detailed description of the concepts and contexts of the study was provided, without compromising the anonymity of the participants. This helps potential users of the study to make comparisons and judgements about the similarity with, hence, transferability to larger populations (Ary *et al.*, 2010:501).

4.7.2.4.5 Reliability of interviews

The reliability of interviews can be ensured by asking standardised questions of the interviewees, and by ensuring the interviewer is trained to conduct interviews. To achieve this, one-on-one interviews were conducted and all interviewees were asked the same questions in the same order. As the interviewer, I made sure I had prepared well to conduct the interviews. The reliability of the interview was enhanced further by involving two coders in analysing and interpreting the interview transcripts. The consistency or agreement of the different coders' analysis and interpretation of the qualitative data was also considered (Creswell & Creswell, 2018:199; DeCuir-Gunby, Marshall & McCulloch, 2011:149; Mamat, Luen, Radzi, Yassin & Yusoff, 2018:1286).

4.8. DATA ANALYSIS

After collecting data, the next step in the research process was the analysis of the data. The type of data analysed can be numerical information gathered on scales of instruments, or text information that includes recording and reporting of the voice of the participants (Creswell & Creswell, 2018:16). The study involved the pre-test post-test scores analysis, analysis of lesson observation of both control and experimental group, test response analysis of the pre-test and post-test, and analysis of questionnaire and interviews with selected leaners, as will be discussed below.

4.8.1 Pre-test Post-test Experimental design data analysis

Both descriptive and inferential statistics were used for the data analysis. Descriptive analysis is a collective name for statistical methods used to organise and summarise data in a meaningful way (Maree, 2016:204). Inferential statistics is based on probability statements, with inferences being made using probability theory, because reporting about a whole population cannot be done with certainty if it is based on a sample chosen from the population (Maree, 2016:220). The test response analysis of the pre-test and post-test of the 12 interviewees was also done.

4.8.1.1 Descriptive statistics

Descriptive statistics is used to analyse raw data that has been collected. It is a statistical method used to organise and summarise data in a meaningful way, thereby enhancing the understanding of the properties of the data (Maree, 2016:204).

A graphical comparison of the mean scores on the pre-test and post-test for both groups, and a frequency polygon were used to represent the data graphically. Frequency polygons are similar to histograms. To construct a histogram, the raw data is grouped into classes and the frequency of classes is used; however, for a frequency polygon, the midpoints of the classes are used on the horizontal axis and the frequency on the vertical axis. Instead of drawing bars in the histogram, the frequency polygon joins points on the graph to obtain a line (Maree, 2016:213). Frequency polygons are preferable to histograms for graphical comparison of two population groups, as it provides an additional visual smoothness and continuity, compared to the corresponding histogram (Bruno & Espinel, 2009:476; Scott, 1985:348).

4.8.1.2 Inferential statistics

Inferential statistics was also used to analyse the data from the pre-test and post-test. Inferential statistics is the field of statistics that depends heavily on probability theory. It allows researchers to make inferences about large populations from relatively small samples. Inferences will, thus, be made from the probability statements, as one can never report on a whole population with certainty if the data collected is based on a small part of the population (Leedy & Ormrod, 2014:275; Maree, 2016:220). For the study to determine the effect of computer simulation on Grade 11 learners' conceptualisation of stoichiometric chemistry, there are two chances: i) using the computer simulation can produce an improvement in learner performance, or ii) there can be no improvement. Therefore, according to the probability rules (Maree, 2016:220), the probability of the two outcomes is likely to be equal. The probability always lies between 0 and 1, which is represented as $0 \leq P(A) \leq 1$, where A is the event.

Statistical significance was determined for the study. It is determined by looking at the p value, which gives the probability of observing the test results under the null hypothesis. Although the cut-off p value for determining statistical significance can be decided by the researcher, a value of 0.05 or less is usually chosen. For the current study, the p-value was chosen as 0.05, which corresponds to a 5% chance of obtaining a result, for example, failing to reject the null hypothesis (Statistics Solutions, 2017). The p value < 0.05 shows that there is a statistically significant difference in performance in stoichiometric chemistry for the pre-test and post-test within a group after the lessons and between the two groups for the post-test under the study. A p value > 0.05 shows no statistically significant difference (see Table 4.4).

ANOVA (see Table 4.4) was used to determine if there was any significant difference between the control and experimental groups before the intervention (Maree, 2016:255). The distribution curve was used for data analysis. Normal distribution is an important probability distribution in statistics, and is used to describe a family of continuous probability distributions that has the same general shape, but differs in their mean values and other scale parameters (Ahsanullah, Kibria & Shakil, 2014:7; Maree, 2016:220). A normal distribution is bell-shaped and symmetrical around its mean, and probabilities are given by the area under the curve. The normal distribution is useful for comparing distributions with different means and standard deviations (SD), thereby making precise understanding regarding a distribution, which, for the current study, is the distribution of test scores for a control and an experimental group, possible (De Vos *et al*., 2011:265). For small sample sizes, of less than 20, a non-normal distribution will be observed. When the sample size increases from 25, the distribution may begin to conform to the normal curve (Krithikadatta, 2014:96). For the current study, the sample sizes of the two groups were 30 and 32, and a distribution curve will be presented.

The shape of the distribution is a function of the SD. As the sample size increases, the SD reduces. The shape becomes broader and flatter when the SD is high, and narrower when the SD is low (Krithikadatta, 2014:96). This distribution is a standardisation tool in inferential statistics. If the distribution of data appears to be a normal distribution, then a paired t-test can be used (Xu, Fralick, Zheng, Wang &

Feng, 2017:187) to determine if there is any statistical difference between the pre-test and post-test scores for the two groups. Paired t-test is one of the most widely used tests in statistics for comparing the mean values of two samples (Xu *et al*., 2017:184). For the current study, the paired t-test will be used to determine whether there is statistical evidence that the mean scores of the pre-test and post-test for each group is significantly different from zero (see Table 4.4).

ANCOVA was also used to determine whether there was a significant difference between the group means of the control and experimental groups, with the pre-test scores as the controlled variable (Kunnath & Kriek, 2018:9). ANCOVA helps to increase the precision of the paired t-test and is recognised as a powerful technique of statistical analysis for measuring differences (Hedberg & Ayers, 2015:277). When hypothesis testing is done to assist in drawing conclusions, a researcher has to test effect sizes to determine the practical significance of any possibly statistically significant difference observed (see Table 4.4). Doing so provides additional information for drawing conclusions (Maree, 2016:234). The effect size for the difference between the two post-test means of the control and experimental groups was calculated by using Cohen's *d*. For mean differences, the effect size is denoted by *d*. If $d = 0,2$, it indicates a small effect, $d = 0.5$ indicates a medium effect, $d = 0,8$ indicates a large effect.

Table 4.4 presents a summary of the tests that will be utilised to test the hypotheses formulated in Chapter 1 (see 1.5.3).

Table 4.4: Statistical analysis of quantitative data

Hypotheses	Test	Level of significance
Hypothesis 1 Comparison of two groups	ANOVA	$p < 0.05$ indicates statistical significance and $p > 0.05$ indicates no statistical significance
Hypothesis 2 Comparison of mean pre-test and post-test scores of control group	Paired t-test	$p < 0.05$ indicates statistical significance and $p > 0.05$ indicates no statistical significance

Hypotheses	Test	Level of significance
Hypothesis 3 Comparison of mean pre-test and post-test scores of experimental group	Paired t-test	$p < 0.05$ indicates statistical significance and $p > 0.05$ indicates no statistical significance
Hypothesis 4 Comparison of mean post-test scores of the two groups	ANCOVA	$p < 0.05$ indicates statistical significance and $p > 0.05$ indicates no statistical significance
Hypothesis 4 Comparison of mean post-test scores of the two groups	Effect size: Cohen's *d*	d = 0,2=, small effect d = 0.5 = medium effect d = 0,8 = large effect

4.8.1.3 Test response analysis of pre-test and post-test

Data from test response analysis is usually used in teaching and learning, as it provides students, teachers and parents with information in relation to improving processes. The test response analysis could be used by a teacher to assess the depth of content knowledge gained by learners, and whether conceptual and or procedural knowledge was acquired and, thereby, they could understand the level of conceptualisation of the content taught (Sapire, Shalem, Wilson-Thompson & Paulsen, 2016:4–6). A qualitative test response analysis of the pre-test and post-test of the interviewees was done and compared. The analysis helped to identify the errors the learners made in the pre-test, and how they answered the same question in the post- test, after the intervention had taken place Therefore, analysis was done to compare performance on the pre-test and post-test, and to determine whether any improvement in performance was due to an improvement in conceptualisation of stoichiometric chemistry concepts.

4.8.2 Questionnaire data analysis

After the post-test, the questionnaire was given to all learners in the control and experimental groups. A demographic section was the first part of the questionnaire. The questionnaire consisted of this demographic section, and both qualitative and quantitative sections, which were analysed separately. The open-ended questions provided qualitative data for which themes were identified and analysed. The short section that collected quantitative data used a six-point Likert scale.

4.8.2.1 Analysis of qualitative section of questionnaire

Though all the participants took part in completing the questionnaire, the questionnaire responses of the same learners who were interviewed were chosen for analysis. When the questionnaire was distributed, learners had not yet been selected for the interviews. Hence, all learners were requested to complete the questionnaire and later, the questionnaire responses of the chosen learners referred to above were used for analysis.

Thematic analysis was done for the questionnaire responses. Thematic analysis is the systematic method that can be used to identify, organise and record the patterns in a set of data, so that themes in data can be detected, analysed and reported. Thus, thematic analysis helps in making sense of collective meanings of shared experiences (Braun & Clarke, 2012:57; Javadi & Zarea, 2016:33). The following multiple-level procedure was used in the study to analyse the data thematically; an inductive approach allowed the data to determine the themes (Creswell & Creswell, 2018:193–198; Javadi & Zarea, 2016:35–54; Nowell *et al*., 2017*:*4).

- Step 1: Familiarising myself with the responses written by the participants, by reading through it several times and reflecting on its overall meaning.
- Step 2: Taking the text data from the responses in the questionnaire, segmenting the sentences into categories and labelling the categories with a term. This step is called coding.
- Step 3: Generating a description and themes from codes. In this step, I used the codes in the previous step to generate themes. These themes appear as major findings in qualitative analysis. An inductive approach to data coding and analysis was predominantly used (Braun & Clarke, 2012:57). It is a bottom-up

approach, where the content of the data collected derives the codes, which closely match the content.

- Step 4: Representing the description and themes by making use of visuals, figures or tables as adjuncts to the discussion. This step involved the final analysis step of writing and reporting.

4.8.2.2 The Likert scale portion of the questionnaire

The quantitative section of the questionnaire consisted of questions that were to be answered on a six-point Likert scale (see Appendix D). The responses of the learners on this section helped to identify learners for the interviews. The purpose of using scales in research is to help the researcher understand the strength of feelings and attitudes. Usually, with a Likert scale, the respondents needs to respond to statements by indicating whether they agree or disagree (De Vos *et al.*, 2011:212; Maree, 2016:186). The Likert scale is a commonly used scale for measuring constructs. In this study, it provided an ordinal measure of responses to the teaching method and conceptualisation of stoichiometric chemistry. For the study, I used a series of six statements, each with six rating options: strongly disagree, disagree, slightly disagree, slightly agree, agree and strongly agree. The Likert scale responses by the control group and experimental group were analysed separately. For every statement, the number of responses for each rating on the scale was added for analysis. The Likert scale was analysed further by grouping the six options into two major keys, and calculating the percentage for each. The questions were used to obtain a numerical measure of learners' understanding of stoichiometric chemistry. Each category was assigned values ranging from 1–6. The total score for each respondent was calculated. The minimum value for this measure was 1 (strongly disagree) and the maximum value was 6 (strongly agree).

4.8.3 Interview data analysis

This section will explain the analysis of the interview data. After conducting the interviews with the selected 12 learners, I transcribed the interviews. During the process of transcription, the spoken words of the interviewees were reproduced into written text from the audio-recorded interviews (Halcomb & Davidson, 2006:38). The transcription was an exact replica of the recorded interviews, word for word.

Thematic analysis was conducted for the interview data. According to Javadi and Zarea (2016:33), thematic analysis is the most commonly used form of analysis for qualitative data. It basically focuses on detecting, analysing and reporting the themes in data. The same steps used for thematic analysis of the qualitative responses to the questionnaire (see 4.8.2.1) were used for the interviews. Hence, the details concerned with the thematic analysis of only the interview data will be included in this section. Much care was taken with the process of transcription. I transcribed the interviews myself, and it helped to familiarise me with the contents in detail and in depth. The whole set of data that I transcribed was read several times before being coded, to get an overall understanding. While examining the data, specific patterns and meanings were observed. Coding was done as explained in Section 4.8.2.1 and themes were extracted from codes. The codes and themes I generated were compared by a second coder and the consistency of the codes and themes was ensured with an inductive approach. Some codes formed themes, while others formed sub-themes (Javadi & Zarea, 2016:35). Thematic analysis enabled me to access the collected data flexibly and helped me to understand the mechanics of coding, and to analyse the data systematically (Braun & Clarke, 2012:57).

4.8.4 Triangulation and interpretation of the data

I analysed the quantitative and qualitative data I had collected separately in the explanatory sequential mixed methods study I conducted (see 4.4.4.3 & 4.7). The two forms of data were then combined by integration, which is called connecting the quantitative results to qualitative data (Creswell & Creswell, 2018:222). This is the point of integration in an explanatory sequential design. For the current study, the quantitative results from the pre-test and post-test and the Likert scale questionnaire were triangulated with the qualitative test response analysis, interviews and the qualitative section of the questionnaire. This helped to integrate the findings of the qualitative data and the quantitative results and enhanced the trustworthiness of the research findings (Creswell & Creswell, 2018:223). For this study, the test response analysis, interviews and the questionnaire helped to clarify, interpret and explain the results, performance and conceptualisation of the learners, as gleaned from the post-test. The quantitative data explained whether the performance of learners changed (improved) after the intervention. Thus, the qualitative data provided greater depth and insight into the quantitative results. It explained how the data from the qualitative method informed the quantitative data.

4.9. ETHICAL ISSUES

While researchers need to collect data, they need to respect participants, protect them from exploitation and respect the sites of research (Creswell, 2009:89). Data collection was based on informed consent from participants. The research adhered to the values and principles of UFS research policy. I obtained ethics clearance to conduct this research from the UFS, ethical clearance No. UFS-HSD2018/1292.

First, I obtained permission from the Department of Education district office of Frances Baard district to access the sample school (see Appendix H). Ethics clearance was approved by the UFS after I submitted a permission letter from the district office. After obtaining ethics clearance, permission from the principal of the school, the school governing body and the teachers who were involved in teaching the topic was obtained (see Appendix I). Consent from participating teachers and the Grade 11 learners' parents, on behalf of learners who were minors, was also obtained. The forms that were sent to each teacher and the parents of all learners are attached as Appendices J and K.

I explained all the procedures relating to data collection, anonymity of the participants, confidentiality of the data collected and the freedom to withdraw from participation to the participants. Only relevant and useful information for the study was collected. For the experimental pre-test post-test design, only the experimental group received the benefit of simulations to learn the topic; however, after the data collection the teacher of the control group was provided with access to the same simulation to teach the topic. By providing access, I made sure that all participants ultimately received the same treatment. During data analysis, the identity of the participants was protected by using codes instead of the names of the participants.

4.10. SUMMARY

The research methodology that was employed to determine the effect of computer simulation on the conceptualisation of stoichiometric chemistry was explored in this chapter. The chapter focused on explaining why pragmatism was deemed the most suitable paradigm for the study (see 4.5), the appropriateness of using a mixed methods approach, and the use of explanatory sequential design as the type of mixed methods used for the study (see 4.4.2, 4.4.4.3). This explanation was followed by a description of the population and sampling techniques used (see 4.6). A discussion of how the data collection was conducted by means of pre-test post-test experimental design, questionnaire and interviews was presented later in this chapter (see 4.7). The validity and reliability of each instrument was explained, followed by the procedure for data analysis of the experimental design, observation of lessons, test response analysis, interviews and questionnaire (see 4.8). Towards the end of the chapter, triangulation of the quantitative and qualitative analysis and interpretation were addressed (see 4.8.4). The chapter ended with the ethical issues and how they were managed (see 4.9).

Chapter 5 presents the discussion of the findings of the data analysis.

CHAPTER 5:
DATA ANALYSIS AND INTERPRETATION

5.1. INTRODUCTION

This chapter will focus on the data analysis and interpretation of the empirical study that had been conducted by employing a mixed methods research approach. The data collection for the empirical study was done through mixed methods – both quantitative and qualitative methods. The quantitative portion of the study relates to the data of the pre-test post-test design, and a small section in the questionnaire. The analysis of the quantitative section of the pre-test post-test design used statistical analysis with SPSS 24.0. The quantitative section of the questionnaire comprised a few questions that had to be answered with a Likert scale, and these responses were also analysed. As part of the qualitative analysis, analysis of lesson observation, and test response analysis of the pre-test and post-test were done. This was followed by thematic analysis of the questionnaire and interview data. Hence, this chapter will unfold the findings and interpretations from the quantitative and qualitative analysis of the study.

5.2. RESEARCH QUESTIONS AND HYPOTHESES

The importance of conceptualising stoichiometric chemistry was discussed in the problem statement of this study (see 1.3). From that discussion the following research questions arose.

5.2.1 Primary research question

The primary research question is as follows:

> What is the effect of computer simulation on Grade 11 learners' conceptualisation of stoichiometric chemistry?

The following secondary questions guided the investigation to answering the primary research question.

5.2.2 Secondary research questions

1) What are the value and importance of teaching and learning chemistry in the South African context?
2) What influence does computer simulation have on learning when it is integrated with the teaching of chemistry?
3) How effective is the use of computer simulation in the teaching of stoichiometric chemistry concepts?
4) What recommendations can be made regarding the effect of computer simulation on the teaching and learning of stoichiometric chemistry for improving its conceptualisation in the Further Education and Training (FET) phase at schools?

The first two secondary research questions were answered through a non-empirical study by conducting literature reviews (see Chapters 2 & 3).

A mixed methods approach was used to answer the third research question. Both quantitative and qualitative methods were used to collect data for the empirical study. The following hypotheses were formulated as a first step in the attempt to find an answer to the third research question.

5.2.3 Research hypotheses

For the quantitative part of the empirical study, the third research question was interrogated by means of the following null and alternative hypotheses.

H_0 1 The learners in the control group and experimental group are not comparable in terms of their knowledge of stoichiometric chemistry.

H_a 1 The learners in the control group and experimental group are comparable in terms of their knowledge of stoichiometric chemistry.

H_0 2 There is no significant difference between the mean pre-test and post-test scores of learners in the control group.

H_a 2 There is a significant difference between the mean pre-test and post-test scores of learners in the control group.

H_0 3 There is no significant difference between the mean pre-test and post-test scores of learners in the experimental group.

H_a 3 There is a significant difference between the mean pre-test and post-test scores of learners in the experimental group.

H_0 4 There is no significant difference between the mean post-test scores of learners in the control group and experimental group.

H_a 4 There is a significant difference between the mean post-test scores of learners in the control group and experimental group.

The quantitative research involved a pre-test post-test design and responses on part of a questionnaire administered to all learners (see 4.7.2.2 & 4.7.2.3).

The second part of the striving to answer the third research question was to determine qualitatively whether any conceptualisation of stoichiometric chemistry took place. During the data collection with the pre-test post-test design, the lessons conducted were observed using an observation schedule (see 4.7.2.1). The findings from the lesson observation were qualitatively analysed. The results of the quantitative data were quantitatively analysed. The learner questionnaire included six open-ended questions which provided qualitative responses by the learners. The interviews conducted with 12 learners (six from each group) provided further qualitative data. All this qualitative data was analysed and interpreted with the purpose of addressing the third secondary research question.

5.3. PRESENTATION AND INTERPRETATION OF THE LESSONS

The lessons the teachers conducted for teaching stoichiometric chemistry to both groups will be reflected upon in this section. Their teaching of the main concepts, such as balancing of equations, applying the mole concept to solve calculations, determining the limiting reagent and solving complex stoichiometric calculations involving limiting reagents will be presented and interpreted in this section. Six lessons were observed for each of the control group and experimental group. During the information session with the teachers before they presented the lessons, I requested that they, for the sake of consistency in teaching the content, as far as possible conducted their lessons in the same order for teaching the main concepts, and to use same examples as questions for problem-solving and explanations.

5.3.1 Context of the school

The school selected for data collection was a girls' high school. The school is one of the oldest schools in Kimberley and was founded in 1887. It falls within the Frances Baard district in Kimberley, in the Northern Cape. The learners and teachers at the school belong to various racial groups. Even though the learners of the school are only girls, the teachers are both men and women. The language of instruction of the school is English, though some learners and teachers have other home languages. The school has good discipline and well-maintained classrooms and laboratories for physical sciences and life sciences. The school also has a well-equipped computer laboratory. The learners can use the computer lab for research and practise after school under the teachers' supervision.

The school has classes from Grades 8 to 12. Each grade is divided in to four to five classes that consist of 40 to 50 learners each. In Grades 10–12, the learners move to specific classes according to their subject choice. There are different subject combinations that the learners can choose in Grade 10, according to the South African secondary school curriculum. Physical sciences is one of the subjects that learners can choose to take in Grades 10–12. The school has two physical sciences classes each for Grades 10, 11 and 12. In Grade 10, the number of learners enrolled for physical sciences in each of the two classes was more than 40. However, the Grade 11 classes involved in the current study consisted of 30 and 32 learners respectively.

According to the teachers at the school, every year, after the Grade 10 end-of-year examination and Grade 11 June examination, many learners drop physical sciences and enrol for other subjects. Having been a physical sciences teacher myself, I had also experienced the same phenomenon, with learners discontinuing physical sciences in Grades 10 and 11. The tendency of learners to drop physical sciences was discussed in Chapter 2 (see 2.7). Learners' poor performance in physical sciences was reported as the main reason for this phenomenon.

The school had two female physical sciences teachers who are of the Black African racial group, and aged 35–40 years. Both teachers had Bachelor's degrees in science and postgraduate certificates in education. The two teachers had approximately the same teaching experience (5 and 6 years) in physical sciences. Both teachers were willing to assist with data collection for the study, though they requested anonymity. The lack of resources, the teachers and their teaching methods, and the language of teaching have been reported by researchers as factors that affect the performance of learners in physical sciences at different schools (see 2.7.1, 2.7.2 & 2.7.3). An analysis of the context of the school showed that the physical sciences teachers were both qualified to teach physical sciences. The school had enough resources to support teaching and learning. Though there were only four learners in the sample that had English as their mother tongue (see 5.5.1.3), all the learners had chosen English home language as a subject for studying at school. This showed that neither lack of resources nor language of teaching were reasons for the poor performance of learners in physical sciences at this school.

5.3.2 Analysis of lesson observation

An observation schedule was used to observe the lessons for both control and experimental groups (see Appendix A). The observation schedule consisted of five themes (A–E) and each theme was measured against certain criteria (see 4.7.2.1). Both class groups were observed while their respective teachers presented the lessons. Table 5.1 presents a summary of the observation of the lessons (L1–L6) under the different themes and criteria for both control group and experimental group.

Table 5.1: Recording from the observation of lessons

Criterion	A: Lesson design and implementation (What teacher intended to do)				
	0	1	2	3	4
A1	L4CG		L1CG, L5CG, L6CG	L2CG, L3CG, L3EG, L5EG	L1EG, L2EG, L4EG, L6EG
A2		L3CG, L4CG.L5CG, L6CG	L1CG, L2CG	L3EG, L4EG,	L1EG, L2EG, L5EG, L6EG
A3			L1CG, L2CG, L5CG, L6CG, L3EG	L3CG, L4CG, L1EG, L5EG, L6EG	L2EG, L4EG
A4		L2CG, L6CG	L1CG, L5CG	L3CG, L4CG, L3EG, L5EG	L1EG, L2EG, L4EG, L6EG,
A5		L1CG, L2CG, L3CG, L4CG, L6CG	L5CG	L1EG, L2EG, L3EG, L4EG	L5EG, L6EG
	B: Content knowledge of teacher, organisation and presentation of material				
B1		L6CG	L1CG, L2CG, L3CG, L4CG, L5CG	L1EG, L2EG, L3EG, L4EG, L5EG, L6EG	
B2				L2CG, L3CG, L3E	L1CG, L4CG, L5CG, L6CG, L1EG, L2EG, L4EG, L5EG, L6EG

B3				L1CG, L3CG, L4CG, L5CG, L6CG, L1EG, L3EG, L5EG	L2CG, L2EG, L4EG, L6EG
B4	L1CG, L4CG, L5CG, L6CG		L3CG	L2CG, L4EG	L1EG, L2EG,4L5EG, L6EG,
B5	L3CG, L4CG, L5CG, L6CG		L1CG, L3EG	L1EG.L2EG, L5EG, L6EG	L4EG
	C: Learner participation in the lesson (What the learners did)				
C1		L3CG, L4CG, L5CG, L6CG	L1 CG, L2CG, L3EG		L1EG, L2EG, L4EG, L5EG, L6EG, L7EG
C2		L6CG	L1CG, L3CG, L4CG, L5CG	L2CG, L1EG, L3EG, L6EG	L2EG, L4EG, L5EG
C3			L1 CG, L2CG, L3CG, L5CG, L6CG, L3EG	L4CG, L1EG, L6EG	L2EG, L4EG, L5EG
C4		L1CG	L3CG, L5CG, L6CG, L3EG	L2CG, L4CG, L1EG, L4EG	L2EG, L5EG, L6EG
	D: Classroom culture: learner-learner interaction				
D1	L3CG		L1CG, L2CG, L4CG, L5CG, L6CG	L1EG, L3EG, L4EG, L6EG	L2EG, L5EG

	E: Classroom culture: teacher-learner interaction				
E1		L2CG	L1CG L3CG, L4CG, L5CG, L6CG, L3EG	L4EG, L6EG	L1EG, L2EG, L5EG
E2		L5CG	L1 CG, L2CG, L3CG, L3EG	L4CG, L6CG, L4EG, L4EG	L1EG, L2EG, L5EG, L6EG
E3			L1 CG, L2CG, L5CG	L3CG, L4CG, L6CG, L1EG,L1EG,L3EG,L4EG, L5EG,L6EG	

Notes:

- Letters A, B, C, D and E represent the different themes under which the lessons were observed. Each theme had certain criteria for lesson observation.
- Criteria under each theme are represented with numbers following the letter of the theme. For example, A1–A5: criteria 1–5 for theme A.
- The performance indicators range from 0–4. See Appendix A (observation schedule) for the description of each performance indicator according to each criterion.
- Keys are used for each lesson and the group observed, example- L1 CG – Lesson 1 control group, L1 EG – Lesson 1 experimental group. The lessons of the control and experimental groups are presented in black font and that of the experimental group in red.

From Table 5.1, it appears that, in the lessons, the experimental group functioned more strongly on the performance indicators of 3 and 4, never in 0 and 1, and occasionally in 2. The control group occasionally functioned in the performance indicator 4. They also functioned in 3, but not to the same extent as the experimental group. The control group functioned mainly in 0, 1 and 2. Further interpretations based on the table for each theme in the observation schedule will be discussed below.

5.3.2.1 A: Lesson design and implementation (What teacher intended to do)

This theme consists of the criteria checking prior knowledge of learners, evidence of engagement of learners during the lesson with the teacher and other learners, active learner exploration of the content and problem-solving, and evidence of prioritising learner ideas in the lesson. For the control group, most of the lessons were designed to check the learners' prior knowledge, and were based on their input, without any adjustments made by the teacher. Only for lessons 2 and 3 was the prior knowledge used for the developmental part, and value was added to the content. The lessons provided minimum opportunity for learners to gain active exploration experience. In lessons 3 and 4, there was some evidence of learners trying to interact with the teacher for problem-solving (see Table 5.1, Theme A).

For the experimental group, in all lessons the learners had the opportunity to apply their prior knowledge, not only for the introduction section, but also for the developmental part. In the experimental group, teacher–learner and learner–learner interactions were evident, and the learners could actively explore the concepts in detail by making use of PhET simulations, followed by discussions on the concept. The teacher gave the learners the opportunity to actively involve with the tools to reach the outcome of the lesson as illustrated in figure 3.2 that demonstrates the model for activity theory. This helped the experimental group to develop meaning of the content. For example, in the PhET simulations, the learners could view the microscopic representation of each molecule in the reaction, which helped them to recall their understanding of atoms and molecules and visualise each molecule and any change that happened. Figures 5.1 and 5.2 show examples that were used in the PhET simulations for lesson 1, for balancing equations. In the other lessons, the PhET simulations showed the reactants and products microscopically and the learners could apply the ratio in the balanced equation to do further calculations. For the control group, the teacher wrote equations on the board and asked the learners to balance the equations by manipulating the coefficients of the formula of each substance in the reaction. (see Figures 5.1–5.3). For the other lessons, the teacher wrote certain steps on using ratios on the board so that learners could do further calculations.

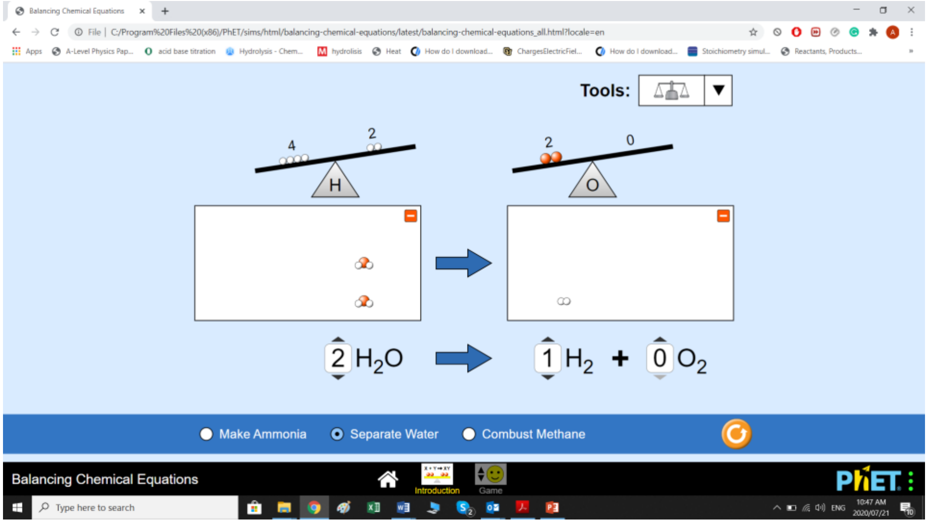


Figure 5.1 PhET interactive simulation before the equation is completely balanced, for the reaction of separation of water for experimental group

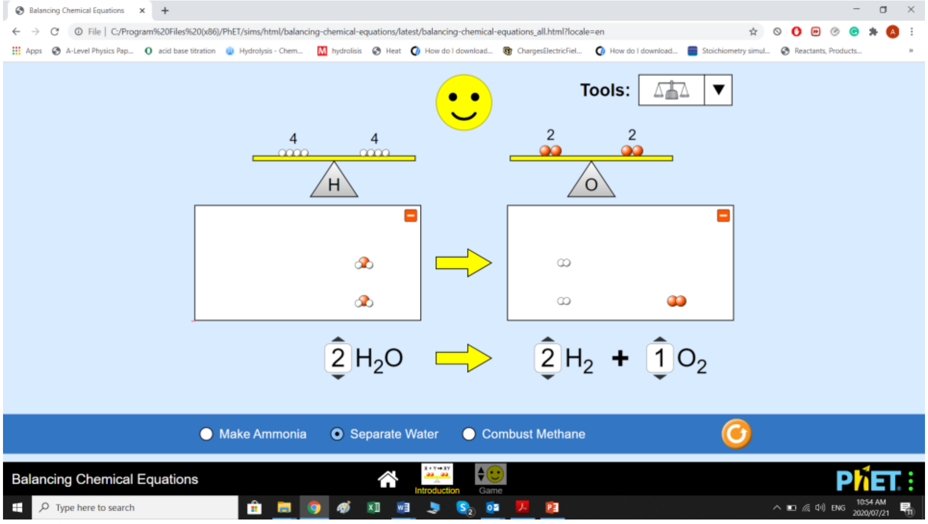
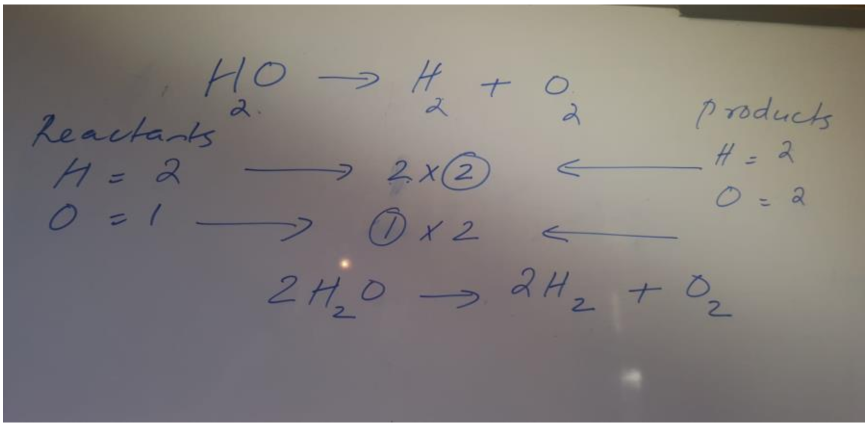


Figure 5.2: PhET interactive simulation after the equation for the separation of water has been balanced



$H_2O \longrightarrow H_2 + O_2$

Reactants

Products

$H = 2 \longrightarrow 2 \times ② \longleftarrow H = 2$

$O = 1 \longrightarrow ① \times 2 \longleftarrow O = 2$

$2H_2O \longrightarrow 2H_2 + O_2$

Figure 5.3: Balancing the equation for the separation of water, which was written on the board for the control group

5.3.2.2 B: Content knowledge of teacher, organisation and presentation of material

For the theme content knowledge of teacher, organisation and presentation of material, lesson observations were conducted with a focus on orientation of the content with fundamental concepts and presentation of the content for conceptualisation, delivery of content, variety in presentation and integration with other content discipline and/or real-world phenomena. In all the lessons I observed, the teachers had adequate content knowledge to teach the concepts. For both control and experimental groups, the content was presented clearly and logically, with consistent relation of content and concepts throughout, except for lessons 2 and 3 of the control group, and lesson 3 of the experimental group.

In the case of the control group, the teacher used the whiteboard and the textbook as media, while, in the experimental group, PhET simulations, along with the whiteboard and textbook, were used for teaching the concepts. In all lessons except lesson 3, it was observed that the teacher of the experimental group linked the concept with real-life experiences, to achieve better conceptualisation. For example, when teaching the application of ratio in the balanced equation to do calculations on products formed and leftovers, the teacher used the example of sandwiches comprising bread slices, ham slices and cheese slices, like in the PhET simulations. Figure 5.4 shows a photograph of the sandwich game that was used in the simulation.

However, in the case the control group, the lessons were mostly presented by delivering factual information. For example, the same concept, that of using ratios to calculate the limiting reagent, amount of product formed, and leftovers, was presented by explaining how to do the calculation following certain steps (see Figure 5.5). Except for lesson 3, it was observed that the teacher allowed the experimental group to provide their ideas and questions while performing the activities required by the PhET simulations. The control group's lessons were purely teacher centred, and direct teaching was used to explain certain facts and were not connected to real-world applications.

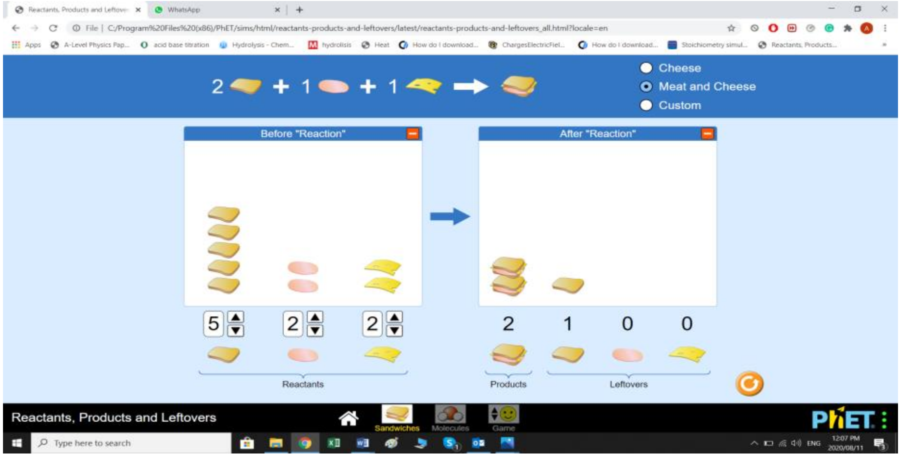
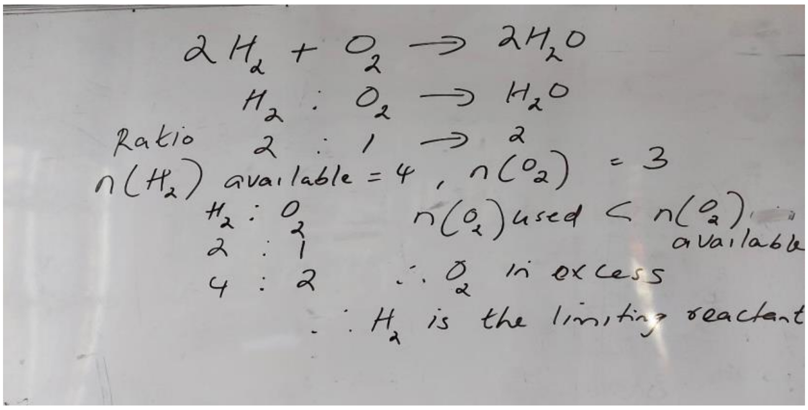


Figure 5.4: PhET interactive simulation, showing the example of making sandwiches to teach limiting reagent, amount of products and leftovers



$2H_2 + O_2 \rightarrow 2H_2O$

$H_2 : O_2 \rightarrow H_2O$

Ratio $2 : 1 \rightarrow 2$

$n(H_2)$ available $= 4$, $n(O_2) = 3$

$H_2 : O_2$ $n(O_2)$ used $< n(O_2)$ available

$2 : 1$

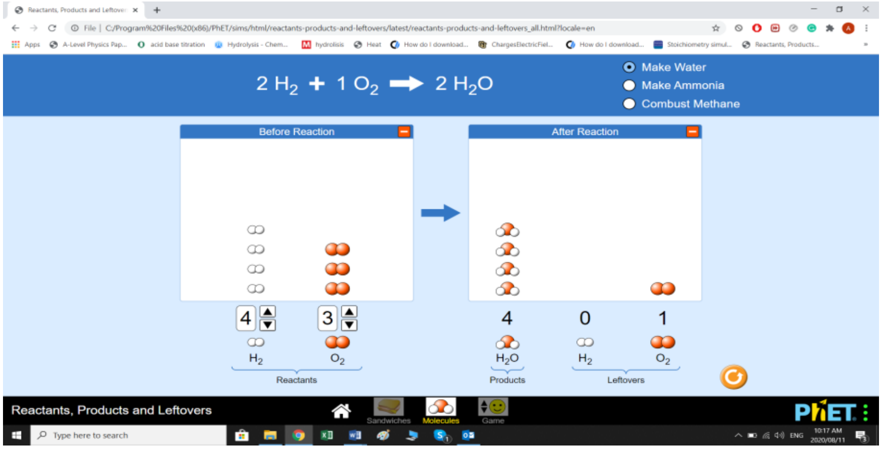
$4 : 2$ $\therefore O_2$ in excess

$\therefore H_2$ is the limiting reactant

Figure 5.5: Calculation of limiting reagent, excess reactant and product formed, done on the whiteboard for the control group by the teacher

5.3.2.3 C: Learner participation in the lesson (What the learners did)

Under the theme of learner participation, the opportunities learners had to use a variety of media, learner involvement in making predictions and estimations, learner engagement in thought-provoking activities and learner reflection about their learning were the criteria for lesson observation. For the control group, the teacher used the whiteboard to explain the concepts in all lessons, and also asked learners to read important points in the textbook. The only media available for learners' learning was the whiteboard and textbook. The learners were mostly focused on the steps of the calculations. In activities, they used the steps to determine the limiting reagent, amount of products formed and reactants left over and, hence, did not ask the teacher for clarity. This shows that the learners were recalling/summarising facts and using algorithmic methods for doing the activities (see 2.10.2.2). In the case of the experimental group, in addition to the whiteboard and the textbook, the PhET simulations were additional media that the learners could work with. Only in lesson 3 the learners in the experimental group did not use the PhET simulations, as the lesson was about revision of the different formulae relating to mole concept. In lessons 2 and 4 of the control group, it was observed that some of the learners took part in discussions in pairs, to make predictions and to get involved in analysing the activities given. Lesson 2 was based on calculations with the mole concept, and lesson 4 required problem-solving with limiting reagents. For the experimental group, all lessons except lesson 3 were taught by making use of PhET simulations. For example, for the complex calculations with limiting reagents, the teacher projected a simulation with the molecular representation of the reaction of hydrogen and oxygen to form water. The learners could view the reactants and products at the microscopic level and the leftovers of the reaction (see Figure 5.6).



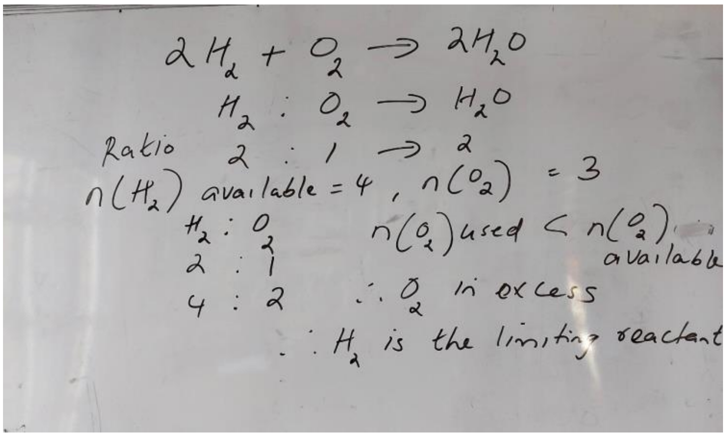
● Make Water
○ Make Ammonia
○ Combust Methane

Figure 5.6: Molecular representation of the reaction between hydrogen and oxygen to form water

The use of PhET simulations gave learners the opportunity to get involved in group discussions about the activities in the games, and it allowed them to engage in critical evaluation of the content that was being taught. This helped the learners to evaluate their understanding and ask the teacher questions if they needed clarity. (The importance of metacognition for conceptualisation was discussed in Section 2.6.2.7).

5.3.2.4 D: Classroom culture: learner–learner interaction

For this theme, the focus was on the involvement of learners in communicating ideas in a variety of ways. In all lessons of the control group, a few of the learners discussed in pairs and helped each other to balance equations and work on other problem-solving activities. The teacher mainly issued instructions to the learners and emphasized using the steps given to do the activities. Figure 5.7 is a photograph of how the teacher solved a question to determine the limiting reagent.



$2H_2 + O_2 \rightarrow 2H_2O$

$H_2 : O_2 \rightarrow H_2O$

Ratio $2 : 1 \rightarrow 2$

$n(H_2)$ available $= 4$, $n(O_2) = 3$

$H_2 : O_2$ $n(O_2)$ used $< n(O_2)$ availabl

$2 : 1$

$4 : 2$ $\therefore O_2$ in excess

$\therefore H_2$ is the limiting reactant

Figure 5.7: Control group teacher’s calculation for limiting reagent, excess reactant and product formed

In lesson 3 of the experimental group, which involved calculations for using the formula for moles to calculate mass or volume, the learners worked in pairs and there was minimum communication between them. In the other lessons, which involved activities that were games in PhET simulations, the learners showed more interest in discussing their answers, first, in their groups, and later, as a whole class. For example, for the reaction between hydrogen and chlorine to form hydrogen chloride, a PhET simulation was projected and the learners were given the opportunity to manipulate the game to find the products and leftovers, and then to discuss their answers. The learners first predicted the products and leftovers. Afterwards, they observed what the correct answer was and then engaged in discussions to evaluate their predictions. It was observed that the lessons with simulations opened doors for inquiry-based learning for problem-solving, which is likely to improve learners’ ability to construct their own knowledge (see 2.6.1.4 & 2.6.1.5). The teacher was in control of the class and the learners were given turns to do activities by manipulating the simulation, while others watched and listened. Figure 5.8 shows a PhET simulation that the learners used for the discussion.

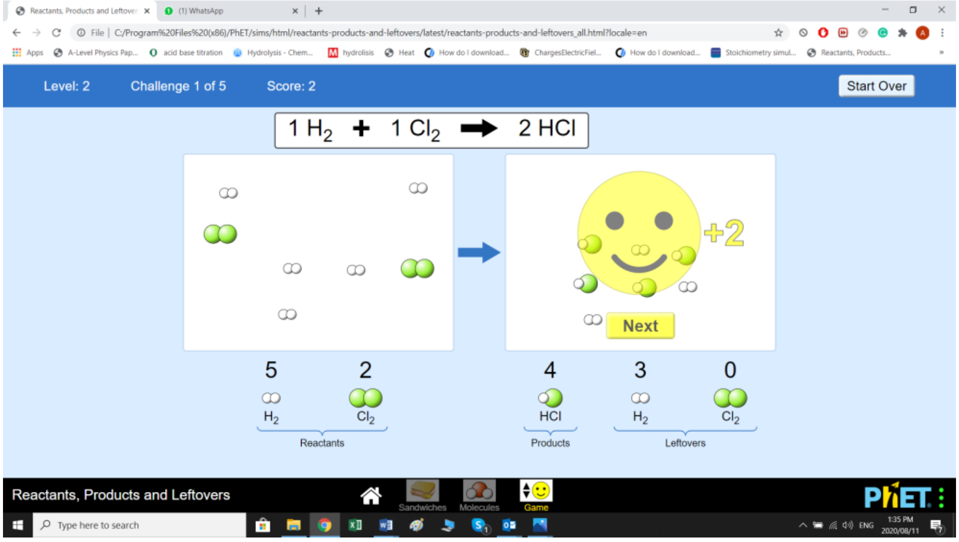


Figure 5.8: PhET interactive simulation used for complex stoichiometric calculations

5.3.2.5 E: Classroom culture: teacher–learner interaction

The focus for the lesson observation for the theme of teacher–learner interaction was interaction between the teacher and learner that lead to meaningful discussions, the patience that the teacher showed in encouraging meaningful conversations, and the support the teacher provided to learners. All the lessons of the control group were mostly teacher centred (direct teaching): The teacher explained the various concepts to the learners, and followed up the explanation by assigning activities they had to complete. Once the learners had completed the activities, the teacher made corrections on the board. Very few learners asked for clarity, and if they did, the teacher explained the concept again. Occasional opportunities were given to learners during the lessons to share their uncertainties, and the lessons were primarily directed by the teacher. For complex stoichiometric calculations, the teacher summarised how to do the calculations, using steps to conclude the lesson.

In the experimental group, the learners worked on activities that took the form of games in the PhET simulations. For example, for the reaction of hydrogen and chlorine to form hydrogen chloride (see Figure 5.8), the learners had regular interaction with the teacher while they completed the activity through games, while they manipulated and completed the games based on problem-solving to determine the products and leftovers. It was observed that the teacher waited for the learners to provide answers for the games and, during explanations, learners were given the opportunity to engage in meaningful conversation to clear up confusion that they experienced and which caused them to make mistakes in calculations. Even though the lessons were controlled by the teacher, the learners had the freedom to interact with the teacher and to determine how the teacher could help with learning.

5.3.2.6 General Interpretation of the lesson observation

The lesson observations helped me to understand how the teachers designed and implemented the lessons, the content knowledge of teachers, the organisation and presentation of the main concepts, the participation of learners in the lesson, and the interaction of learners among themselves and with the teacher. It was evident from the lessons that both teachers had a good knowledge regarding the main concepts that were taught. I noticed that the lesson design with the PhET simulations for the experimental group gave the learners opportunities to apply their prior knowledge to different parts of the lesson. Using simulation helped the experimental group's learners to interact more effectively with each other and with the teacher throughout the lesson than the control group learners.

The teacher of the experimental group explained each lesson by letting the learners visualise the microscopic representation of the different examples used to teach the concepts. In turn, the learners in the control group were taught by the teacher writing the equations on the board, using examples and explanations, and using certain steps for calculations. For the control group, the lessons were conducted using the whiteboard and textbook as media, while the experimental group participated with activities from PhET simulations which provided a visual representation of the concepts taught. Using PhET simulations helped the teacher to explain the concepts by connecting them to real-world applications.

It was also observed that the learners in the experimental group had the self-motivation to actively engage in completing the activities through games by continuous interaction with each other and with the teacher. During the activities, the learners worked with the simulations to predict observe and evaluate their understanding of the concepts (see 5.3.2.4) This showed that the lessons provided an environment for inquiry-based teaching and learning, which could have helped to achieve better conceptualisation (see 2.6.1.5). However, in the control group, limited engagement among themselves and with the teacher was observed, instead, the teacher followed the lecture method for the lessons. The majority of the lessons was based on applying the steps emphasized by the teacher during the lesson. While giving corrections, the teacher explained the steps for calculating the correct answer, and clarification requested by the learners lead to the steps being repeated for clarity. Thus, it could be interpreted that the lecture method only helped the learners to accumulate raw knowledge and the teaching method did not help in conceptualisation, which could be a reason for a poor performance in the post-test for the control group (see 1.2.1).

It was discussed in Chapters 1 and 2 that the PCK of the teacher for applying a teaching method and the teaching approach for teaching affects the conceptualisation of the topic by learners (see 1.1, 2.6.2.6 & 2.7.1). It was also discussed in Chapter 2 that the appropriate teaching approach, together with teaching strategies and methods, create a learner-centred environment. This can result in effective learning, in which learners construct knowledge for conceptualisation (see 2.6.1.1 & 2.7.1). It can be interpreted from the lesson observation that more effective PCK was demonstrated by the teacher of the experimental group than the control group. Using simulation for demonstrations with explanations probably helped the teacher of the experimental group to apply her PCK more effectively to meet the abilities of the learners for conceptualising the concept. In the control group, the teacher merely explained the concepts using the lecture method.

It was observed that using games through simulation for problem-solving meant the lessons of the experimental group were more learner centred. Therefore, it could be interpreted that the teacher of the experimental group took a facilitator approach and engaged the learners in activities. The use of different games and simulations, including activities related to real-world experiences, created a learner-centred approach and helped the learners to create their own knowledge. However, from the lesson observation of the control group it can be interpreted that the teacher applied the lecture method by giving explanations on how to solve a problem, and writing notes on the board. The teacher had an executive approach and created a teacher-centred environment (see 2.6.1.1 & 2.6.2.6).

Section 1.6 discussed that, for conceptualising stoichiometric chemistry, learners need to construct their own knowledge through activities. The teacher of the experimental group provided an environment that was suitable for learning, by teaching and giving activities through the simulations. The use of PhET simulations during the intervention with the experimental group allowed learners to engage in activities in the simulations and interact with each other.

It was discussed in Chapters 1 and 3 that activity theory, which is the theoretical framework of the study, supports human–computer interaction (1.6 and 3.4). In the current study, the learners in the experimental group received an intervention that made use of PhET simulations to teach the concepts. During the lessons, the learners interacted with each other and with the teacher during activities using the visual tools for achieving the objective for the lessons which was the conceptualisation of stoichiometric chemistry (see figure 3.2). This could have helped the learners to construct knowledge (see 3.4), leading to better conceptualisation of the concepts. However, in the control group, the activities were done by learners individually or, occasionally, in pairs – there was minimum interaction between the learners.

Regarding learners' understanding of the content, the following interpretations could be made from the lesson observations. The majority of the learners in the control group and experimental group could balance the equations after the lesson. However, when engaged in activities, it was observed that the learners of the experimental group could do the activities for balancing equations better than those in the control group. It could be interpreted that the learners in the experimental group had better conceptualisation, as they could visualise the compounds and the number of atoms of each element involved in the reactions microscopically, and this enhanced their understanding. Regarding the questions where learners had to directly apply the different formulae from the mole concept, the majority of the learners in both groups could answer the questions after the teachers had explained the formulae to them. However, when the learners had to apply the mole concept using the ratio in the balanced equation to calculate the amount of product formed, the majority of learners in the control group struggled to answer the question. The learners appeared to be confused about how the mole ratio could be applied to determine the unknown. Some of them tried using the steps the teacher had given for problem-solving during the lesson, without interpreting the problem correctly. It was discussed in Section 2.10.2.1 that learners find it difficult to perform stoichiometric calculations, because they struggle to interpret and transform word problems into the steps required to do calculations correctly. As a result, when solving problems, learners applied algorithmic methods when following the steps that had been explained by the teacher, without conceptualising how to apply the mole ratio (see 2.10.2.2). The lecture method for direct teaching used by the teacher of the control group only helped learners to scribe the concepts, and memorise and reproduce them during problem-solving (see 2.6.1.1). But it was observed that more learners in the experimental group seemed to do the calculation correctly after viewing the activity as a simulated game.

Another challenge that was observed relates to calculations with limiting reagents. During the correction and feedback session for the lesson on limiting reagents, the majority of the learners in the control group, without applying the mole ratio, identified the limiting reagent as the one which was present in the lowest amount (see 2.10.2.1). Moreover, the learners ignored the concept that the amount of product formed depends on the amount of limiting reagent available. Hence, they used any amount of reactant given to determine the amount of product formed. Misconceptions relating to limiting reagents and calculations by applying the concepts for problem-solving were discussed in Chapter 2 (see 2.10.2.1). In the experimental group, most learners determined the limiting reagent correctly after visualising the question as a simulation with reactants, products and leftovers (see 5.3.2.3 & 5.3.2.4). The visual representation could have helped the learners to rearrange their thoughts and thereby improve their conceptual understanding of limiting reagents (see 2.6.2.3 & 3.9.4.1.2). The importance of reformed teaching for effective teaching and learning to take place was discussed in Chapters 3 and 4 (see 3.9 & 4.7.2.1). From the observation of the lesson and using the observation schedule adapted from RTOP, it was observed that the lessons of the experimental group satisfied the criteria in the observation schedule better than the control group lessons did and, hence, reformed teaching was observed in the lessons of the experimental group than that of the control group.

5.4. PRESENTATION AND ANALYSIS OF THE PRE-TEST AND POST-TEST DATA

Both descriptive and inferential statistics were used for the analysis of the data obtained from the experimental design (see 4.8.1.1 & 4.8.1.2). In this section, the analysis of the data using SPSS 24.0 will be discussed.

5.4.1 Comparing the control group and experimental group

In Chapter 1 (see 1.7.2), it was stated that the control group and the experimental group had to be comparable. A pre-test was conducted before the lessons of both groups. The means, modes, medians and SD were calculated. ANOVA was used to determine whether the learners in the two groups were comparable in terms of their knowledge of the topic of stoichiometric chemistry (see 4.8.1.2). The following hypotheses were tested using ANOVA.

H_0 1 The learners in the control group and experimental group are not comparable in terms of their knowledge in stoichiometric chemistry before.

H_a 1 The learners in the control group and experimental group are comparable in terms of their knowledge in stoichiometric chemistry before.

Table 5.2 shows the results the ANOVA obtained for the pre-test administered to the two groups.

Table 5.2: ANOVA results of the pre-test

ANOVA- Pre-test							
	Mean scores	SD	Sum of squares	df	Mean square	F	Sig.
Control group	23.87	21.179					
Experimental group	19.63	15.521					
Between groups			5498.667	10	549.867	1.391	.257
Within groups			7508.800	19	395.200		

Total			13007.467	29			

Notes:

- F = variance of the group mean(s) of the within-group variances
- Sig = significance probability, which is the p value
- p value = probability of observing the specific value of the test statistics (triggers to decide when to reject a hypothesis or when to fail to reject a hypothesis)
- $p < 0.05$ shows that there is a statistically significant difference in the learners' knowledge of stoichiometric chemistry between the two groups (see Table 4.4 & 4.8.1.2)

It was found that there was no significant difference in the pre-test scores at $p < 0.05$ level for the two groups [$F(10, 19) = 1.391$, $p = .257 > 0.05$]. The null hypothesis is, thus, rejected. The probability is that the two groups were comparable in terms of their knowledge of the topic of stoichiometric chemistry.

5.4.2 Descriptive statistics: Visual presentation of data

Descriptive statistics was used to represent the quantitative data through graphical presentations (see 4.8.1.1).

5.4.2.1 Graphical representation of the means of the groups

A graphical comparison of the means of the pre-test and post-test of the control group and experimental group is given in Figure 5.9.

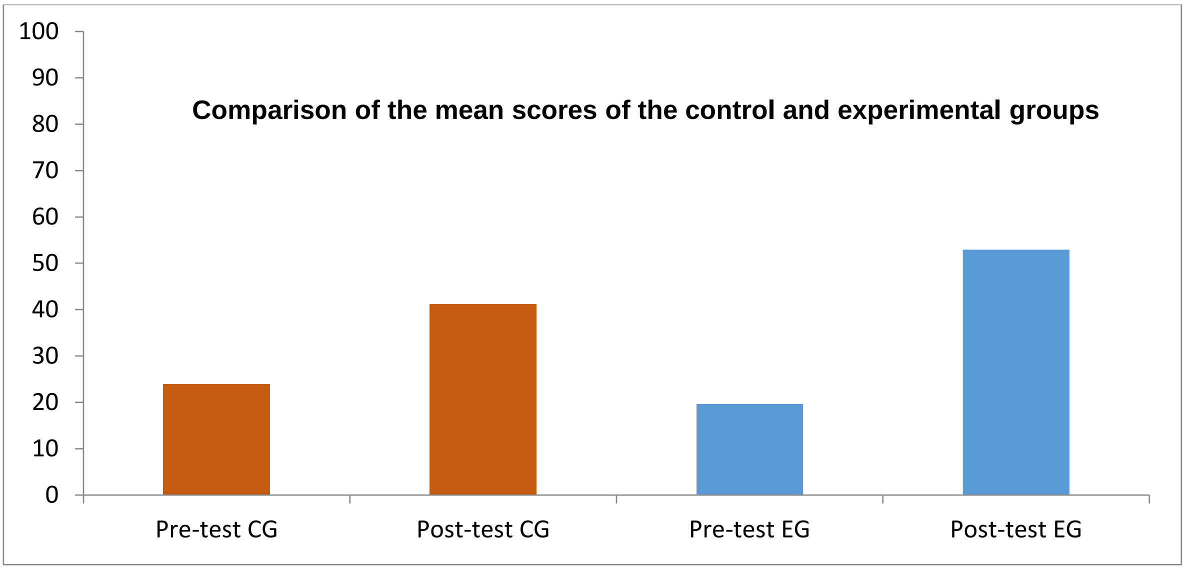


Figure 5.9: Means of the pre-test and post-test scores of the control group and experimental group

It can be observed that the mean pre-test score of the control group was slightly greater than the mean pre-test score of the experimental group. The mean post score of the control group was also greater than the mean pre-test score of the same group. It can also be observed that the mean post-test score of the experimental group was greater than their its pre-test score. However, the difference between the mean pre-test and post-test score of the experimental group was greater than the difference between the mean pre-test and post-test score of the control group. Another observation was that the mean post-test score of the experimental group was greater than the mean post-test score of the control group.

5.4.2.2 Frequency polygon of control group and experimental group test scores

A frequency polygon is a graphical representation of data, and makes use of frequency distribution (see 4.8.1.1). Frequency polygons for both the control group and experimental group were drawn. For both groups, the frequency polygon was drawn for percentages of scores for the SCAT (pre-test & post-test) on the horizontal axis and frequency of scores on the vertical axis. Figure 5.10 presents the frequency polygon for the control group.

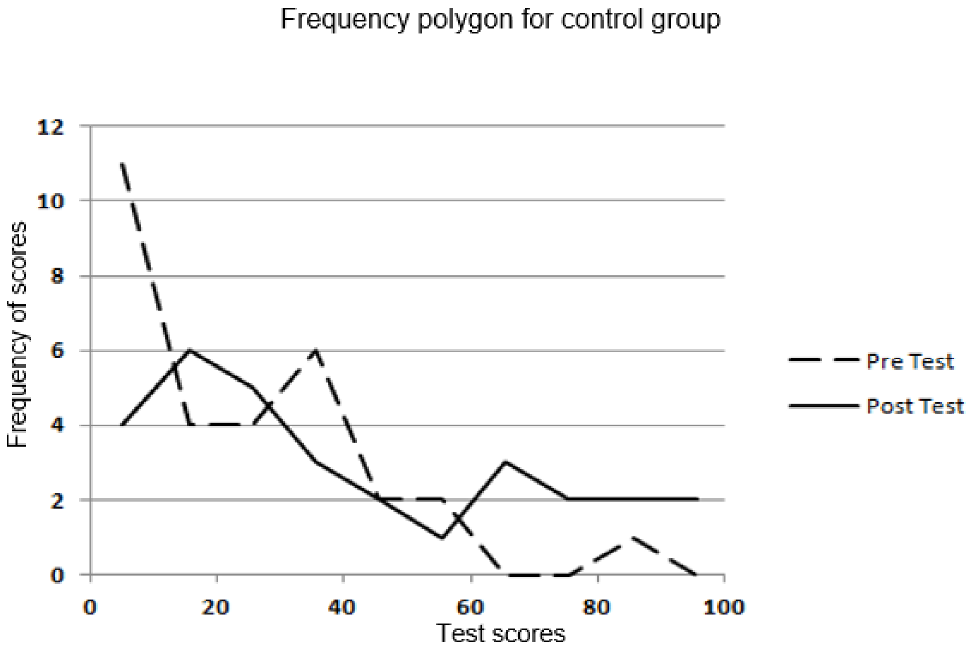


Figure 5.10: Frequency polygon for the pre-test and post-test scores and the frequency of scores of control group

The graph in Figure 5.10 shows that, for both tests, the lowest score was close to 10%. In the pre-test, the highest frequency of learners scored this lowest mark; however, in the post-test, the frequency of learners scoring this low mark decreased. For the post-test, the highest frequency of scores achieved by learners was 20%. More learners scored 40% in the pre-test than in the post-test. The frequency of learners who scored 60% and above increased from the pre-test to the post-test; in the post-test, two learners scored 80% or above.

Figure 5.11 represents the frequency polygon for the experimental group. The frequency polygons for the pre-test and post-test of the experimental group are quite different. It could be observed that more learners scored above 40% in the post-test than in the pre-test.

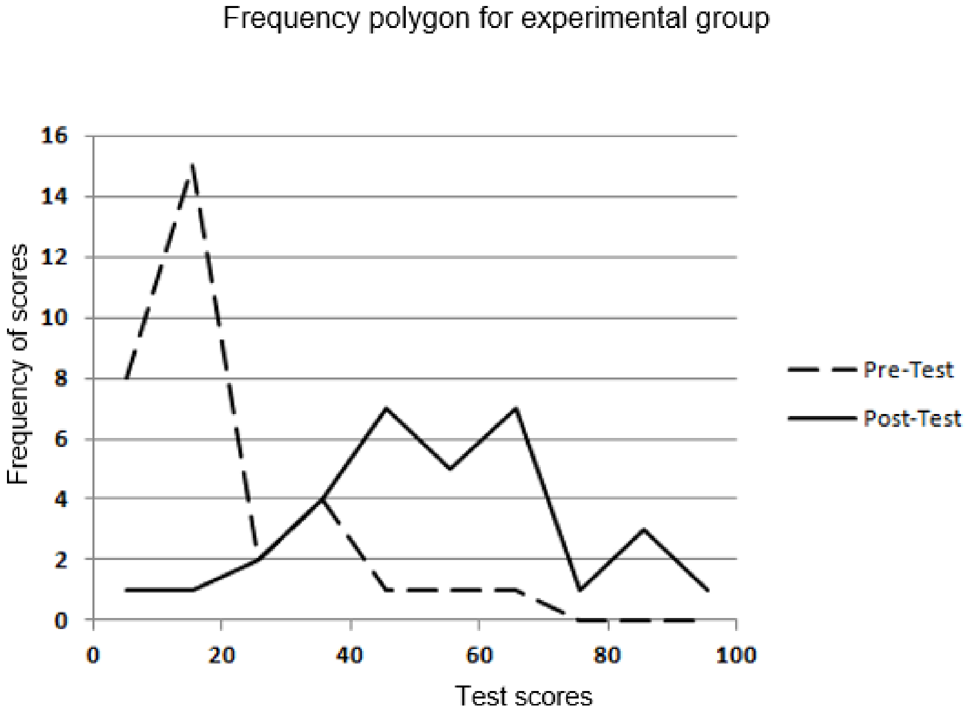


Figure 5.11: Frequency polygon for the pre-test and post-test scores and the frequency of scores of experimental group

The lowest test score for the experimental group was less than 10% in both post-test and pre-test. For the pre-test, the highest frequency of learners obtained test scores rounded up to 20%, however, for the post-test, the highest frequency of learners had test scores between 50% and 70%. In the pre-test, none of the learners had a test score of 80% or above, but in the post-test, a few learners achieved marks above 80%.

When comparing the frequency polygons of the two groups, it can be observed that more learners in the experimental group obtained marks between 60% and 70% compared to the control group.

5.4.3 Inferential statistics

The quantitative data of the pre-test and post-test were also presented using inferential statistics. The findings from ANOVA were discussed earlier (see 5.4.1). Distribution of data, paired t-test, and ANCOVA were also used to represent the data inferentially (see Table 4.4 & 4.8.1.2).

5.4.3.1 Distribution of data of the control and experimental groups

The distribution of the test scores was used to represent and interpret the pre-test and post-test data of the two groups (see 4.8.1.2). The distribution served as a standardisation tool for inferential statistics. The distributions of the test scores for the pre-test and post-test were plotted and an approximately bell-shaped curve was obtained for both control and experimental groups, which means the distributions are normal distributions. Normal distribution characteristics simplify the statistical analysis and makes it feasible to make forecasts with better accuracy. The normal distributions obtained for the control group and experimental group were used to compare the distribution of the pre-test and post-test scores within a group, and also to compare scores between the groups. To understand the changes in patterns, the normal density curve was drawn by changing the original frequency of scores to relative frequency, thereby making the area under each curve equal to 1, which represents 100% of the data (Bennett, Briggs & Triola, 2009).

5.4.3.1.1 Control group

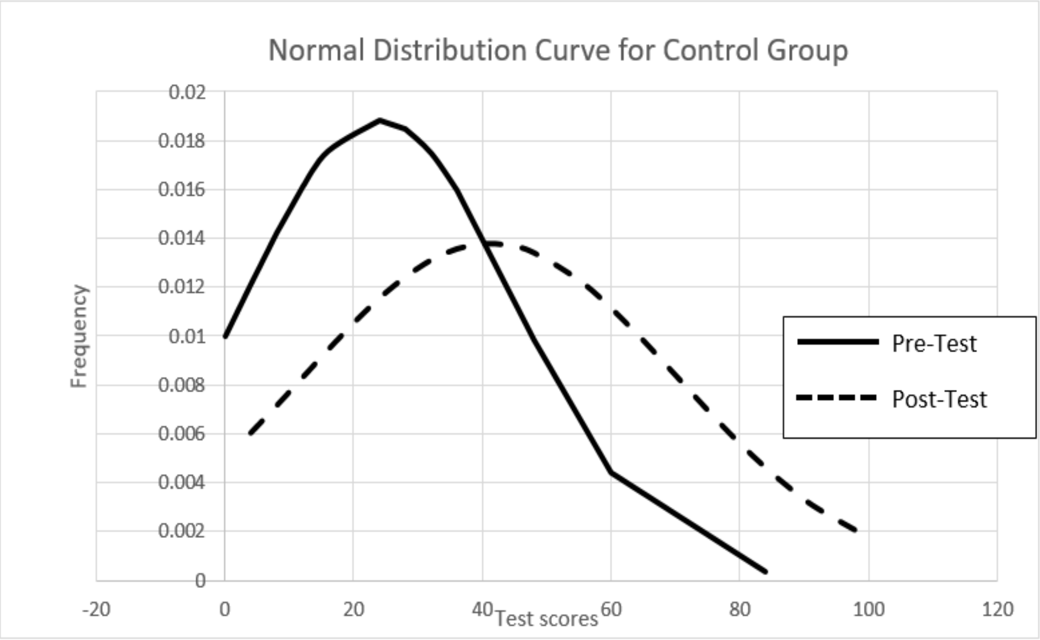


Figure 5.12: Distribution curve for test scores of control group

Figure 5.12 shows that, for the control group’s pre-test, the highest frequency of learners scored between 20% and 30%. Only a few learners obtained a score of 80%

or above. However, in the post-test, the highest frequency of learners in the control group obtained scores between 35% and 45%. It can be observed that the normal distribution curve shifted to the right from the pre-test to the post-test. The highest score in the pre-test, of just above 80%, increased to just under 100% in the post-test. The frequency of learners obtaining a mark above 35% increased in the post-test. This shows that there was an improvement in the learners' scores in the post-test.

5.4.3.1.2 Experimental group

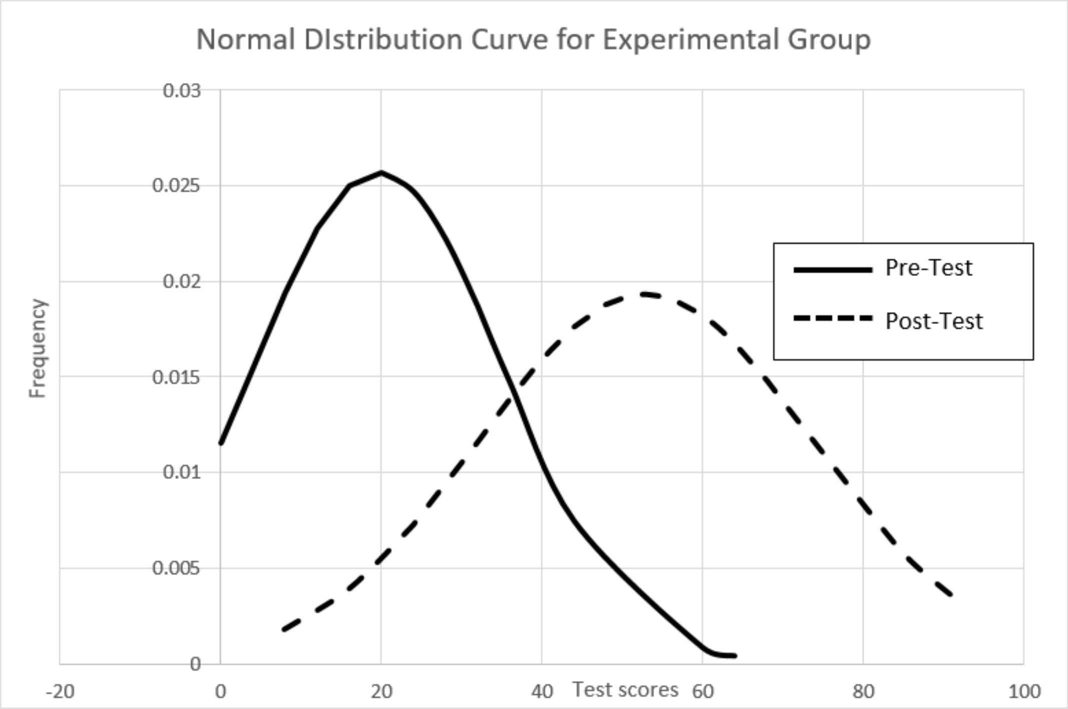


Figure 5.13: Distribution curve of test scores of experimental group

For the experimental group (see Figure 5.13), it can be observed that, in the pre-test, the largest number of learners scored 20%; the highest score was between 60% and 70%, and very few learners achieved this score. However, for the post-test, the distribution curve shifted to the right – the shift was bigger than that of the control group. It can be observed that the highest frequency of scores in the post-test was between 50% and 60%. This shows that the learners in the experimental group had a greater improvement than the control group in performance in the post-test after the intervention. The highest scores obtained by learners in the post-test were between 80% and 100%. There was a noticeable increase in the frequency of learners with the highest scores compared to the highest scores in the pre-test. Therefore, it is evident that, after the intervention, there was a considerable improvement in the performance of the experimental group learners.

5.4.3.2 Paired t-test

A paired t-test was done to obtain statistical evidence for a possibly significant difference between the mean scores of the pre-test and post-test for each group. A paired t-test can be done only if there is a normal distribution of data, and the normality of the distribution was discussed in 5.4.3.1. Using paired t-tests for analysis of data was discussed in Chapter 4 (see table 4.4 & 4.8.1.2).

The paired t-test was used to test the following hypotheses:

H_0 2 There is no significant difference between the mean pre-test and post-test scores of learners in the control group.

H_a 2 There is a significant difference between the mean pre-test and post-test scores of learners in the control group.

H_0 3 There is no significant difference between the mean pre-test and post-test scores of learners in the experimental group.

H_a 3 There is a significant difference between the mean pre-test and post-test scores of learners in the experimental group.

5.4.3.2.1 Control group

The paired sample t-test was conducted to find out if there was a significant difference between the mean scores of the pre-test and post-test of the control group. Means and SD for the pre-test and post-test of the control group were calculated. Table 5.3 shows the results of the calculation.

Table 5.3: Means and SD for pre-test and post-test of control group

SCAT	Mean	N	SD
Pre-test	23.87	30	21.179
Post-test	41.20	30	28.924

It was observed that the control group had improved from the pre-test (M = 23.87, SD = 21.179) to the post-test (M = 41.20, SD = 28.924).

Table 5.4: Paired samples t-test for control group

Paired difference							
	Mean	SD	95% confidence interval of the difference		t	df	Sig. (2-tailed)
			Lower	Upper			
Pre-test-Post-test	-17.33	21.485	25.536	-9.311	-4.419	29	.000

Table 5.4 shows that there is a significant difference between the pre-test and post-test scores of the control group (t (29) = -4.419, $p < 0.05$, Sig. (2-tailed) = .000). As the p value is < 0.05, the probability is, thus, greater that there is some significant difference between the pre-test and post-test mean scores of the control group. The null hypothesis (H_02) was, thus, rejected.

5.4.3.2.2 Experimental group

The paired t-test was utilised to determine the effect of the intervention on the learners in the experimental group's achievement. The means and SD calculated are shown in Table 5.5.

Table 5.5: Means and SD for pre-test and post-test for experimental group

SCAT	Mean	N	SD
Pre-test	19.63	32	15.521
Post Test	52.94	32	20.666

Table 5.5 shows that there was improvement in the post-test scores (M = 52.94, SD = 20.666) after the intervention, compared to the pre-test scores (M = 19.63, SD = 15.521) of the experimental group. The paired samples t-test was done to determine whether there was a significant difference between the mean scores of the pre-test and post-test; findings are shown in Table 5.6.

Table 5.6: Paired samples t-test for experimental group

Paired difference							
	Mean	SD	95% confidence interval of the difference		t	df	Sig. (2-tailed)
			Lower	Upper			
Pre-test-Post-test	-33.313	-19.633	-40.391	-26.234	-9.598	31	.000

The results in Table 5.6 show that there is a significant difference between the pre-test and post-test scores of the experimental group (t (31) = -9.598, $p < 0.05$, Sig. (2-tailed) = .000 (p value < 0.05)), and, hence, the null hypothesis $H_0 3$, which states that there is no significant difference between the mean pre-test and post-test scores of the experimental group, is rejected.

5.4.3.3 ANCOVA

ANCOVA was used to find out whether there is any significant difference between the group means of the SCAT administered for the two groups. The following hypotheses were stated regarding the mean post-test scores of the control group and experimental group.

H_0 5 There is no significant difference between the mean post-test scores for learners in the control group and experimental group.

H_a 5 There is a significant difference between the mean post-test scores for learners in the control group and experimental group.

The lecture method (direct teaching) was used with the control group, and computer simulations were the tool used for the intervention with the experimental group. These methods were the independent variables for the one-way ANCOVA. The post-test scores were, thus, the dependent variables and the pre-test scores were used as the covariate to control for individual difference.

The means and SD were calculated for the pre-test and post-test are shown in Table 5.7.

Table 5.7: Achievement scores of control and experimental group

Group	N	Pre-test		Post-test	
		Mean	SD	Mean	SD
Control	30	23.87	21.179	41.20	28.924
Experimental	32	19.63	15.521	52.94	20.666

From the table, it can be observed that the mean pre-test score of the control group (23.87) is higher than the mean pre-test score (19.63) of the experimental group. For the post-test, the mean score for the control group is 41.20, while the experimental group has a mean score of 52.94. Thus, it can be interpreted that the experimental group performed better in the post-test than the control group did.

Table 5.8 shows the summary of the ANCOVA results.

Table 5.8: ANCOVA summary of achievement by control group and experimental group

Tests of between subject effects						
Dependent variable: Post-test						
Source	Type III sum of squares	Df	Mean square	F	Sig.	Partial Eta squared
Corrected model	15141.473	2	7570.736	18.237	.000	.382
Intercept	22332.658	1	22532.658	54.279	.000	.479
Pre-test	13008.277	1	13008.277	31.336	.000	.347
Group	3491.589	1	3491.589	8.411	.005	.125
Error	24492.398	59	415.125			
Total	178100.000	62				
Corrected Total	39633.871	61				
a. R Squared =.382 (Adjusted R squared = .361						

The result of the ANCOVA is that there is a significant effect of the covariate, which is the pre-test, as F (1,61) = 31.336, $p < 0.05$, Sig. value = .000. Moreover, the result shows that the instructional method had a significant effect (Group), as F (1,61) = 8.411, $p < 0.05$, Sig. value = .005 (p value < 0.0). The ANCOVA results show that there is a statistically significant difference between the mean post-test scores of learners in the control and experimental groups (see 4.8.1.2). Therefore, the null hypothesis (H_04), which states that there is no significant difference between the mean post-test scores of learners in the control and experimental groups, after controlling for the effect of pre-test scores, is rejected.

5.4.3.4 Practical significance and effect size

As the null hypothesis is rejected because there is a significant difference between the mean post-test scores of learners in the control group and experimental group, the effect size, as additional information, served a purpose for the statistical significance found. The effect size using Cohen's *d* (see Table 4.4 & 4.8.1.2) was calculated to assist in drawing conclusions on the practical significance. For the study, Cohen's *d* was determined by calculating the mean difference between the post-test scores of the two groups, and then dividing the result by the pooled SD, using the formula given below.

Cohen's $d = (M_2 – M_1) / SD_{pooled}$

Where $SD_{pooled} = \sqrt{((SD_1^2 + SD_2^2)/2)}$

If the Cohen's d = 0.2, it represents a small effect, d = 0.5, represents medium effect and d = 0.8 represents a large effect.

The Cohen's *d* was calculated as 0,46, which shows that there was a medium effect on the difference between the two means. Hence, it can be understood that the intervention for the experimental group had a medium effect and the statistical difference found between the mean post-test scores of learners in the experimental group and control group was meaningful.

5.4.4 Analysis of the pre-test and post-test answer scripts

A detailed analysis of the answer scripts for the pre-test and post-test of the 12 interviewee learners was done.

5.4.4.1 Test response analysis of the pre-test post-test answer scripts of interviewee learners

A test response analysis of the pre-test and post-test of the 12 interviewee learners was conducted, as discussed in Chapter 4 (see 4.8.1.3). The findings of the test response analysis were explored further through the questionnaire and interviews. Therefore, the test response analysis was only done for the 12 interviewee learners. The quantitative analysis determined only whether there was improvement in performance from the pre-test to the post-test. The test response analysis, as the first part of the qualitative analysis, provided the means for conceptual analysis. The analysis was done by going through the answers provided for each question by each learner regarding mistakes made and correct answers. A summary of the findings relating to the answers of the learners on each question is given in Table 5.9. The test response analysis helped to understand how well the learners performed on each question for the pre-test and post-test and whether conceptualisation occurred regarding the relevant concepts after the lessons. The analysis also helped to compare the control group and experimental group regarding the extent of conceptualisation, and whether conceptualisation was the reason for the improvement in performance.

Table 5.9: Summary of analysis of answers from pre-test and post-test

Question 1.1. Balancing of the equation		
	Pre-test	Post-test
Control group- six learners	Learners could not balance the equation. Various ratios were used as coefficients for reactants and products to balance the equation.	Three learners could correctly balance the equation.
Experimental group- six learners	Learners could not balance the equation. They used random numbers as coefficients to balance the equation (see 2.10.2.1).	Five learners in the experimental group could balance the equation correctly. This was found to be more than that of the control group
Question 1.2. Defining limiting reagent		
	Pre-test	Post-test
Control group	None of the learners could correctly define limiting reagent – it was a new concept in Grade 11. There was an understanding that limiting reagent limited the reaction and it had the least moles available for the reaction (see 2.10.2.1). .	Two learners understood what a limiting reagent is, but the four learners had a misconception that it will always be present as the reactant with the least moles available for the reaction.
Experimental group	As it was a new concept in Grade 11, learners had no understanding of what a limiting reagent was.	Four learners in the experimental group knew what a limiting reagent is, and two learners displayed misconceptions about limiting reagent.

Question 1.3. Calculation to determine the limiting reagent		
	Pre-test	Post-test
Control group	Learners could find the number of moles of each reactant or one reactant provided, but did not know which one was the limiting reagent, as it was a new concept in Grade 11.	Learners displayed very poor conceptualisation of determining the limiting reagent, and had the misconception that the limiting reagent will have the least moles available, as reactants still exist.
Experimental group	Learners could calculate the moles but did not know how to determine the limiting reagent, because this was a new concept in Grade 11.	Four learners in experimental group could apply the mole ratio to determine the limiting reagent. This was found to be more than that of the control group. Two learners in the experimental group had the misconception exhibited by the control group.
Question 1.4. Calculating the maximum mass of one of the products formed		
	Pre-test	Post-test
Control group	Learners could not apply mole ratio for determining mass of product formed.	Three learners could apply the mole ratio and determine the mass of products formed, but used algorithms of selecting a formula, substituting in the formula and finding the answer. However, only one of the learners could give the correct final answer.
Experimental group	The majority of learners failed to answer the question correctly by applying the mole ratio.	Five learners could apply the mole ratio and do further calculations to determine the amount of product formed correctly. Two learners could get the final answer correct.

Question 1.5. Calculating the mass of excess reactant left over		
	Pre-test	Post-test
Control group	All learners could not use the mole ratio to calculate the mass of excess reactant left.	Five learners did not attempt the question, while one learner applied the algorithmic steps for the calculation, but arrived at a wrong answer.
Experimental group	Only one learner tried the question with mole ratio, while the others did not attempt the question.	Four leaners in the experimental group could apply their understanding of mole ratios for calculations and could determine the mass of reactant left.
Question 2.1. Writing down a balanced equation from the word equation given		
	Pre-test	Post-test
Control group	Two learners could write down the correct formula for a reactant and product and balance the equation correctly. Use of multiple ratios was also observed.	Two learners could balance the equation correctly, while others could not write down the formula of the reactant and product and, hence, the balancing was wrong.
Experimental group	One learners could write the formulae and balance the equation correctly. Others used random numbers for the balancing equation. Two of them wrote the wrong formula for reactant and product.	Four learners (more than in the control group) could balance the equation correctly. One learner could not write the correct formula for the compounds and, hence, balancing went wrong. One used random numbers to balance the equation

Question 2.2. Calculating volume of product produced when a certain mass of reactant is heated		
	Pre-test	Post-test
Control group	Two learners got partially correct answers by calculating the moles of the reactant reacted from mass given, and attempting to use the mole ratio, but they could not complete it correctly. They also tried to use the formula to calculate volume by using mole and molar volume directly. Some answers were left blank without an attempt to answer being made.	There was an improvement in the answering of the question correctly by three of the learners.
Experimental group	Two learners succeeded in converting mass to moles, but they could not continue with the correct method. Two other learners could not use the correct formula to find the moles of the reactant. Two learners did not attempt the question.	Four learners in the experimental than in the control group could apply the mole ratio correctly for the calculation and could obtain the correct answer.

5.4.4.2 General interpretation of the pre-tests of control and experimental groups

The following general interpretation was done from the test response analysis of the pre-test done for the 12 interviewee learners (see 5.4.4.1).

- Learners of control and experimental groups found it equally challenging to balance equations. Some learners did not know how to write the correct formulae for reactants and products when word equations were given, leading to incorrect balancing. Some learners used multiples of the actual coefficients to balance the equation, while other learners did not know that, when balancing equations, the number of atoms of each element on the left-hand side must be equal to the number of atoms of each element on the right-hand side of an equation – learners just tried to make the total number of molecules the same on both sides of the equation (see 2.10.2.1.).
- Limiting reagent is a new concept in Grade 11 and, hence, neither group knew the definition for limiting reagent.
- As limiting reagent is a new concept, none of the learners could determine the limiting reagent through calculation.
- Learners in both groups could apply the mole-concept formula, which they had learned in Grade10, but could not use it for further calculations to find the number of moles when mass was given, and vice versa.
- One learner each from the control and experimental groups (two learners out of the total 12 learners) applied ratios in balanced equation to do calculations based on a reaction, while the other did not attempt the question.
- Learners of neither groups were able to use the formula for mole concept correctly and apply the mole ratio in balanced equation for further calculations. Learners used the number of moles of a solid substance to calculate the volume of a gas formed as the product, which is a misconception (see 2.10.2.1).

5.4.4.3 General interpretations of the post-tests of control and experimental groups

The following general interpretation was made from the test response analysis of the post-test done for the twelve interviewee learners (see 5.4.4.1).

- More than half the learners of both control and experimental groups could balance equations correctly after the lessons, but learners in both groups found it challenging to write down formulae correctly.
- More learners in the experimental group than the control group could write the definition of limiting reagent correctly after the lessons. A few learners in the control group still understood the limiting reagent to be the substance with the lowest number of moles available in a reaction. This shows that the learners in the control group had not experienced a conceptual change from the learning experience involving the lecture method; the lecture did not cause a more powerful understanding of the scientific phenomenon (see 2.6.2.2). In turn, through the simulation using the example of sandwiches, the learners in the experimental group could see clearly that the limiting reagent is the reactant that was used up first in a reaction. The simulation helped to cause the necessary conceptual change.
- Regarding calculations in the post-test, learners in both the experimental group and control group could apply the mole concept formula to find moles This shows that both groups of learners gained the factual knowledge of different symbols in the formula representing certain physical quantities, for example, n, m and M means moles, mass in grams and molar mass respectively (see 2.10.2.3). A few learners in the control group multiplied the coefficient of the substance in the balanced equation with the molar mass (M) before substituting in the formula for calculating moles. This shows that the learners in the control group made a conceptual mistake relating to when to use the coefficient in a balanced equation.

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- More learners in the experimental group than the control group could apply mole ratios in balanced equations for further calculations to determine the limiting reagent, mass of product formed and excess reactant left after using the mole concept formula. This shows that more learners in the experimental group than the control group had gained procedural knowledge for problem-solving (see 2.6.1.4 & 2.10.2.3).
- In response to the question requiring learners to calculate the volume of product formed from a certain mass of reactant heated, more learners in the experimental group than in the control group could apply the mole ratio correctly, and few of them could complete the calculation successfully. This shows that the experimental group gained procedural knowledge, in addition to factual and conceptual knowledge, for problem-solving (see 2.6.1.4).
- Some learners in the control group did not know that n = V/VM cannot be applied to solid substances (see 2.10.2.1). This also showed a misconception in these learners' understanding in making use of different formulae in the mole concept.

Hence, the test response analysis shows that more learners in the experimental group than the control group improved their performance, and this improvement was due to learners having an understanding of the different concepts after the lesson. From the general interpretations in 5.4.4.2 and 5.4.4.3, after the lessons both groups had improved in balancing equations. The limiting reagent and its calculations were a new topic in Grade 11, however, after the lessons there was an improvement in their understanding regarding the concept. The microscopic representations of the different reactions and the activities in the form of games in the simulations that were used for teaching and learning could have helped the learners to rearrange their initial understanding about the concepts in stoichiometric chemistry, thereby improving their conceptual understanding (see 2.6.2.2 & 3.9.4.1). It was also observed that the learners in the control group used algorithms to do calculations, for instance, selecting a formula and substituting the data that was available (see Table 5.9, questions 1.4 &1.5). However, the data analysis of the questionnaire and interview will provide a more detailed explanation of the conceptualisation of the topic.

5.5. DATA ANALYSIS OF THE QUESTIONNAIRE

After writing the post-test, all the learners were given a questionnaire to answer, so that I could obtain more qualitative data and, to a lesser extent, quantitative data. The face validity, content validity and construct validity of the questionnaire had been ensured (see 4.7.2.3.4). Ensuring trustworthiness made the qualitative section of the questionnaire reliable, while Cronbach's alpha reliability coefficient was used to determine the reliability of the quantitative section of the questionnaire (see 4.7.2.3.5). All 30 learners in the control group, and 31 out of the 32 of the learners in the experimental group completed the questionnaire. One leaner in the experimental group was absent from school when the questionnaire was distributed and collected. The questionnaire consisted of a demographic section, and qualitative and quantitative sections (see 4.8.2).

5.5.1 Demographic information

The demographic information in section A collected by the questionnaire will be summarised in this section. All learners in the school were girls. The reason for selecting the particular school was discussed in Chapter 4 (see 4.6.2).

5.5.1.1 Age in years

The first item in section A which was the ages of learners in the sample are shown in Figure 5.14.

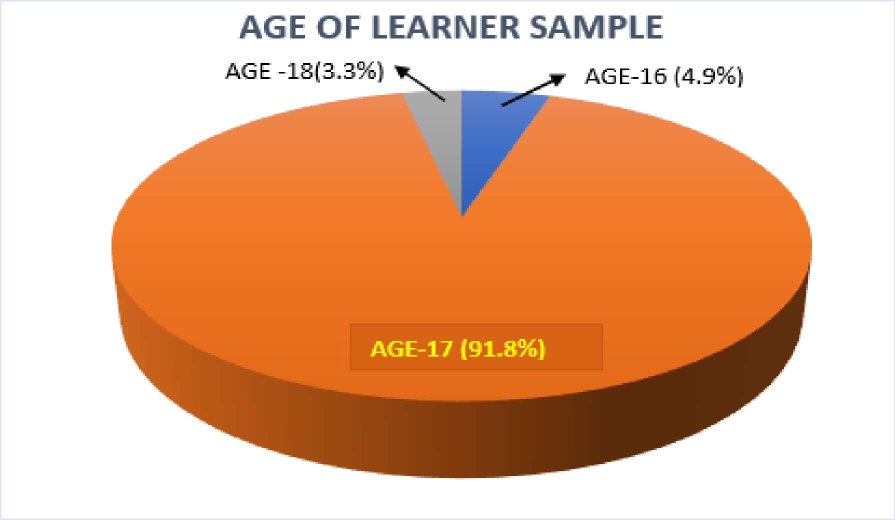

Figure 5.14: Age distribution of learner sample

All the learners who participated in the study were in Grade 11. Of the total number of learners in the two groups that completed the questionnaire, 56 learners were 17 years old, which is the expected age of Grade 11 learners; 91.8% of the learners were 17. Two of the learners were 18 years old, which is a year older than the expected age of learners. The reason for this age difference could because they had repeated a grade in a previous year. Four of the learners were 16 years old, which is one year younger than the expected age. These four learners may have completed the questionnaire before their birthdays that year.

5.5.1.2 Home language

In the South African school curriculum, a learner can write a test or examination in either English or Afrikaans, according to the medium of instruction chosen by the learner. The language of teaching and learning and the mother tongue (home language) of the learners – which is different from the language of teaching and learning – also plays an important role in the field of education (see 2.7.3 & 2.10.2.4). The language of teaching and learning plays an important role in education (see 2.10.2.4.). In South Africa, a learner can write a test or examination in either English or Afrikaans. The participating school's language of instruction was English. For the demographic information to be complete, it was necessary to enquire about the home language or mother tongue of the learners. Table 5.10 lists the home languages of learners which was item two in the questionnaire.

Table 5.10: Home languages of the learners

Home languages	English	Afrikaans	Setswana	Sesotho	IsiXhosa	IsiZulu	Other	Total
Frequency	4	19	25	6	2	2	3	61
Percentage	6.6	31.2	40.9	9.8	3.3	3.3	4.9	100

Of the 61 learners, 25 indicated Setswana and 19 Afrikaans as their home languages. Only 4 of the learners indicated English as their home language (mother tongue), which was the language of instruction at the school. Sesotho, IsiXhosa and IsiZulu were the home languages of 6, 2 and 2 learners respectively. There were 3 learners who indicated ‘other’ as their home language.

5.5.1.3 Level achieved in physical sciences in Grade 10

The percentage marks and the corresponding levels of the learners in the two groups in the Grade 10 November examination in physical sciences in 2018 which was given as item three in the questionnaire is given in Table 5.11.

Table 5.11: Level achieved in 2018 November examination in physical sciences

Level/ marks in 2018	1: (0-29)	2: (30-39)	3: (40-49)	4: (50-59)	5: 60-69)	6: (70-79)	7: (80-89)	Total
Frequency	0	8	12	20	11	5	5	61
%	0	13.1	9.7	32.8	18	8.2	8.2	100

The frequencies and percentages for categories of marks and corresponding levels are shown in Table 5.11. According to the South African schooling system, a learner obtaining a percentage of 0–29% has failed or not achieved in the subject. There were no learners in the sample who had obtained below 30% for physical sciences in the previous grade (Grade 10). It was observed that 8.2% of the learners had achieved level 7, which is 80% and above in the November examination in Grade 10. The biggest number of learners obtained level 4, namely 32.8% of the learners.

5.5.1.4 Discipline of physical sciences that learners enjoy learning the most

The discipline in physical sciences that the learners enjoy the most was item four in the questionnaire and is shown in Figure 5.15.

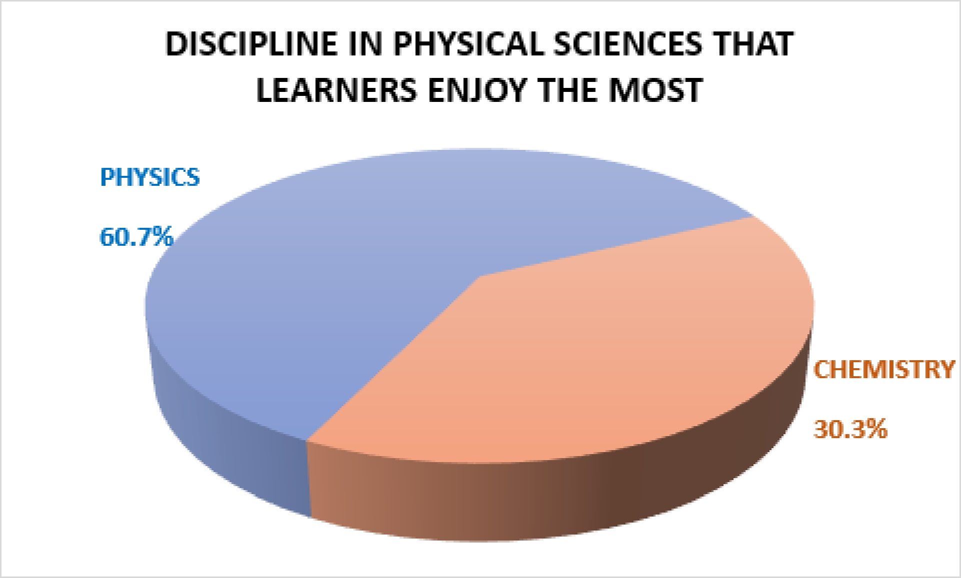

Figure 5.15: Discipline in physical sciences that learners enjoy learning the most

It was found that 60.7% of learners enjoyed learning physics, while only 30.3% chose chemistry as their most enjoyable discipline. A reason could be the abstract nature of chemistry, and the difficulties learners experience with stoichiometric chemistry (see 2.10.2).

5.5.1.5 Interest in proceeding with further studies in physical sciences

The interest of learners in proceeding with further studies in physical sciences was item five in the questionnaire. It is summarised in Figure 5.16.

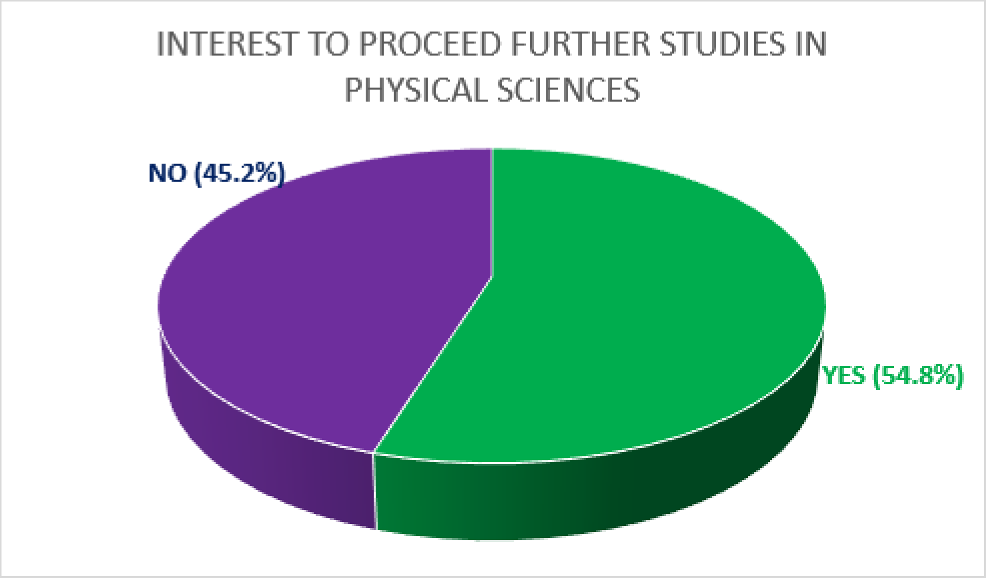

Figure 5.16: Interest in proceeding with further studies in physical sciences

More than half the sample of learners showed interest in studying physical sciences further at the tertiary level. However, this was only 54.8% of the group, which needs to be increased if the country is to train professionals in the fields of science, such as scientists, doctors and engineers. It was discussed in Chapter 2 (see1.2.1 and 2.5.2) that the country has a need for more students in the field of physical sciences at higher education levels.

5.5.2 Analysis of qualitative data obtained from the questionnaire

A questionnaire (see Appendix D, section B),consisting of a qualitative section (see section B, questions 1.1- 1.6) and a quantitative section (see section B, statements 2.1- 2.6), was given to all learners in both groups. However, only the 12 interviewee learners' questionnaire responses were analysed. As the selection of the interviewees was done only after the distribution of the questionnaire, all learners were requested to complete the questionnaire and the questionnaire responses of the interviewees were chosen later for the qualitative analysis (see 4.8.2.1). The qualitative section of the questionnaire consisted of open-ended questions and thematic analysis was done for this section (see 4.8.2.1).

All learners in both groups were assigned codes instead of their names being used, for ethical reasons (see 4.7.2.3.3). The learners selected for the analysis in the control group had the codes CGL1, CGL7, CGL14, CGL15, CGL16 and CGL20.The learners selected for the analysis from the experimental group had the codes EGL3, EGL7, EGL10, EGL11, EGL31 and EGL32. These codes will be used to refer to a specific learner in the discussion of the analysis.

5.5.2.1 Procedure of thematic analysis

The following steps were taken to conduct the thematic analysis of the qualitative section of the questionnaire through an inductive approach, which used the theme determined from the data (see 4.8.2.1):

- Step1: I familiarised myself with the responses written by the participants, by reading through it several times and reflecting on its overall meaning.
- Step 2: This step involved the coding of all the data. During this step, certain phrases and sentences were highlighted and codes were generated to describe the content. Each question in the questionnaire was analysed separately. All the responses for each question were thoroughly studied, and anything that was relevant and potentially interesting was highlighted. Afterwards, all the data were collated into groups identified by codes.
- Step 3: In this step, I generated and reviewed the themes and identified patterns among the codes I had created, and came up with themes. The themes were broader than the codes. Later, the themes were reviewed to make sure that they represented the original data that had been collected.
- Step 4: I named and defined themes in this step. Each theme was defined clearly, in order to understand the data collected by each question in the questionnaire. This was done by formulating exactly what each theme meant. Each theme was also named according to the definitions.
- Step 5: The final step was writing up the thematic analysis that had been done. It will be described in the section below.

5.5.2.2 Discussion of themes identified

Themes identified from each question in the questionnaire will be discussed below. The examples of responses by the learners are given in italics. Appendix F shows the themes generated, and the responses to each question.

> Question 1.1: Write down what you understand about stoichiometric chemistry

The following themes were generated from the responses to Question 1:

- Uncertainity

The theme of uncertainty was identified in both the control and experimental groups. Some of the learners in both groups seemed to be uncertain about how to explain their understanding of stoichiometric chemistry (see Appendix F).

Examples of the learner responses for the theme of uncertainty are given below.

> *CGL1: extremely difficult, only thing that I understand is it has to do with determining empirical formulae.*
>
> *EG32: it has chemical equations and limiting reagents.*

These responses show that the learners were uncertain about what the topic of stoichiometric chemistry deals with, which shows a poor conceptualisation of stoichiometric chemistry in general. However, the learner in the experimental group recalled that stoichiometric chemistry has chemical equations and limiting reagents. These two concepts were the topic of the main activities that the experimental group participated in during simulation. Hence, it can be interpreted that, even though the learner was uncertain about the concept of stoichiometric chemistry, the intervention helped the learner to recall a few concepts that had been dealt during lessons.

- Calculation of moles

This was another theme that was identified from the learner responses:

> *CG L7: calculations to determine amount of products and reactants that are needed during a chemical reaction.*
>
> *CGL16: I understand that in most cases you have to use moles to find the rest.*
>
> *EG L 3: it is all the calculations, the mole.*
>
> *EG L10: calculations based on reactions including moles and ratios.*

From the above responses it can be understood that the learners gained an understanding that mole calculations are involved in stoichiometric chemistry, which is the basic concept of the topic (see 2.10.1). It was also noticeable that more learners in the experimental group than the control group had this response.

- Calculations with ratios

In response to Question 1, more learners in the experimental group responded that stoichiometric chemistry involves calculations based on chemical reactions, while some of the learners in both groups responded that stoichiometric chemistry involves calculations of reactions with ratios. The following are examples of the responses by learners.

> *CGL14: calculations between chemical reactions which involve ratios that has to do with atoms and molecules.*
>
> *EGL11: using chemical reactions and ratios in balanced equations for calculations with moles, limiting reagents.*

The examples of responses by the learners show that their knowledge and understanding of the mole concept, as remembered from Grade 10 and the lessons in Grade 11, gave them the understanding that stoichiometric chemistry deals with calculations based on chemical reactions. From the responses of learners in both groups, it is clear that more learners in the experimental group understood that, when studying stoichiometric chemistry, calculations using moles and ratios in a balanced equation to determine the amount of substances in a chemical reactions are involved.

The concepts dealt with in stoichiometric chemistry in Grades 10 and 11 were discussed in Sections 2.10.1 and 2.10.2. During the lessons, both control and experimental group learners were given activities based on calculations, to determine either the moles of the reactants or products, the limiting reagent, the mass of product formed, and reactant reacted (see 5.3.2). It was observed during the lessons that the learners in the experimental group interacted with each other while performing the activities through simulation, and engaged in discussions, while the learners in the control group mostly tried to apply the steps written on the whiteboard to do the activities (see 5.3.2).

To achieve conceptualisation according to activity theory, learners need to construct their own knowledge by interacting with each other while performing activities. Once conceptualisation has happened the learners will be able to apply what they learnt into new situations (see 2.6.2.6 & 3.4). The test response analysis of the post-test showed that more learners in the experimental group than in the control group could apply the mole ratios in balanced equations in problem solving (see 5.4.4.3). Therefore, it could be interpreted that the experimental group had better conceptualisation than the control group.

Question 1.2: What is the need of balancing a chemical equation of a reaction based on stoichiometric chemistry?

In the literature review of stoichiometric chemistry, the importance of balancing the equation for the study of stoichiometric chemistry was discussed (see 2.10.1). Learners need to conceptualise balancing of equations and the need to balance equations for a chemical reaction. Hence, Question 1.2 focused on determining whether the learners had conceptualised the concept. Two themes were generated from Question 1.2 and will be discussed below.

- Uncertainty

The following responses correspond with the theme of uncertainty.

> *CGL1: left hand side equal to right hand side*
>
> *CGL16: to conserve law of conservation of mass.*
>
> *CGL20: to see that your products can be equal to your reactants.*
>
> *EGL7: making sure that both sides of the reactions are balanced.*

The responses of the learners suggest that more learners in the control group did not conceptualise the need to balance the equation for a reaction in stoichiometric chemistry. They only knew that balancing equations involved making both sides of the chemical equation equal and related to the law of conservation of mass.

- Use mole ratio

As explained earlier, in balanced equations, the coefficients of reactants and products represent the ratio in which reactants react and products form (see 2.10.1). Hence, these coefficients or mole ratios are important for determining the limiting reagent, the amount of product formed, the amount of reactant used, and the amount of any reactant left when the reaction is completed. During the lessons for both groups, learners were taught to use the coefficients in the balanced equation as the ratio in which reactants react and products form. They were also given examples to balance equations, first, before attempting calculations (see 5.3.2).

Some of the learners in the control group responded that balancing of equations was needed for using mole ratios. They could not give a clear response indicating the importance of a balanced equation. However, learners in the experimental group responded with an explanation that balanced equations are needed if mole ratios of reactants and products are to be used for accurate calculations and to determine the limiting reagent. The following resulted in this theme for the question asking about the importance of balanced equations in stoichiometric chemistry.

CGL7: To determine the mole ratio and number of moles.

EGL31: To get mass or mole ratio correct for accurate calculations.

During the lessons, it was observed that learners in the control group were given activities to balance a chemical equation, and corrections were made on the board. Most of the learners did the activities individually, although a few of them formed pairs to discuss how to balance the equation. In the experimental group, the learners were exposed, first, to the simulation using the sandwich example, and later chemical reactions as games (see 3.9.4.1.1). It was observed that the learners actively engaged in the games by interacting with each other, which promoted conceptualisation of learning (see 3.9.3). Hence, it could be interpreted that the experimental group conceptualised the importance of balancing a chemical equation better than the control group.

> Question 1.3: What is the importance of a limiting reagent in a chemical reaction?

A limiting reagent and its importance in stoichiometric calculations was discussed in Chapter 2. The CAPS document for physical sciences and the diagnostic report for the NSC examination recommends explaining the definition of limiting reactants, determining the limiting reagent in a reaction, and using it to calculate the amount of product formed and the amount of reactant left behind (see 1.2.1). The concept of limiting reagent is introduced in Grade 11 in the South African schools curriculum. Learners are introduced to the definition of limiting reagent, as the reactant that is used up first in a reaction. The following are the themes generated from the responses to the question.

- Uncertainty

In both groups, the learners were taught about limiting reagent and how to determine the limiting reagent. The control group learners were taught a certain step that they could follow to determine the limiting reagent after defining the concept. The experimental group used simulations with the sandwich example, and games with chemical reactions for the lesson (see 3.9.4.1.2). It was noticed that more learners in the control group were uncertain about the importance of limiting reagent than in the experimental group. Examples of responses corresponding to the above theme are given below.

> *CGL16: Gives an idea of the properties of the substance.*

> *EGL7: Because the reaction needs to be reduced.*

- Definition

The theme of definition was identified because some learners in the control group provided the definition of limiting reagent as their response to the question on the importance of limiting reagent in a reaction.

> *CGL15: It is a reagent that is used up first within a reaction.*

> *CGL14: So that we can know which one will be used first (definition) and use it in other calculations.*

It could be interpreted that learners in the control group could recall factual information and, hence, responded by giving the definition for the limiting reagent as an explanation for the importance of limiting reagent (see 2.6.1.4).

- Determines products

The responses of learners in both groups show that more learners in the experimental group understood the concept that the limiting reagent is used to determine the amount of product formed in a reaction. Some of them understood that the limiting reagent controlled the amount of product, and that the ratio between the limiting reagent and the product in the balanced equation was used to do calculations. This shows that the experimental group conceptualised the importance of limiting reagent by gaining conceptual knowledge (see 2.6.1.4) better than the control group did. Examples of responses by learners are given below.

CGL7: Determines the amount of the products.

EGL10: To find which one is used up and use its ratio to find the amount of product formed and reactants used.

EGL11: Limiting reactant slows down/stops a reaction / how much the reaction will produce.

Question 1.4: How confident are you in doing calculations based on stoichiometric chemistry?

The themes discussed below were identified for Question 1.4.

- Varied confidence

Learners in both groups gave varied responses. A few were fairly confident about performing stoichiometric calculations. Few learners in both groups responded that they were scared, confused and struggling to understand the calculations, while responses that indicated moderate confidence were also observed. Examples of responses that led to the above theme are given below.

CGL7: Fairly confident.

CGL20: I am not entirely confident but also really scared and some questions can be confusing.

EGL3: Slightly confident, needs to practise more often.

EGL11: Fairly confident.

Question 1.5: Briefly explain a method that you will follow to answer a question to determine the limiting reactant.

The following themes were identified for the above question.

- Misconception

In response to the question about the method to determine limiting reagent, the majority of learners knew that calculating moles of the given substance was an important step. However, more learners in the control group understood that, after calculating the moles, the substance with the lowest moles would be the limiting reagent.

> *CGL14: Balance the equation, find the ratio, calculate the moles, one with least number of moles is the limiting reagent.*
>
> *CGL20: Write down balanced equation, determine mass of both agents and subtract.*
>
> *EGL32: Calculate the moles and find which has less moles.*

This understanding was discussed as a misconception in Chapter 2 (see 2.10.2.1), but it was observed that very few learners in the experimental group had this misconception.

- Correct method for calculation

Using the correct method for calculations was another theme that was generated from the responses of the learners in response to a question about the method to determine limiting reagent. In the responses, it was noticed that the learners in the experimental group had a better understanding than the control group learners of how to determine the limiting reagent. The responses given below are examples.

> *EGL3: Find moles, use mole ratio with smallest ratio and find how much of the other needed, then compare which one finishes first.*
>
> *EGL11: Find moles, use mole ratio with smallest ratio and find how much of the other will be needed, then compare which one finished first.*

There was only one learner in the control group who responded by showing conceptualisation. The response by this learner is given below.

> *CGL7: Calculate moles, compare ratio, determine from ratio how many moles needed, reactant that cannot meet the need compared to how much is available is the limiting reagent.*

Hence, it could be interpreted that the experimental group conceptualised the concept better than the control group did.

> Question 1.6: What difference in the lessons you attended make in answering the post-test?

The themes that were generated will be discussed below.

- Little understanding

Some of the learners in both control and experimental groups responded that they had some understanding of the concepts, which helped them to do better in the post-test. However, they were sometimes confused about applying the knowledge that they had acquired from the lessons they had attended before the post-test. Examples of responses from both groups are given below.

> *CGL1: I felt more confused, it gave me some sort of knowledge, but I do not know where to apply things.*

> *EGL32: I can do some of the calculations better than before.*

From the responses, it is understood that some learners in the control and experimental groups faced challenges in applying what they had learned in the lesson before the post-test. Some of them could apply the mole concept formula, but they struggled with the complex calculations, such as using the limiting reagent to calculate the mass of product formed.

- Improvement in understanding

This theme was generated because some learners from both groups responded that their understanding had improved. Examples of responses are given below.

> *CGL16: It gave more insight and a better and a clearer understanding of the moles and formula.*

> *EGL32: I can do some of the calculations better than before.*

The responses above could be interpreted to mean that, for the learner in the control group, improvement resulted in using certain formulae, while the learner in experimental group responded that the improvement is generally in relation to calculations.

- Simulations improved understanding

This theme was generated from the responses of the learners in the experimental group, where there were learners who specifically commented about the benefits of the simulation for understanding the concept better. Examples from the responses are given below.

> *EG31: I knew some of the work on the post-test than before because I could remember much in the visual lessons with simulations.*
>
> *EGL10: The lessons attended with simulations made answering the test much easier to understand and gave me more confidence.*

In lesson observation it was evident that the learners in the experimental group enjoyed the lessons more than learners in the control group did. The simulations used during lessons encouraged learners to actively participate in each activity and also to interact with each other and with the teacher while engaging in games. It was observed that more learners in the experimental group were aware of their own learning, and they emphasized that using simulations helped to improve their learning.

The experimental group's lesson was in line with activity theory, which is the theoretical framework for the study. According to activity theory, conceptualisation happens when learners interact with each other while they are engaged in activities. The learners in the experimental group engaged in activities in the form of games as part of the simulations. Using simulation was found to reduce the cognitive load of learners and to promote inquiry-based teaching (see 3.8.2 & 3.9.1). As a result, the learners in the experimental group improved their conceptualisation, which could be the reason for the improvement in their performance better than the control group (see 5.4.3.3).

5.5.3 Analysis of quantitative data obtained from the questionnaire

A short quantitative section was included in the questionnaire. This section contained a few questions on the conceptualisation of stoichiometric chemistry and the effectiveness of the particular method of teaching used for the group. The short section provided an ordinal measure relating to learners' attitudes towards conceptualisation of stoichiometric chemistry, which helped to identify learners for the interview (see 4.8.2.2). This section of the questionnaire consisted of six questions, which were answered by selecting options from a six-point Likert scale. The scores of the learners were analysed by adding the number of responses from each rating on the scale by using the numbers 1, 2, 3, 4, 5, 6 as keys for strongly disagree (S_tD), disagree (D), slightly disagree (S_lD), slightly agree (S_lA), agree (A), strongly agree (S_tA) respectively, where S_t represents 'strongly' and S_l- represents 'slightly'. The Likert scale responses were analysed further by dividing the keys into two categories, namely, agree and disagree. The statements in Questions 2.1 and 2.2 refer to the learners' understanding and conceptualisation of the topic of stoichiometric chemistry. The statements in Questions 2.3, 2.4, 2.5 and 2.6 investigate the effect the teaching methods used for the lessons had on the conceptualisation of stoichiometric chemistry. The responses of the control group and experimental group were analysed separately. Tables 5.12 and 5.13 show the analysis. For each question, the frequency of learners who chose each option and the percentage of learners who fall in the categories Agree and Disagree were calculated and analysed.

Table 5.12: Frequency of control group learner responses

Question No.	Keys						Likert scale categorised as Agree and Disagree			
	S_tD	D	S_lD	S_lA	A	S_tA	Agree	%	Disagree	%
2.1	1	6	4	13	5	1	19	63	11	37
2.2	2	4	3	8	11	2	21	70	9	30
2.3	3	1	7	6	6	7	19	63	11	37
2.4	2	3	5	13	4	3	20	67	10	33
2.5	2	2	6	9	7	4	20	67	10	33
2.6	6	6	6	6	3	3	12	41	18	59

Table 5.13: Frequency of experimental group learner responses

Question No.	Keys						Likert scale categorised as agree and disagree			
	S_tD	D	S_lD	S_lA	A	S_tA	Agree	%	Disagree	%
2.1	2	2	4	9	8	5	22	73	8	27
2.2	0	2	4	10	9	6	25	81	6	19
2.3	0	2	10	10	4	5	19	63	12	39
2.4	1	5	3	7	8	7	22	73	8	27
2.5	2	4	4	10	8	3	21	68	10	32
2.6	2	9	4	8	2	6	16	52	15	48

5.5.3.1 Effect of the teaching methods used for the control and experimental groups

The first two questions (2.1 and 2.2) enquired about the effect of the teaching methods used for the two groups on the conceptualisation of the topic. Only 37% and 30% of the learners in the control group disagreed for questions 2.1 and 2.2, respectively: 63% and 70% of the learners agreed that the teaching method contributed to their understanding and conceptualisation of stoichiometric chemistry. For the experimental group only 27% and 19% of learners disagreed on questions 2.1 and 2.2 respectively. The analysis showed that 73% and 81% agreed that the use of simulations to teach stoichiometric chemistry helped to improve their conceptualisation. It could be interpreted from the analysis of the Likert scale that more learners in the experimental group agreed that the teaching method that used computer simulation contributed to a better understanding and conceptualisation of stoichiometric chemistry, than learners in the control group. To obtain further understanding of the effect of teaching method on learners' conceptualisation, a similar question was included in the interview.

5.5.3.2 Understanding and conceptualisation of stoichiometric chemistry by learners in the control and experimental groups

Questions 2.3 to 2.6 were based on the conceptualisation of stoichiometric chemistry. The analysis shows that, for question 2.3, 63% of the learners in both control and experimental groups agreed and 37% disagreed that they had a better understanding of the mole concept in Grade 11 than they had had in Grade 10. This shows that the lessons improved the learners' conceptual understanding in both groups. This could be the reason that 67% of learners in the control group agreed that they had more confidence in learning chemistry than before, while only 33% disagreed (question 2.4 on Likert scale). In the experimental group, for question 2.4, 73% of learners agreed that they were more confident about learning chemistry than before, while 27% of them disagreed. The percentage of learners who agreed that they had more confidence in learning chemistry was greater than that of the control group.

For question 2.5, which relates to confidence to perform better in stoichiometric chemistry-based questions, 67% of learners in the control group and 68% in the experimental group agreed that they felt that they could perform better. For the same question, 33% and 32% of learners in control group and experimental group disagreed, respectively.

Lastly, while only 41% of the control group agreed that stoichiometric chemistry calculations can be fun (question 2.6), 52% of the experimental group agreed on the same question. During the intervention, it was observed that the learners in the experimental group actively participated in the stoichiometric chemistry calculations, through the games in the simulations. With the simulations, the teacher was able to show change of reactants into products and the leftovers. This is a concept that cannot be learned by conducting experiments. It was discussed in Chapter 3 that simulations offer visual representations of physical and chemical phenomena that cannot be carried out in a classroom situation as an experiment (see 3.9.2). Hence, the simulations gave a different experience where learners could visualise a concept in a simpler manner for the experimental group than the control group. From the observations made above, it can be interpreted that learning through simulations helped learners in the experimental group to apply their learning in more complex calculations, improved their understanding and increased their confidence level in relation to performing stoichiometric calculations.

It was also found that more learners in the experimental group enjoyed and had fun doing stoichiometric chemistry calculations than the control group. It was discussed in Chapter 3 that the use of simulations can improve the learning of a group of learners that has varied abilities and who construct their own learning through social interaction (see 3.8.1) Therefore, it could be interpreted that learning with simulations enhanced experimental group learners' interaction with each other, resulting in them constructing knowledge better than the control group.

5.6 QUALITATIVE DATA ANALYSIS OF INTERVIEWS

After the questionnaire, a semi-structured interview was conducted with six learners selected from each group. The validity and reliability of the interview were ensured (see 4.7.2.4.4 & 4.7.2.4.5). After reviewing the questionnaire responses, I realised that some of the questions had not been clearly answered by the learners. Therefore, a few of the questions in the questionnaire that were important for the analysis, were added to the interview. A thematic analysis was done for the interview (see 4.8.3). The procedure and steps taken for the thematic analysis were the same as for the qualitative questionnaire analysis (see 5.2.1.1) and, hence, it is not described here. The transcribed responses were read carefully several times. For each interview question, codes were identified and, from the codes, themes were generated. Hence, an inductive approach was taken for the analysis of the interview responses (see 4.8.3). It was mentioned in the data analysis of the questionnaire that the questionnaire responses of the same learners who had been selected for interviews were used for the analysis (see 5.5.2). The test response analysis was also done with answer scripts of the interviewees. As a result, the analysis of the interview added to the understanding about the conceptualisation of stoichiometric chemistry that was gained through the questionnaire response and test response analysis. The questions, themes and learner responses of all learners who were interviewed are attached as Appendix G. The interpretations from the themes for each interview question are discussed below. Each learner was labelled with the same code for the interview response as was used for the questionnaire (see 5.5.2).

> Question 1: In Grade 10, you were introduced to the quantitative aspects of chemical change. Briefly explain how well you understood the topic of mole concept and other calculations based on chemical reactions.

As discussed earlier (see 1.2.1), the learners are taught stoichiometric chemistry with mole concept and calculations based on chemical reactions in Grade 10. They were taught to use the different formulae of moles in relation to other quantities, such as number of particles, mass, volume of gases and concentration of solutions. For the question above, the themes stated below were generated from the learner responses.

- Moderate understanding

Examples of responses that led to the above theme are given below.

> *CGL7: I think in Grade 10 it was introduced; I didn't understand it well as it was new but after a while I could understand well and perform better.*
>
> *CG L14: Hhmm, in Grade 10 it was a little bit difficult because it was new. But as I got hold, I had to practice it more because I had to be familiar with the reactions, how to put it and how to structure the equations as well so.... it went well.*
>
> *EG L3: Hhmm, not that well. It was very complicated; I did not understand the elements and the numbers on it I needed to understand before I could do any calculations. Moles can be calculated from the formula in gr10, that was my understanding.*
>
> *EG L10: I had very little understanding on quantitative changes, the aspects of chemical change in gr10. I did not understand what a mole is. I just used the formula mam, check what I was given and what I needed to find, I just depended on the formula.*

A few of the learners responded that they had very little understanding of the mole concept and the calculations they had been taught in Grade 10. The responses of the learners gave the understanding that learners did not conceptualise stoichiometric chemistry in Grade 10. Some learners could use the formula of mole concept and substitute the other quantities that were related to mole. The discussion of learners using algorithms for calculations with the formulae of moles without conceptualisation was done earlier (see 2.10.2.2). Another learner responded that practise with reactions and equations helped them to understand.

Therefore, it could be interpreted that, even though the learners had been taught stoichiometric chemistry in Grade 10, the majority of learners had very little understanding of the mole concept and its calculations based on a chemical reaction.

> Question 2: You were first given a pre-test on stoichiometric calculations, how did the understanding that you had in Grade 10 about the moles help you in answering the pre-test?

For the question above, the themes stated below were generated from the learner responses.

- Forgetting

The following are responses that gave rise to the theme of forgetting.

> *CGL1: I remembered a few things in grade10, so that helped.*
>
> *EGL32: Well ... not as well, not as good as I didn't remember most of the things, so it didn't help me as well in the pre-test. Yeah*
>
> *EGL3: Okay mam, I don't think I remembered that well, the work and all that. So, I had to go back and start from over. But think from grade 10 it was the basics it helped a little bit.*

- Balancing equations

In response to the question asking how learners' understanding in Grade 10 helped them to answer the pre-test, the theme of balancing equations was identified, as learners emphasized balancing equations as a concept that helped them to answer the pre-test. It was evident from the pre-test response analysis that many learners could, to some extent, balance equations. A related response from a learner is given below.

> *EGL10: The only thing that I could do in the pre-test was balancing the equation. So, it did not help at all.*

- Calculate moles

Calculate moles is a theme that was identified from learners' statements that they could recall information about moles in the pre-test. Examples of their responses are given below.

> *EGL31: I could remember only that there are moles and formula to calculate moles.*
>
> *CG16: I could calculate only the calculation on number of moles.*

- Learning method

The theme of learning method was identified from the response of a learner who expressed concern about the way they learn, as it did not help them to recall concepts later. The response of the learner is given below.

> *EGL11: It made me realise that we don't know much about stoichiometry and that we need to focus on it and learn every day and then we should change the way that we learn it because we can't recall it on how we did it in Grade 10.*

The above themes and responses could be interpreted to mean that the majority of learners failed to apply their learning about stochiometric chemistry, acquired in Grade 10, in the pre-test. A common reason given was that they had forgotten much of what they had learnt. Some of them could remember only how to calculate the number of moles by substituting into the formula. Another learner responded that they could only balance the equation. From the responses of the learners, it was understood that the majority of learners could not remember or apply the concepts that they had learned in stoichiometric chemistry in Grade 10. I interpret the response of the learner about the way of learning, for example, using algorithms for calculations and memorisation, that this approach will not help to conceptualise concepts. Conceptualising is necessary to apply a concept in a new situation (see 2.10.2.6).

> Question 3: You have gone through a series of lessons with your teacher. What is your understanding about the term stoichiometric chemistry?

The following themes were generated from the responses.

- Calculation of moles

A similar question was included in the questionnaire, and in the interview the learners gave a better explanation of their conceptual understanding of stoichiometric chemistry. For some of the learners, stoichiometric chemistry required calculations to determine moles, mass, limiting reagents, concentration, percentage purity and so on. During the lessons, the learners in both groups were exposed to activities related to calculation of moles of certain reactants or products, or mass or volume of the substances involved in the chemical reaction, or to determine the limiting reagent. Hence, the learners responded that the topic of stoichiometric chemistry involves calculation of moles and limiting reagent. Examples of responses that provided the theme are given below.

> *CGL16: Calculating the number of moles and to identify the mass used, identifying the limiting reagent.*
>
> *EGL10: Calculate the moles, use them to calculate mass or volume at STP, find concentration, percentage purity. I know how to do calculations concerning stoichiometry other than just balancing the equation.*

- Calculations with ratios

The above theme was identified specifically from the responses of the experimental group. Examples of responses are given below.

> *EGL7: We are learning about number of moles and then also calculating the quantitative composition of a given chemical substance and then breaking down into a ratio and comparing the answer that you got, stoichiometric chemistry is basically the ratio in a balanced equation.*

> *EGL3: Understand that it is calculating this one substance from the reaction that you will need to find out and why the outcome of the reaction is that. Stoichiometry means finding the mass or moles of a substance using the ratio.*

The responses show that, in addition to calculating moles, the learners understood that there are certain ratios in which substances react and form products. The response that the ratios from the balanced equations represent stoichiometry, and that these ratios are used in calculations, shows that the learners in the experimental group had a better understanding of stoichiometric chemistry than the control group. Hence, it could be interpreted that, even though both groups improved in performance, the experimental group improved in their conceptualisation of the concepts to a greater extent than the control group.

> Question 4: You know that this topic deals with chemical reactions. What is the need of balancing chemical equations before attempting a calculation?

During the lessons, learners were taught that reactions take place according to a ratio that relates to the coefficients in the balanced equation. They were taught to use the ratios in the balanced equations to calculate the moles of reactants used and products formed. Therefore, if the equation were not balanced, their calculations would be affected. Hence, learners need to conceptualise the importance of balanced equations. The following themes were identified from the responses of the learners.

- Misinformation

Misinformation was identified as a theme from the responses of a few of the learners, who reported that they lacked understanding of the need for balanced equations. The following are the responses that illustrate this theme.

> *CGL1: You need it to calculate the moles, quantity, balanced equation makes sure that both sides are equal.*
>
> *CGL20: Eehhm because the one side you see there is a law that says that I don't know that it has to be equal, I feel that the number of moles or something has to be equal, so they have to be equal eh yes.*
>
> *CG L15: Balancing chemical equations you need to ... see ... how do I put this? When you balance an equation, you need to see the number of moles to calculate let's say the limiting reagent, something to see which reactant is used up and yeah.*

The misinformation in the examples was provided by learners in the control group. Their responses show that the learners did not possess the necessary understanding of the importance of using balanced equations for stoichiometric calculations, which shows poor conceptualisation of the concept.

- To calculate moles

The theme, to calculate moles, was identified from responses in which learners showed a vague understanding of the need to balance equations. The responses given below are examples that led to the generation of this theme.

> *CGL1: You need it to calculate the moles, quantity, balanced equation makes sure that both sides are equal.*
>
> *CGL16: To calculate the number of moles.*

It is possible that the incomplete explanations are due to a lack of understanding of learners in the control group. They were taught that, to calculate the number of moles of reactant used or product formed, the ratio in which reactants react and products form, obtained from the coefficients in the balanced equation, is needed. However, the learners did not conceptualise the concept and responded that balanced equations are needed for calculating moles. Hence, it can be interpreted that, even though the learners knew how to balance an equation, they failed to conceptualise how the balanced equations help in further calculations.

- To use ratio for calculations

The following responses generated the theme, to use ratio for calculations.

> *EGL31: I need to balance the equation for calculations. I will need the ratio for calculations. Hhmm yeah*
>
> *EGL7: You can get an accurate amount; you break it down to a ratio to know the amount in the substance. We get the ratios in the reactants react and products from the coefficients in the balanced equation.*
>
> *EGL10: So that you can get the correct ratio, if your mole ratio is wrong, the number of moles formed calculated becomes wrong. All your answers calculated automatically becomes wrong.*

It was noticeable from the responses in the interviews that more learners in the experimental group than in the control group understood that balanced equations are important, as they provide the ratios for performing accurate calculations. A few of them responded that coefficients in the balanced equations are the ratios in which reactants react and products form. If the coefficient is wrong, the calculations of the amount of product formed and reactant used will also be wrong. The above response can be connected to the lesson observation. During the lessons, it was observed that the experimental group was taught balancing of equations and further calculations through games with simulation, and further calculations making use of the example of sandwiches, and other simulations with molecules of reactants and products formed. The learners were observed to be actively engaged in the activities with these simulations for calculations with balanced equations (see 5.3.2.1). However, in the control group, the lessons focused mainly on certain steps for calculations (see 5.3.2.1). Therefore, connecting the observation with the interview responses it could be interpreted that more learners in the experimental group gave correct responses about the need to balance equations as conceptualisation took place, than learners in the control group.

> Question 5: Your teacher might have introduced you with a new term ‘limiting reagent’ in the lesson. How important is identifying the limiting reagent in a chemical reaction?

Question 5 was asked to determine whether conceptualisation took place in relation to limiting reagent. Identifying the limiting reagent when there is more than one reactant in a reaction is important for further calculations. The ratio between the moles of limiting reagent and the product is used to determine the amount of product that is formed. The amount of another reagent used also depends on the limiting reagent. Once the limiting reactant is used up, the reaction stops. Therefore, conceptualisation of the limiting reagent is important for complex stoichiometric calculations.

- Uncertainty

The responses given below are examples from the interviews that led to the generation of the theme of uncertainty.

> *CGL1: It would be the one that is used up first so for calculating concentration you would use it as volume, amount or like the substance that you would use as the chemical formula for calculation.*
>
> *CGL16: To know which chemical or substance is going to be used up first. I cannot answer it, I am not sure, I think it is how much at the end you gonna get for the reaction. We have been calculating number of moles for substances and then the lowest one will be your limiting reagent. Then you know that when you calculate the mass, that reaction, that chemical is going to be used up first, so you need to know if it is sufficient or correct for the reaction, yeah.*

The above theme was identified from certain responses of the learners, in which they expressed that they had a vague understanding of what a limiting reagent is.

The learners could only respond that limiting reagent is needed to determine which substance finishes first in the reaction, though they could not explain further. From the responses I understand that more learners in the control group failed to conceptualise the importance of identifying the limiting reagent.

- Calculation of products

The following responses suggest that learners understood that limiting reagent determines the completion of a reaction and the amount of product formed.

> *CGL7: Once you know the limiting reactant you know how much of the other reactant was needed for the products to form. So you need to know which one was used so that you can find the moles of the reactant to work out the moles of the other one to find like the overall.*

> *EGL7: You need the limiting reagent to see if there is any excess of the reactants and how much of the products can be formed. The limiting reagent decides on how much of the product will be formed.*

It was also noticeable that more learners in the experimental group than in the control group could explain the importance of limiting reagent in a reaction (see Appendix G). Hence, it can be interpreted that the experimental group had a better understanding than the control group of the importance of identifying the limiting reagent. This shows that more learners in the experimental group had improved their conceptualisation of the concept of limiting reagents.

> Question 6: Is there any specific steps that you will use to determine the limiting reagent in a chemical reaction?

As determining the limiting reagent is important in complex stoichiometric calculations, learners need to conceptualise how to determine the limiting regent. The following themes were generated from the responses.

- Misconception

It was discussed in the literature review (see 2.10.2.1) that many learners understand that, when there is more than one reactant for a chemical reaction, the reactant with the lowest moles will be the limiting reagent. This is not necessarily true in all cases. This belief arises from a misunderstanding of the definition of limiting reagent, which is the reactant that is used up first. As a result, learners may think that the limiting reagent finishes first, as it is available in the lowest number of moles. The learners in the control group gave responses that led to the theme of misconception.

> *CGL16: You find the moles of the reactants, and the one with the lowest will be the limiting reagent.*
>
> *CGL20: You calculate the number of moles of each compound and see which one has the lowest and the lowest is your limiting reagent.*

The responses above show that there was poor conceptualisation of the concept. The test response analysis of the post-test found that more learners in the experimental group than in the control group attempted to determine the limiting reagent with the mole ratio. More learners in the control group calculated the moles of the reactants and identified the one with the smallest mole as the limiting reagent.

- Calculate the moles

This theme also was generated from the previous responses (ICGL16 and ICGL20). The calculation of moles is important for determining limiting reagent with further mole ratio calculations. However, the learners could not explain further, due to a lack of understanding.

- Mole ratio

Learners had already responded to a previous question that the coefficients in the balanced equations are the ratios in which reagents react and products form and are, hence, used to determine the limiting reagent, amount of product formed, and amount of excess reagent used. This understanding helped them to respond correctly in relation to determining the limiting reagent. The following are examples of learners’ responses.

> *CGL7: Yes mam, you first calculate the number of moles of each reactant and you see the ratio in which the reactants make with one another and you apply the ratio to see if there is ... OK then you see how many moles there for each are and the one with the least moles will be the limiting reactant.*

The learner CGL7 started off with a good explanation, but ended up saying that the one with the least moles will be the limiting reagent.

> *CG L14: Ahh yes, what I normally do is ... I do the mole ratio of one substance and then I calculate the moles and then I compare with the number of moles that I was given to the number of moles I calculated and if I see that it is smaller then I know that it is the limiting reagent because it was all used up.*

Though the learner ICGL14 knew that there were calculations with mole ratio, the learner could not give a clear explanation of how to determine the limiting reagent. Learners in the experimental group were able to provide better explanations regarding the use of mole ratio to determine the limiting reagent. Some of their responses are given below.

> *EGL10: Start by balancing your equation, then you use the mole ratio to find the number of moles of each reactant using the mass and molar mass. The you compare the ratio and from that you can see the one that is finishing first and the other is the limiting reagent and which one is in excess can be got.*

> *EGL11: I need to first get the ratios from the balanced equation, see the number of moles of one and see how much of the other will be needed from the ratio.*

Question 7: How confident are you in answering questions based on stoichiometric chemistry?

- Improvement in confidence

In the interviews, the majority of learners responded that their confidence level regarding stoichiometric calculations had improved. However, two learners responded they were not particularly confident in stoichiometric chemistry, compared to the other topics in chemistry; they suggested that more practises could help them to improve. The following are the responses that relate the above theme.

> *CGL14: I am definitely more confident because I know more, I know how to do and I know how to attack the problem.*
>
> *EG L3: Compared to then, okay I am a bit confident because I understood more when to do what in a calculation.*
>
> *CGL20: To be honest I am not that confident. Compared to other topics in chemistry, I am not that confident.*
>
> *EG L7: Not much ... but if I can get more practise, I can be better in the calculation.*

- Method of learning

The theme, method of learning, was identified from learners' comments that they enjoyed doing calculations in stoichiometric chemistry when using simulation for learning, and that this method of teaching increased their confidence levels.

> *EGL11: My confidence level has increased because of the process of the lessons because we understood how the reaction happens through the simulation. It's just that I need more practise to increase the skill.*
>
> *EGL31: I think I am more confident now after the classes.*

The above responses reveals a positive attitude that evolved through learning stoichiometric chemistry during the intervention. The influence of the teaching methods for effective learning was discussed in chapter 2 (see 2.7.1).

> Question 8: How did the teacher's method of teaching help in your conceptualisation of stoichiometric chemistry?

The next question in the interview was asked to determine the effect of the method of teaching on conceptualisation of stoichiometric chemistry.

- Application of steps

This theme was generated from responses of learners in the control group. In their lessons, the teacher focused on explaining how to do the calculations using particular steps. A few of the learners responded that the steps the teacher explained helped them to improve their understanding. An example of a response is given below.

> *CGL14: The teacher showed us the steps to approach while doing the calculations, so it was easier to understand.*

However, the responses by other learners in the control group contradicted ICGL14's response. They stated that the method suggested by the lessons did not help them. One of the learners said that watching YouTube videos helped them to understand than the lessons better – this shows the importance of visualising a concept for better understanding. The response is given below.

> *CGL20: To be honest, the class that I am in ... I feel like it did give me a concept but didn't really help to understand. But rely a lot on YouTube videos to help me understand, the reason why I have the knowledge I have is because of the YouTube videos that I watched and yes, I also had a few extra lessons, because I did not understand stoichiometry at all.*

From the responses of the learners, it can be understood that the teaching method for the control group focused on applying general algorithmic methods for stoichiometric calculations. Some learners responded that the “steps that was taught” helped, while other learners were not satisfied with just with following steps.

By comparing the post-test response analysis carried out for these learners it became clear that learners just followed certain steps (see 5.4.4.3). As a result, learners could not apply the algorithmic steps into new questions based on calculations in a chemical reaction.

- Visualising using simulations

The above theme arose from responses by learners in the experimental group. The presentation of lessons using simulations and how simulation can improve learning chemistry were discussed in Chapter 3 (see 3.9.3). From the responses of learners, it was understood that the visual presentations in the simulations gave learners a better understanding of balancing equations, helped them to find limiting reagents, and understand how the limiting reagents affect the products. The following example relates to this theme.

> *EGL10: It gave me a visual understanding of what actually happens during a chemical reaction and how the limiting reagents affects the products that you get. I remember the bread and sandwiches in place of reactions.*

The lesson observation analysis suggested that using simulation allowed the learners to learn by being actively involved in the activities presented as games; thereby they constructed their own knowledge (see 5.3.2.6).

- Sandwich simulation

Some of the learners in the experimental group responded by emphasizing how the simulation using the example of building sandwiches helped them to understand the concepts better. The following are examples of their responses.

> *EGL7: I enjoyed working on how to balance equations and finding the limiting reactants with simulations, sandwiches.*
>
> *EGL10: It gave me a visual understanding of what actually happens during a chemical reaction and how the limiting reagents affects the products that you get. I remember the bread and sandwiches in place of reactions.*
>
> Question 9: How did the lessons you attended help in answering the post-test?

The following themes were identified from the responses of the learners.

- Improved understanding

The theme of improved understanding is related to responses by the learners in both groups. They all responded that they found the post-test much easier after the lessons. Examples of responses are given below.

> *CGL16: It helped me to answer the post-test better.*
>
> *EGL31: It helped me to perform better.*

- Simulated lessons

In response to the same question, other learners in the experimental group responded that learning with simulations helped them to remember what they saw during the lessons and, hence, it made answering the post-test easier. Learners in the experimental group responded that the visual representations in the simulations helped them to remember and understand the concepts better, which helped them to perform better in the post-test. The examples of responses are given below.

> *EG L10: Thinking back in the simulation helped me to remember that I need to first find the limiting reagent and how it will affect your product and the agent in excess and it also helped me to balance the equation before I do the calculation.*

> *EGL3: We could understand how and see the reactions in a different way it helped one to understand better and answer the post-test better*

Question 10: According to your understanding about stoichiometric chemistry calculations, can you give some basic steps that can be followed in doing calculations with chemical reactions?

- Use of formula

The response of a learner from which the above theme was generated is given below.

> *CGL20: I am not sure, but I know I use some formula and do calculations.*

The above response shows that the learner could only recall that a certain formula was used in performing stoichiometric calculations.

The following theme was also generated from the learners' responses, of which examples are given below.

- Calculation of moles

> *CGL16: You first calculate the moles of each substance and then convert it into other quantities.*
>
> *CGL15: In doing a stoichiometric chemistry calculation I would first calculate the moles by using the n = m/M and then I would use, sometimes they ask ... let's say for the concentration, you use one of the two formulae c = n/v or c = m/MV and then calculate the concentration.*
>
> *CGL14: OK, let's say they give you the mass, and the question is to calculate the moles, you are already given the periodic table, so you calculate the moles, and then you gonna balance the equation and use*

> *the mole ratio and from there you calculate the … you have your moles and there you can calculate the mass of the substance.*
>
> *EGL32: I will find the moles and then use the formulae to find what is asked. Yeah, I will use the mole ratio from the balanced equation.*

Even though CGL14 mentioned the use of mole ratio, the learner could not explain how the mole ratio would be used. More emphasise was given to calculation of moles. From the responses it can be observed that the above learners showed factual knowledge that calculating moles was what is needed to perform any calculations and, hence, to explain how to perform stoichiometric calculations, they just responded by referring to calculation of moles (see 2.6.1.4).

The following themes were generated from the responses of other learners.

- Comparison of ratio

> *CGL7: I will calculate the moles, see the equation if it is balanced, then I always do the moles because that's the basic, then you can use the ratio and see of the other reactant and its moles.*
>
> *EGL7: I will use the balanced equation and use the mole ratio to find how much of the other substance is used and also find the products.*

It could be understood from the response of CGL7 that the learner knew that mole ratio was needed for the stoichiometric calculation to find the other reactant, but the learner could not give a proper explanation. The experimental group learner could provide a better explanation for the order of, first, balancing the equation and then using the mole ratio to find how much of the other substance is used, and also to find products. This showed that the learner EGL7 had a better understanding of procedural knowledge than the control group learner.

- Limiting reagent and leftovers

> *EGL31: First you must calculate moles from mass, then use ratio and find the products. Also find limiting reagent and leftovers with ratio and moles*

From the response given above it can be understood that the experimental group learner had the procedural knowledge of using mole ratio to find the products, though she mentioned finding the limiting reagent and leftovers in relation to the procedure for performing calculations. It can be understood that the simulations used for lessons had a section of reactants, products and leftovers and this could have helped the learner to remember the calculation of limiting reagent and leftovers to explaining the procedure for calculations.

- Conceptualisation of method

The responses given below are examples that led to the generation of the theme given above.

> *EG L10: We use the ratio compare the ratio of the limiting reactant to the ratio of the product and then calculate the moles of the product.*
>
> *EG L11: As I said it is the ratios first getting the number of moles, Balance the equation first and then take the ratio and find the number of moles of the one after that compared to the other and you divide and see how much is there?*

It can be observed that the learners in the control group were not clear on the application of the mole ratio, even though they mentioned it, which shows that they did not conceptualise the method for performing calculations. The learner CGL7 showed some understanding, but could not provide clear explanations. The above responses create the impression that more learners in the experimental group than in the control group understood that the ratios in the balanced equation are important for finding the reactant used and product formed other than only using formulae of moles for calculations. More learners in the experimental group could explain the use of the mole ratio and how to proceed with calculations, which shows that they had a better conceptualisation stoichiometric chemistry. It can be understood that the learners in the experimental group could explain their understanding better, due to the metacognitive skills gained during the lessons, which they acquired by making use of the simulations and engaging in discussions with each other and the teacher (see 2.6.2.7).

5.7 INTERPRETATION OF THE QUALITATIVE DATA ANALYSIS OF THE QUESTIONNAIRE AND INTERVIEWS

The quantitative data analysis showed that learners in both groups improved their performance from the pre-test to the post-test. It was, furthermore, found that the experimental group performed better than the control group. The qualitative data analysis was conducted to determine if conceptualisation of stoichiometric chemistry had occurred in addition to the improvement in learners' performance.

From the data analysis of the questionnaire, it can be interpreted that some learners in both control and experimental groups, even after the lessons, faced challenges in applying their understanding of stoichiometric chemistry. The responses showed that deep learning did not take place (see 2.6.2.6). The learners only gained factual knowledge to solve stoichiometric calculations (see 2.6.1.4), as they could not provide clear explanations for questions, such as the importance of finding the limiting reagent in order to proceed with a calculation (see 5.5.2.2, response to question 1.3).

However, the data analysis of the responses given in the interviews suggests that the lessons of the experimental group resulted in an improvement in the learners' conceptualisation of stoichiometric chemistry (see 5.6, question 10 themes, responses and discussion). The test response analysis of the post-test implies that, even though the control group's performance improved, greater conceptualisation of stoichiometric chemistry took place for the experimental group than for the control group (see 5.4.4.3). This is evident from the responses in the post-test of the experimental group, where more learners used ratios in balanced equations for further calculation better than the control group.

In response to questions about the teaching method, more learners in the experimental group than in the control group said that using simulations helped them to visualise the balancing of equations and to do calculations based on amount of reactants, products, limiting reagents and leftovers (see 5.5.2.2 question 1.6 and 5.6 questions 7 & 8). Therefore, it can be interpreted that the activities in the simulations, which involved visual representations in the form of games, helped learners to construct their own knowledge (see 3.9.4.1). The test response analysis of the pre-test showed that learners had misconceptions about the limiting reagent – they believed it was the reactant available with the lowest moles. It was observed in the post-test response analysis that learners in the experimental group had experienced a conceptual change in relation to the limiting reagent (see 2.6.2.2 & 5.4.4.3). This was evident in responses to the questionnaire and in the interviews (see 5.5.2.2, question 1.3 & 5.6, question 5). Conceptual and procedural knowledge about the importance of balancing equations, limiting reagents and its calculations helped the experimental group learners to explain how the calculation to determine the limiting reagent could be performed, and how they could apply it in calculations – they were better than the control group learners at explaining this (see 2.6.1.4, 5.4.4.3, 5.5.2.2 & 5.6). It was evident from the responses of the control group that these learners still had this misconception (see 5.5.2.2 & 5.6).

In relation to the question in the interview asking learners to explain how a stoichiometric calculation could be performed (see 5.6, question 10), experimental group learners' responses could be interpreted as that they had gained procedural knowledge and could apply problem-solving skills, which means that conceptualisation had improved (see 2.6.1.4 and 2.10.2.3). According to activity theory, activities and learning are interactive and interdependent. The active participation of learners in simulations brought changes in the conceptual understanding of the experimental group learners (see 3.4). While executing the activities for calculations with limiting reagents in the simulation, the learners observing the microscopic representations could predict the amount of products and leftovers. Afterwards, they checked whether their answers were correct. This helped to them to observe and evaluate their answers, leading to conclusions. This way of doing inquiry-based teaching could have helped the learners to construct their own learning (see 2.6.1.4). It was discussed in Chapter 3 (see 3.9.1) that using simulation to teach promoted inquiry-based teaching. It was suggested that classroom discussion with computer simulation guided learners to engage in learning through the different stages of inquiry learning. Therefore, it can be interpreted that development of stoichiometric chemistry concepts took place through active participation and interaction of learners with each other and with the teacher during simulation activities. As a result, the desired outcome, which is the conceptualisation of stoichiometric chemistry, improved for the experimental group.

5.7 SUMMARY

In this chapter, the data analysis of the pre-test and post-test, together with the observation of lessons, questionnaire, and interviews, as well as the interpretation of the analysis, were discussed. During the lesson presentation, it had been observed that, in the control group, the teacher explained the concepts by emphasizing certain steps that learners could follow for problem-solving in stoichiometric chemistry (see 5.3.2). These lessons were observed to be more teacher-centred, and the learners mostly followed certain steps, as instructed by their teacher. The teacher-centred lesson was discussed in Chapter 2 (see 2.6.1.2). In turn, in the experimental group, the presentation of the lessons with PhET simulations helped the learners to be actively involved in activities in the form of games under the framework of activity theory. The visual molecular representations and the examples of reactions helped the learners visualise the chemical reactions and helped them to understand the topic better than only following certain steps for problem-solving could achieve.The visual representation in the simulations as the tool helped the subject in the study which were the learners in the experimental group to actively construct knowledge. This led in achieving the outcome which was improvement in the conceptualisation of stoichiometric chemistry.

ANOVA results of the pre-test showed that the learners in the two group were comparable in terms of stoichiometric chemistry knowledge before the lessons (see 5.4. 1). Frequency polygons (5.4.2.2) and normal distribution curves for both control and experimental groups (5.4.3.1) were presented. Paired t-tests (see 5.4.3.2) showed that there were significant differences between the means of the pre-test and post-test for both groups. The ANCOVA results showed that there were statistically significant differences between the mean post-test scores for learners in the control group and experimental group (see 5.4.3.3). The analysis of effect size showed that the intervention had a medium effect, and that the statistically significant difference between the mean post-test score of the experimental group and control group was meaningful (see 5.4.3.4). Therefore, the quantitative analysis shows that there was a greater improvement in the performance of the experimental group than in the control group.

The test response analysis of the pre-test and post-test, performed on the answer scripts of the 12 learners, also showed that the learners had improved their performance, as well as their conceptualisation of the topic. The test analysis helped to understand how the learners responded to each question in the post-test after the lessons. From the responses it could be interpreted that the experimental group had a greater improvement in conceptualisation than the control group.

The thematic analysis of the questionnaire shows that the lessons presented to both control and experimental groups lead to an improvement in the learners' performance in and understanding of stoichiometric chemistry. However, the analysis shows that the experimental group had a better understanding than the control group, which lead to better conceptualisation of the topic by the former group (see 5.5.2.2). From the analysis of the quantitative section of the questionnaire, it can be interpreted that more learners in the experimental group than in the control group had improved their understanding of stoichiometric chemistry (see 5.5.3) after the lessons. The teaching method that used simulation had an effect on the conceptualisation of the experimental group. The analysis of the interviews supports the interpretation that experimental group learners improved their conceptualisation of stoichiometric chemistry to a greater extent than control group learners (see 5.6). In the interviews, the learners in the experimental group could elaborate their explanations about the conceptualisation of stoichiometric chemistry and the effect of the teaching methods used better than the control group.

Hence, the following summarises the analysis of the data collected.

The quantitative analysis shows that using computer simulation for the intervention produced a greater improvement in performance than the lecture method. The test response analysis helped to understand how the learners responded to each question in the post-test after the lessons. From the responses it can be interpreted that the experimental group had a greater improvement in conceptualisation than the control group. The responses of the experimental group on the questionnaire also shows that the learners in the experimental group could provide better explanations for each question than those in the control group could. In the interviews, the learners in the experimental group could elaborate on their explanations about the conceptualisation of stoichiometric chemistry and the effect of the teaching methods used, to a greater extent than the control group.

In Chapter 6, a discussion of the findings of the study, triangulation of the quantitative and qualitative data, the conclusion, recommendations from the findings and limitations of the study will be discussed.

CHAPTER 6:

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.1. INTRODUCTION

The aim of the study was to determine the effect of computer simulation on Grade 11 learners’ conceptualisation of stoichiometric chemistry. The first chapter provided an overview of the desire to improve learners’ conceptualisation of stoichiometric chemistry. The second chapter is a literature study of the value and importance of teaching and learning chemistry in the South African context. The influence of integrating computer simulation in the teaching of chemistry was investigated through a literature review in the third chapter. The fourth chapter explored the methodology for conducting the empirical research, and the data collection and data analysis procedures were explored. In the fifth chapter, the data analysis was done and interpretations from the analysis were discussed.

The current chapter will focus on the findings, conclusions and recommendations of the study. The findings about the value and importance of teaching and learning chemistry in the South African context and the influence computer simulations have on learning when integrated with teaching of chemistry will be discussed in this chapter. The findings of the empirical study on how effective the use of computer simulations are for the teaching of stoichiometric chemistry concepts will be explained later in this chapter. Finally, recommendations based on the interpretations of the findings regarding the effect of computer simulations on the teaching and learning of stoichiometric chemistry in the FET phase at school will be presented.

6.2. FINDINGS AND CONCLUSIONS

The primary research question to be answered in this research is:

> What is effect of computer simulation on Grade 11 learners' conceptualisation of stoichiometric chemistry?

To find an answer to the primary research question, the following secondary research questions guided the study.

1) What are the value and importance of teaching and learning chemistry in the South African context?
2) What influence does computer simulation have on learning when it is integrated with the teaching of chemistry?
3) How effective is the use of computer simulation in the teaching of stoichiometric chemistry concepts?
4) What recommendations can be made regarding the effect of computer simulation on the teaching and learning of stoichiometric chemistry for improving its conceptualisation in the Further Education and Training (FET) phase at schools?

The first two secondary research questions were answered through a non-empirical study. A literature review was conducted to understand the value and importance of teaching and learning chemistry in the South African context. Another literature review, to understand the influence that computer simulation could have on learning when integrated with the teaching of chemistry, was conducted. To determine the effect of using computer simulation in the teaching of stoichiometric concepts, an empirical study was conducted. It involved determining whether performance and conceptualisation improved when computer simulations were used to teach stoichiometric chemistry.

Findings of the empirical research provided the answer to the primary research question, and recommendations regarding the effect of computer simulation on the teaching and learning of stoichiometric chemistry in the FET phase at school.

6.2.1 Findings of the non-empirical research

The findings of the non-empirical research will be discussed in this section.

6.2.1.1 Value and importance of the teaching and learning of chemistry in the South African context

The most important findings that helped to determine the value and importance of learning chemistry will be discussed in this section.

6.2.1.1.1 The importance of knowing the nature of science

To understand the value and importance of teaching and learning chemistry, the nature and structure of science were investigated first (see 2.2). When learning science, learners need to learn different scientific concepts, including laws, theories, definitions and explanations of certain terms and facts, and the application of the laws and theories in problem-solving. It is understood that the nature of science conveys the empirical nature of scientific knowledge – learners and students study the various concepts that are based on empirical evidence and verified by scientists, as well the processes involved.

There could be conflicting evidence in science, and learners and students can be confused. However, scientific reasoning skills that are developed by the nature of science help learners and students to interpret and evaluate the conflicting evidence and help them to acquire scientific knowledge through conceptual change. The interrelation of scientific concepts can be understood through the nature and structure of science. According to its nature, learning science enables a person to acknowledge that people may have different perspectives on the way they look at nature. Scientific knowledge, which is tentative in nature, is based on evidence from investigations, observations and interpretations. The nature of science teaches that empirical evidence is the fruit of hard work by different people around the world, and their findings need to be appreciated.

From the study it can be understood that a science teacher needs to teach science by looking through the lens of the nature and structure of science, and connecting the concepts and processes accordingly, to achieve conceptualisation. Learning science through the nature of science also helps one to understand and appreciate the contributions science has made and how it has affected our lives. Doing so would enable science teachers to create scientifically literate citizens who can contribute to the wellbeing of their own societies and countries (see 2.3).

6.2.1.1.2 Importance of learning chemistry in the South African context

Chemistry is a sub-discipline of physical sciences in South African schools. The literature study helped me to understand the aim of having physical sciences as a discipline, and chemistry as a sub-discipline at schools, and how it helps in the overall development of the learner. The aim of including physical sciences, which consists of theory and practical lessons, as a discipline is to equip learners with knowledge and understanding of how the physical environment around them works, and to acquire the skills needed to investigate physical and chemical phenomena. Doing so will create scientifically literate people who are aware of and responsible for their environment (see 2.4). The different concepts and principles learned in physics and chemistry leads citizens to discharge their roles in their society responsibly. Moreover, it prepares learners for their future learning, employment and holistic development. Learning physical sciences and performing well also contributes to increasing the number of scientists, engineers, doctors and other skilled people in a country, which, in turn, can promote the development of society and a country’s sustained development (see 2.5.2).

The investigation into the teaching and learning of chemistry led to the following findings. There is acknowledgment of the negative impact of the processes of chemical industries on air, water bodies and land and, therefore, learning chemistry in the South African context has advantages. As a developing country, South Africa will benefit by having students and learners who learn chemistry at the tertiary level. Through the study of chemistry, people understand how to reuse, recycle, reduce and replace. This helps to conserve the natural resources of a country, creates a healthier environment by reducing pollution, and reduces the expense of large-scale production of certain materials. Learning chemistry also promotes economic growth of a country by providing employment opportunities. Another important benefit of learning chemistry relates to its role in the development of the mining and agricultural industries, which are a major economic activity in South Africa (see 2.9.1).

The above findings from the literature study helped me to understand the value and importance of learning physical sciences and, specifically, chemistry at schools and at tertiary level in South Africa.

6.2.1.1.3 Teaching and learning chemistry and stoichiometric chemistry

To apply the value and importance of learning chemistry to everyday life, learners need to conceptualise the different topics in chemistry. Research shows that studying chemistry plays a major role in the development of a country such as South Africa. Learners' poor performance in physical sciences and the negative impact it has on producing skilled professionals in the various fields related to chemistry were reported in Section 2.7.

Stoichiometric chemistry is a topic that causes difficulties for learners, which affects their conceptualisation and further learning of chemistry (see 2.9.2). Hence, the teaching and learning of chemistry and stoichiometric chemistry was the focus topic of the study.

In teaching physical sciences, it is teachers' responsibility to make sure that effective learning takes place, which results not only in good performance, but, most importantly, conceptualisation. By making use of an executive, a facilitator or a liberationist approach, the teacher teaches a topic in either a teacher-centred or learner-centred way. From the literature review, the teacher-centred method was found to be advantageous for the teacher; however, for effective learning to take place, the learner-centred method is important. It was also found from the literature review that a teacher can combine a teacher-centred method with a learner-centred method, mainly through strategies such as demonstration, questioning during demonstrations, and direct teaching, deductive and inductive reasoning, problem–solving and inquiry-based teaching (see 2.6.1). Doing so will help the teacher to have control over the learning process, while the learners learn by constructing their own knowledge by gaining factual knowledge, conceptual knowledge and procedural knowledge.

From an investigation into the poor performance of learners in physical sciences and, more specifically, chemistry, teachers and their teaching methods, lack of resources, such as textbooks and laboratory equipment, and the language of teaching and learning were found to be reasons for poor performance (see 2.7). Taking these reasons as contextual factors affecting the effective learning of chemistry, I realised that steps needed to be taken to change the situation. Furthermore, abstract concepts in chemistry make learning difficult and the subject less attractive. To achieve conceptualisation of the various concepts in chemistry, and specifically stoichiometric chemistry, learning must take place at the macroscopic, molecular and symbolic levels, which is not happening in South Africa, due to the various reasons mentioned above (see 2.9.2). For studying the section on chemical change in chemistry, stoichiometric chemistry plays an important role. If stoichiometric chemistry is not conceptualised, a learner will not be able to apply its concepts in other topics in chemistry.

The mole concept is the foundation of learning stoichiometric chemistry; learners need to use the mole concept and its applications for problem-solving for chemical reactions. Therefore, balancing a chemical reaction equation, conceptualising the importance of balanced equations, determining the limiting reagents and using the limiting reagent to find the amount of the other reactant used or product(s) formed, are important for problem-solving in the topic of stochiometric chemistry (see 2.10). Further study into the reasons for learners’ poor conceptualisation of stoichiometric chemistry brought to light that learners have misconceptions about terms such as molecule, atom, elements, compounds, moles, molar mass and molar volume. Other misconceptions relate to constructing balanced equations, applying the coefficients in balanced equations as mole ratios for a reaction, determining limiting reagent, and their application in complex calculations. Due to these misconceptions, few learners are able to successfully solve application questions in other topics, such as acids and bases, rate of reaction and chemical equilibrium. In most cases, learners use algorithmic methods to solve simple and basic stoichiometric calculations that require them to apply the formula linking moles with other quantities to do calculations based on a single substance. When learners have to do complex stoichiometric calculations based on chemical reactions, using algorithmic methods are not particularly useful (see 2.10.2.2).

To rectify the misconceptions and to conceptualise stoichiometric chemistry, I determined that the teaching of stoichiometric chemistry played an important role. Misconceptions regarding the different terms need to be rectified by clear explanations of each term. Learners need to get a good foundation on balancing equations and using mole ratios in the balanced equations for calculations involving excess and limiting reagents for successful problem-solving. I found that teachers should avoid suggesting that learners use algorithmic methods to solve stoichiometric chemistry problems and should use a learner-friendly pedagogical approach to enhance the conceptualisation of stoichiometric chemistry instead (see 2.10.2.2).

From the above findings, the objective of understanding the value and importance of teaching and learning chemistry in the South African context was achieved. This achievement led to the literature study about the influence of computer simulation as a pedagogical approach in teaching for learning with conceptualisation and its integration in the teaching of chemistry. The findings of the study will be discussed in the following section.

6.2.1.2 The influence of computer simulation in learning when it is integrated with the teaching of chemistry

Advances in technology provide numerous tools that teachers can use for teaching. The literature study into the use of ICT for teaching and learning and integrating computer simulation in teaching produced the following findings.

6.2.1.2.1 Benefits of introducing ICT in education

The literature study done about ICT in education led to the finding that ICT had the potential to provide teachers and learners with exciting and effective opportunities in teaching and learning. The most useful benefit is that teachers can interact with learners through a variety of techniques and strategies from any part of the world, and facilitate learning through ICT integration (see 3.2.2). In 2020, teachers and learners all over the world were forced to institute distance learning due to the Covid-19 pandemic. The advantages of ICT integration in learning became clear during the pandemic. The literature review found that ICT provides instructional resources for teaching and learning. Both teachers and students can use computers as a tool for performing calculations, making and using graphical displays and animations, and learning and teaching through simulation. When ICT is integrated with teaching and learning, it promotes education transformation, resulting in economic and social development of students and development of society and the nation (see 3.2). In earlier years, the most readily available resource for teaching was textbooks, and though many teachers still use this resource, the introduction of ICT in classes has introduced a variety of new resources, such as simulation, video, and slides with images for teaching and learning.

To make use of the above resources to benefit learners, teachers need to skilfully demonstrate their ability to integrate technology within the constructs of content and pedagogical domains (see 3.3). A teacher with appropriate TPACK can integrate computer technology in teaching, and learners and students can construct their own knowledge by getting involved in activities through interaction. According to activity theory, the teacher teaches a concept by integrating various resources in technology, and engages learners with activities during which they actively participate by interacting with each other (see 3.4).

As a result of the positive impact of ICT in the teaching and learning process, the Action Plan 2019 – Towards Schooling in 2030 recommends integrating ICT in teaching (DBE, 2015b) (also see 3.5). Further literature study led to the finding that

ICT helps students express their knowledge, and examine, exploit and process information relating to abstract concepts.

Despite the advantages of and positive impact that ICT can have on education, it was found that there were several barriers that hindered its integration. A barrier was the time requirements of using ICT in teaching, which are more than for using traditional methods. Other barriers that were found include lack of accessible resources, lack of confidence of teachers due to insufficient training in integrating ICT in teaching, poor fit with the curriculum, technical constraints and lack of support by management and other stakeholders (see 3.7). However, the positive impact proven by ICT in creating authentic, interesting and successful educational activities outweighs the barriers. Hence, schools and tertiary institutions are encouraged to introduce ICT into their classrooms to the best of their abilities (see 3.6).

6.2.1.2.2 Influence of integrating computer simulation to teach chemistry

Advances in computer technology and its positive impact on educational activities brought a variety of tools to enhance learning, and computer simulation is one of them. In the traditional methods of teaching, teachers draw diagrams on the chalkboard, or use the diagrams in a textbook as the medium for teaching. Some of them make use of charts and models for teaching. All these tools provide only a static visualisation of the subject content that is being taught.

The introduction of computer simulations to teach provides a dynamic visualisation of the subject content, with which learners can interact by exploring, manipulating and modifying the parameters of the simulation (see 3.8). In the case of teaching physical sciences and chemistry, the barrier of not having laboratory equipment could be eliminated by using simulation, as it allows learners to view events, processes and activities that are not available in their school contexts.

Using simulations in a classroom with learners of varying learning abilities was found to be beneficial. In a normal classroom situation, teachers just explain the concepts to learners and all learners need not understand the concepts equally. The literature review found that simulation can reduce the cognitive load of learners by breaking the concepts in to simplified versions with instructions. Simulations enhance the learning of all learners, where learners can work at their own pace, some may understand the concept easily and hence they may finish learning before the others (see 3.8.1).

It was found that computer simulations also have disadvantages, such as lack of realism, and that learners do not get hands-on experience of doing experiments, and less exposure to quick thinking in problem-based scenarios (see 3.8.4). However, the advantages of using simulation to enhance learning were found to outweigh the disadvantages. A highlight of simulations is that it supports inquiry-based teaching and conducting experiments when they cannot be done practically.

Researchers found that computer-based science simulations have a greater enhancing effect on conceptualisation in a chemistry course than traditional methods. When simulations were integrated to teach gas behaviour at a sub-microscopic level, positive results in enhancing learning were achieved for balanced equation for chemical reactions, acids and bases, chemical equilibrium and chemical bonding (see 3.9.3). From the above findings, the objective of understanding the influence of integrating computer simulations to teach chemistry was achieved.

The literature review found that using PhET simulations for teaching various concepts in science has a positive impact on the conceptualisation of the various concepts and can enhance the performance of learners. The review reported that PhET simulations have two main simulations, namely, balancing chemical equations and reactants, products and leftovers. These two simulations were explored and the PhET simulations were chosen as a tool to determine the effectiveness of computer simulation in the teaching of stoichiometric concepts.

6.2.2 Conclusions from the non-empirical study

The literature study conducted in the first two chapters led to the findings that were discussed in Sections 6.2.1.1 and 6.2.1.2. It was found that learning chemistry produces professionals in the field of chemistry and is important for the holistic development of an individual, society and the nation. Findings from the study relating to the influence of computer simulations on learning are that, despite of the disadvantages of simulation, simulation helps to enhance learners' conceptualisation of concepts and topics in chemistry.

In South Africa, learners have a poor conceptualisation of stoichiometric chemistry, which has an impact on their conceptualisation of other topics, like acids and bases, reaction rate and chemical equilibrium. This leads to fewer students continuing their learning of chemistry. Therefore, there is a need to improve the conceptualisation of stoichiometric chemistry by science learners (see 1.3). I have been a chemistry teacher for years, and I have experienced that the poor conceptualisation of stoichiometric chemistry is a barrier for learners to excel in chemistry, leading to lower enrolment in studying chemistry further. The non-empirical study provided the background for conducting the empirical study. As integrating computer simulations to teach chemistry was found to have an influence on chemistry learning, the focus of the current study was to determine the effect of computer simulation on the conceptualisation of stoichiometric chemistry, which was done through an empirical study.

The findings of the empirical study that led to the study answering the third secondary research question (see 6.2) will be discussed in the next sections.

6.2.3 Findings of the empirical study

The aim of the study was to determine the effect of computer simulation on Grade 11 learners' conceptualisation of stoichiometric chemistry. The objectives guided the study (see 1.5.2). The first two objectives of the study were achieved through the non-empirical study, which was discussed above (see 6.2.1). The third objective was to determine whether learners who are exposed to computer simulation in the teaching of stoichiometric chemistry conceptualise the concepts better than learners who are not exposed to computer simulation in the teaching of stoichiometric concepts. To achieve the objective, an empirical study on the effect of using computer simulation in teaching stoichiometric chemistry was conducted. The study used a mixed methods approach to collect data through a pre-test post-test experimental design that included the observation of lessons, a questionnaire and interviews.

Two Grade 11 classes were taught physical sciences by two different teachers at the school selected for the study (see 4.6.2). The two classes were randomly assigned as the control group and experimental group. The control group had 30 female learners and the experimental group had 32 female learners. The physical sciences teachers of the respective classes were chosen to teach the learners in each group. The control group was taught stoichiometric chemistry by using a traditional method (lecture method/direct teaching) of teaching at the school. The experimental group was taught by using PhET simulations.

6.2.3.1 Findings of the quantitative data analysis

The findings of the quantitative data analysis of the SCAT 9 pre-test and post-test and the analysis of the Likert scale responses to the questionnaire administered for both groups will be discussed in this section. The analysis was done to determine whether there was any improvement in the performance of learners in stoichiometric chemistry, and also to determine which group showed greater improvement. This investigation provided partial answers to the third secondary research question.

6.2.3.1.1 Findings from the SCAT pre-test post-test results

The quantitative data analysis helped mainly to understand the effect of the lessons on the performance of learners. The findings were made using both descriptive and inferential statistics. While descriptive statistics was used to collect, organise, analyse and present the quantitative data in a meaningful way, inferential statistics was used to compare data and to test hypotheses for making predictions based on the quantitative data (see 5.4.2 & 5.4.3). The findings of the statistical analysis are discussed here.

Firstly, from the ANOVA results, it was found that learners in control and experimental groups were comparable in terms of knowledge of the topic of stoichiometric chemistry, and the null hypothesis that the learners in both groups were not comparable was rejected (see 5.4.1).

From the paired t-test to compare the pre-test and post-test scores of the control group, it was found that the learners in the control group had a significant difference between the two tests – the mean post-test score was higher than the mean pre-test score (see 5.4.3.2.1). The mean distribution graph and the frequency polygon also indicated and supported this finding (see 5.4.2.1 & 5.4.2.2). The graphs indicate that the traditional lecture method that was used to teach stoichiometric concepts improved the performance of the control group.

The paired t-test to compare the pre-test and post-test scores of the experimental group also showed a significant difference between the mean scores of the pre-test and post-test (see 5.4.3.2.2). The mean distribution graph and the frequency polygon of the experimental group also indicated this finding (see 5.4.2.1 & 5.4.2.2). This shows that the use of computer simulation to teach stoichiometric chemistry concepts improved the performance of the experimental group.

The distribution curves of the pre-test and post-test for both control and experimental groups also supported the above findings (see 5.4.3.1).

However, a finding that must be highlighted is that the difference between the mean scores of the pre-test and post-test of the experimental group was much greater than corresponding scores of the control group. The ANCOVA results showed that there is a significant difference between the mean post-test scores for the control and experimental groups. It was also found that the mean post-test score of the experimental group is higher than that of the control group (see 5.4.3.3). The effect size, calculated using Cohen’s *d,* shows a medium effect size (see 5.4.3.4), which shows that the intervention had an effect on performance; hence it was found that the statistical difference found was meaningful.

This shows that the learners performed better when they were taught stoichiometric chemistry concepts using computer simulation, than when they were taught without computer simulation.

6.2.3.1.2 Findings from the questionnaire

The quantitative data of the questionnaire was used to analyse whether understanding and conceptualisation of stoichiometric chemistry improved in both groups, and the effect of the teaching methods used to teach both groups on improving conceptualisation (see 5.5.3). The analysis found that the percentage of learners who agreed that the teaching method that used computer simulation as a tool to teach stoichiometric chemistry improved their understanding and conceptualisation of stoichiometric chemistry was greater than that of the learners in the control group, who had been taught by direct teaching (lecture method) (see 5.5.3.1). The analysis also found that the percentage of learners in the experimental group who agreed that their understanding and conceptualisation had improved was higher than that of the learners in the control group (see 5.5.3.2).

6.2.3.2 Findings of the qualitative data analysis

The analysis of the quantitative data provided answers about the improvement in performance of the learners in stoichiometric chemistry. In the analysis of the qualitative data, evidence was sought to determine if conceptualisation of stoichiometric chemistry had occurred. In the following sections, the analysis of the qualitative data obtained from the lesson observations, pre-test post-test response analysis, questionnaire and interviews will be discussed.

6.2.3.2.1 Findings from the analysis of lesson observations

The lesson observations were conducted by using an observation schedule with certain themes and specific criteria for each theme (see 5.3.2.1–5.3.2.5). Analysis of the lesson observations regarding balancing equations, applying mole-concept formulae and stoichiometric calculations based on chemical reactions, led to the following findings (see 5.3.2.6).

The lessons for the control group were conducted by using the lecture method with a whiteboard and textbook as media, while the experimental group was taught by using PhET computer simulation. The experimental group also had a whiteboard and textbook as media during the lessons (see 5.3.2). The lesson observation found that, although both teachers had adequate content knowledge for teaching, a better PCK was demonstrated by the teacher in the experimental group (see 5.3.2.6). The importance of effective PCK by practicing different approaches by teachers so that learners construct knowledge for conceptualisation was discussed in Section 2.6.1.1. It was also found that the teacher in the control group took an executive approach and, hence, the lessons were mostly teacher-centred. In turn, using PhET simulations to teach enabled the particular teacher to take a facilitator approach, and it was found that the lessons were more learner-centred (see 2.6.1.1).

It was found that using simulation engaged the learners in discussions and in active participation in activities, which they did by interacting with each other and with the teacher. A facilitative approach was followed by the teacher in the experimental group. This was found to be the reason for the teacher being able to demonstrate better PCK than the teacher in the control group. The interaction with simulated activities also helped the learners to construct their own knowledge, thereby improving their conceptualisation of stoichiometric chemistry (see 3.4). According to the activity theory model used for the study (see figure 3.2), the visual tools which was mainly the PhET simulations engaged the learners in activities based on chemical reactions. During the lessons with simulations the learners could view the reactants and products and the leftovers at the microscopic level which contributed to analyse critically their theoretical knowledge on balancing equations, reactants, products, leftovers and making use of mole ratios to perform calculations. The interdependence of the activity and learning was discussed in chapter 3 (see 3.4). The use of PhET simulations made the learners to actively construct their own knowledge thereby leading to the internalisation of the object which was the development of stoichiometric chemistry concepts and calculations for problem solving (see figure 3.2).

However, in the control group, the teacher explained the concepts directly by writing notes on the board and showing learners how to perform calculations in stoichiometric chemistry. In this lesson, learners occasionally asked questions and were answered by the teacher, but there was minimum interaction between them (see 5.3.2.6). Learners in the experimental group had the opportunity to apply their prior knowledge throughout the lessons, and teaching of the concepts was connected to real-world experience. The PhET simulations used an example of making sandwiches to simulate the balancing of equations and the concept of limiting reagent and leftovers (see 5.3.2.2). This example enabled the learners to connect their knowledge with real-world experience (see 3.9.4.1.1). While engaging with simulation of activities, it was found that the learners were engaged in inquiry- based learning for problem-solving (5.3.2.4 & 5.3.2.6). The importance of inquiry-based learning for conceptualisation of concepts was explained in Chapter 2 (see 2.6.1.4). However, in the control group lesson, the teacher showed learners directly on the board how to balance an equation by changing coefficients and using steps to teach them how to determine the limiting reagent and leftovers. It was found that the learners applied algorithms when dealing with activities on the topic, and proper conceptualisation did not occur (see 2.10.2.2). Using computer simulations helped the learners in the experimental group to gain not only factual knowledge, but also conceptual and procedural knowledge for problem-solving (see 5.7), while the learners in the control group mostly gained factual knowledge, which meant they have to memorise and reproduce facts during problem-solving with algorithmic steps (2.10.2.3). This finding was also evident in the responses to the questionnaire and interviews (see 5.5.2 & 5.6). Hence, it can be understood that the algorithmic steps increase the extraneous cognitive load, in the absence of conceptualisation of how to do the calculation (see 2.6.2.5). It was also found that, if learners use algorithmic statistics, it will not help them to comprehend, or develop critical thinking skills (see 2.10.2.1). Using simulation was found to help learning in the experimental group, even though learners had different abilities, and simulation reduced the cognitive load of learners (see 3.8.1 and 3.8.2).

6.2.3.2.2 Findings from the pre-test post-test response analysis

Pre-test and post-test response analysis was conducted for the 12 interviewee learners by analysing their answer scripts. The pre-test response analysis found that, though the learners had studied balancing of equations and the mole concept using different formulae for calculation, the learners experienced challenges answering these questions. Limiting reagent was a new topic in Grade 11 and, hence, learners performed poorly on questions relating to this topic (see 5.4.4.2). However, in the post-test there was an overall improvement in performance of both control and experimental groups. A noticeable finding regarding the pre-test was misconceptions about limiting reagent, namely that it was the reactant with the lowest moles available, and using the formula $n = V/V_M$ for calculations with solids (see 2.10.2.1). These misconceptions were rectified by the learners in the experimental group, while some of the learners in the control group whose responses were analysed still had the misconception. This led to the finding that the lesson using simulation helped to bring a conceptual change (see 2.6.2.2) in the experimental group, but not in the control group (see 5.4.4.3).

It was found that learners in both groups gained the factual knowledge needed to correctly write the definition for limiting reagent, and to use appropriate formulae for calculations with moles, which helped to improve their performance in the post-test. However, for the calculations using moles, mass and molar mass, some learners in the control group made the conceptual mistake of using the coefficients in the balanced equation to calculate molar mass of a compound present in the reaction (see 5.4.4.3). This mistake was the result of these learners only learning facts and gaining skills, but not achieving conceptualisation, as they could not transfer their learning into new situations (see 2.6.2.6). It was found that using algorithms can lead to the correct answer, though conceptualisation did not necessarily occur (see 2.10.2.2 & 5.4.4.3). It was found that balancing an equation could be done correctly by learners if molecular formula of the compound is correct, by making the number of atoms of each element on both sides the same (see 5.4.4.3). Interpreting the balanced equation as the stoichiometric ratios and applying it in complex calculations shows conceptualisation. The test response analysis found that more learners in the experimental group could write the formula of compounds correctly, and they could balance equations correctly (see 5.4.4.3). For the calculations with limiting reagents in complex stoichiometric calculations, more learners in the experimental group than the control group could apply the ratios in the balanced equation to perform calculations after attending the lessons with simulations, than in the pre-test (see 5.4.4.2 & 5.4.4.3). This was also evident in the responses of the experimental group learners in the interviews (see 5.6, question 10). These findings show that the experimental group had improved their conceptualisation of the different concepts in stoichiometric chemistry to a greater extent than the control group.

6.2.3.2.3 Findings of the questionnaire analysis

The questionnaire had a demographic section, a qualitative section for open-ended responses and a quantitative section of questions with responses on a Likert scale. The findings from the quantitative section were discussed in Section 6.2.3.1.2. The questions in the qualitative section were used to determine whether conceptualisation of stoichiometric chemistry occurred after the intervention. Demographic information collected was reported in Chapter 5 (see 5.5.1). It was found that majority of the learners in both groups were 17 years old (see 5.5.1.1). Only four of the learners had English as their home language (mother tongue). The biggest number of learners had Setswana as their mother tongue (see 5.5.1.2). All learners in both groups had passed physical sciences in Grade 10 and only 30.3% of learners enjoyed learning chemistry – most of all, the physical sciences disciplines (see 5.5.1.3 & 5.5.1.4). The difficulties related to learning chemistry was discussed in Chapter 2 (see 2.9.2). More than half the learners (54.8%) were found to be interested in proceeding further with studies in physical sciences at the tertiary level (see 5.5.1.5). The importance of more learners in the field of science in the tertiary level was also discussed in chapter 2 (see 2.5.2 & 2.7).

The analysis of the qualitative section of the questionnaire found that more learners in the experimental group understood that stoichiometric chemistry involves calculations with mole ratios in the balanced equation for determining amount of any reactant involved or product formed. It was found that learners in the control group only understood that balanced equations are needed for accurate calculations and could not explain clearly how to use mole ratios – an important concept in stoichiometric calculation (see 5.5.2.2). It was found that some learners in the control group could only explain that a balanced equation was needed for accurate calculations. In turn, more learners in the experimental group responded that the ratios in the balanced equation, which are the coefficients of the reactants and products, are used for calculating unknown amounts of reactant or product and, hence, correct balancing was important (see 5.5.2.2). From the analysis and interpretation of responses, it was found that the learners in the control group remembered that stoichiometric chemistry calculations involved following certain steps that their teacher had taught them in class. As a result, they responded by using algorithmic steps, and calculating moles and finding the one with the smallest mole as the limiting reagent. The responses indicate that the control group failed to achieve conceptualisation (see 5.5.2.2). Learners in the experimental group specifically referred to the use of mole ratios after calculating the moles for comparison, and did further calculations to determine the limiting reagent. This supports the findings of the test response analysis, that learners in the control group gained factual knowledge while those of the experimental group had gained conceptual and procedural knowledge after the intervention (see 2.6.1.4 & 6.2.3.2.2).

Regarding the teaching methods used, the experimental group responded that they enjoyed the lessons that used simulations. This was also found in the lesson observations (see 6.2.3.2.1). During the lesson observations, it was found that experimental group learners were actively engaged in activities to construct their own learning through interaction.

6.2.3.2.4 Findings of the interview analysis

The interview questions were structured to obtain a deeper understanding of the effect of the teaching method used on the conceptualisation of stoichiometric chemistry. From the analysis of the interview, it was understood that the majority of learners had failed to conceptualise the quantitative aspects of chemistry in Grade 10, which was the reason for learners' poor performance in the pre-test (see 5.5.4.1). The findings of the test response analysis supported this finding (see 6.3.2.2.2). There were 10 questions in the interview and a few of them were similar to the questions posed in the questionnaire. The interview gave the learners the opportunity to elaborate and respond more clearly to questions than when they had had to write their responses in the questionnaire. The interview responses complemented the findings from the lesson observations, test response analysis and qualitative section of the questionnaire, as the same learners' responses were used for all three analyses (see 6.2.3.2.1, 6.2.3.2.2 & 6.2.3.2.3).

Most of the learners who were interviewed understood that stoichiometric chemistry involves the calculation of moles, limiting reagents and excess reactants in a chemical reaction. However, more learners in the experimental group responded that using ratios in the balanced equations was important for calculations based on chemical reactions (see 5.6, question 6). More learners in the experimental group than in the control group understood that balanced equations were important for applying the ratios in which reactions take place and, hence, for performing accurate calculations (see 5.6, question 6). Some of the learners in the control group who were interviewed, when asked about the importance of knowing the limiting reagent in a chemical reaction, responded by defining a limiting reagent. This shows that they had acquired only factual knowledge. Learners in the experimental group could give a better explanation than the control group learners of the importance of limiting reagent in a reaction (see 5.6, question 6 & 6.2.3.2.4). This finding can be connected to the test response analysis finding that more learners in the experimental group applied the mole ratio to determine the limiting reagent, while the control group mostly only used the formula to calculate moles (5.4.4.3 & 6.2.3.2.2).

Learners in both experimental and control groups had gained confidence in performing stoichiometric calculations after the lessons. Most of the learners in the control group who were interviewed responded by referencing algorithmic steps they would use to perform the calculations in stoichiometric chemistry. However, two of the learners did not even understand the steps used by the teacher (see 5.6 questions 6 & 10). One learner pointed out that she depended on YouTube videos to learn the concepts, which helped her to understand better (see 5.6 question 8). This response shows the importance of microscopic visualisations for conceptualisation (see 3.9.4.1). The test response analysis of the control group also found that learners tried new application questions by using the steps taught by their teacher for the calculations, but they could not get the correct answer (see 6.2.3.2.2). By connecting and comparing the responses from the interviews with the findings of questionnaire and test response analysis, it seems the learners in the control group were only recalling the steps for calculations, without having achieved conceptualisation (see 5.5.2.2 & 5.6 question 6). From the interview responses of the experimental group, it is clear that the learners were aware of their own learning that took place through interaction and activities with simulation. Their metacognitive knowledge helped them to construct their own learning for conceptualisation and helped them to explain better in the interview, than the control group (see 2.6.2.7 & 5.6). By comparing the responses of the learners in the control group and experimental group, it was found that the learners in the experimental group responded with clear explanations to questions based on stoichiometric calculations. As a result, it was found that learners in the experimental group showed a greater improvement in conceptualisation of stoichiometric chemistry than the control group did.

While the learners in the control group responded about the teaching method by saying it was good and emphasizing that the teacher taught them the steps for calculations, the experimental group responded that the visual representations of molecules helped them to understand how the reactants reacted and products were formed according to the ratios in the balanced equation (see 5.6 question 8). Therefore, it was found from the interviews that teaching through visual presentations in simulation helped the learners in the experimental group to improve their understanding and to conceptualise better than the teaching of algorithms for problem solving did (see 2.10.2.2, 2.10.2.5 & 3.9.4.1).

6.2.3.3 Triangulation of quantitative and qualitative findings

It was discussed in Chapter 4 that, after collecting and analysing the data, findings from the quantitative and qualitative methods would be compared and contrasted by triangulation (see 4.8.4). While the quantitative analysis focused on the performance of learners in stoichiometric chemistry, the qualitative analysis focused on the conceptualisation of stoichiometric chemistry. The results that emerged from the quantitative analysis of the pre-test post-test design and the questionnaire questions answered through the Likert scale, guided the whole research process and were complemented by the qualitative analysis of the test response analysis, questionnaire and interview. Figure 6.1 shows the essence of the way triangulation was facilitated for the study.

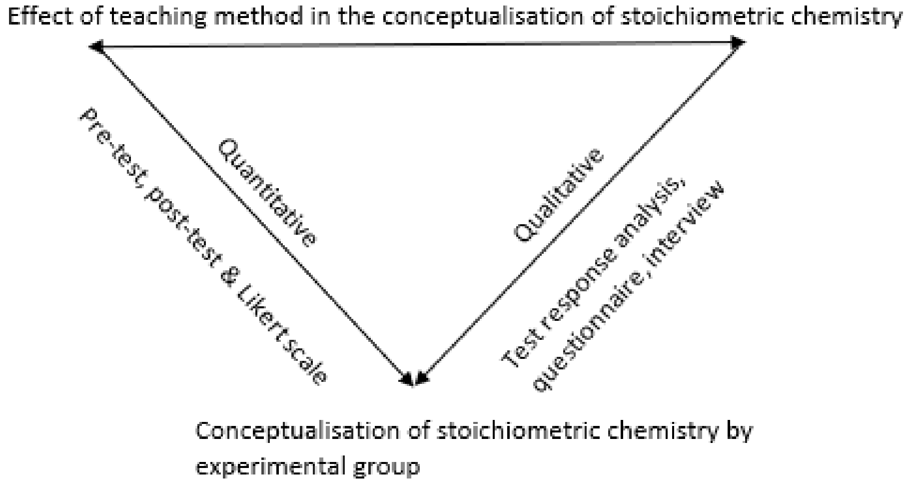

Figure 6.1: Triangulation

The quantitative data analysis of the pre-test and post-test inductively found that both control and experimental groups improved in their performance of stoichiometric chemistry (see 5.4.2 & 5.4.3). Further analysis found that the performance improvement of the experimental group was greater than that of the control group (see 5.4.3.3). The qualitative test response analysis of the answers of the post-test supports this finding (5.4.4.3).

An inductive approach was used for the analysis of the questionnaire and interview responses, and an interpretation of the qualitative analysis was discussed in Chapter 5 (see 5.6). The qualitative questionnaire section and the interviews found that some of the learners in the control group were not satisfied with the way the lecture method of the teacher explained the concepts by writing on the board. However, most of the learners in the control group were satisfied with the algorithmic methods taught by the teacher for performing calculations (see 5.5.3.2). As a result, in the post-test, these learners followed the algorithmic steps to perform calculations and could not complete the calculations successfully. This shows that, if conceptualisation does not occur, using algorithmic steps may fail to help a learner perform complex calculations correctly, because it comes down to applying steps without reflection and understanding (see 2.10.2.2).

From the findings of the interviews and questionnaire for the experimental group, it is clear that learners could interact with each other during discussions during the simulation (see 5.6). Moreover, the visual microscopic representations in the simulations helped many of the learners to understand the chemical reactions better (see 3.9.4.1.1, 3.9.4.1.2 & 5.3.2.6). The visual representations helped them to remember what had been taught and helped them to perform better in the post-test (see 6.2.3.1.1) A major finding of the quantitative analysis is that the performance of experimental group learners in the post-test was better than that of learners in the control group (see 5.4.3.3). The interview and questionnaire analysis found that the learners in the experimental group were better at explaining the importance of balancing equations, determining the limiting reagent, and explaining how ratios could be used to determine the limiting reagent and the amount of products formed (see 6.2.3.2.3 & 6.2.3.2.4). This finding explains that experimental group learners had a better conceptualisation than the control group learners at the time of the post-test. Thus, the qualitative data that had been collected and analysed integrated with the quantitative data that had been collected and analysed, and helped me to develop a deeper understanding of the data and to gain a more complete picture of the study (see 4.8.4).

6.2.4 Conclusion from the empirical study

The findings reported on in the previous sections indicate that the third objective of the study, namely, to determine whether learners who are exposed to computer simulation in the teaching of stoichiometric chemistry conceptualise the concepts better than learners who are not exposed to computer simulations in the teaching of stoichiometric concepts, was achieved (see 1.5.2). The quantitative analysis found that both groups improved in performance, however, the experimental group had a greater improvement in performance relating to stoichiometric chemistry (see 5.4.3.3). From the analysis of the experimental design, questionnaire and interviews it can be concluded that there was greater improvement in learners' conceptualisation of stoichiometric chemistry in the experimental group than was the case for learners in the control group.

The aim of the study was to determine the effect of computer simulation on Grade 11 learners' conceptualisation of stoichiometric chemistry. From the study, it can be concluded that computer simulations had a significant effect on Grade 11 learners' conceptualisation of stoichiometric chemistry.

6.3. RECOMMENDATIONS FROM THE STUDY

The study recommends using computer simulations for the teaching and learning of stoichiometric chemistry, as it is likely to improve its conceptualisation in the FET phase of schools in South Africa. The need for greater student enrolment in the field of chemistry at tertiary institutions, which would help meet the requirement for more knowledgeable and skilled professionals in the field of chemistry for the development of South Africa, was discussed in Chapter 2 (see 2.9.1). It was reported in Chapter 1 that many learners perform poorly in the NSC Grade 12 chemistry examination, due to their failure to conceptualise stoichiometric chemistry, and that it had a negative impact on learners who wish to continue studying chemistry (see 1.2.1). For continued studies in chemistry, conceptualising stoichiometric chemistry plays an important role (see 1.3). As a result, the aim of this study, namely, to determine the effect of computer simulations on the conceptualisation of stoichiometric chemistry, was achieved.

A further recommendation is to use computer simulations to teach other concepts in chemistry, such as rate of reaction and chemical equilibrium. From studies done by other researchers it is clear that using computer simulations as a tool helps to enhance the conceptualisation of various topics in chemistry. Using visual representations through simulations for teaching and learning could improve conceptualisation of abstract concepts (see 3.9). It is also reported that using simulations reduces learners' cognitive load (see 3.8.2). The use of simulations to conduct experiments has also been reported to be successful in cases where an experiment could not be conducted in a classroom situation (3.9.2).

In short, I recommend a change in the teaching methods used by teachers, to integrating computer simulation to teach various concepts, instead of using only direct teaching (the lecture method). The current study findings show that using computer simulations to teach leads to greater improvement in the conceptualisation of stoichiometric chemistry than the lecture method did. The study found that the lecture method, which was used for the control group, resulted in learners making use of algorithmic methods, which did not help in conceptualisation and solving stoichiometric calculations (see 2.9.2, 2.10.2.2 & 6.2.3.2). In the study, the simulations, through games in PhET, helped learners to visualise the microscopic representation of reactants and products in a chemical reaction while the teachers explained it to them. By practising with games in the simulations, learners got actively involved in finding the amount of products formed, reactants in excess, leftovers and limiting reagents. When the learners were given a problem to solve in the simulation, they discussed it among themselves and interacted with each other to solve the problem. The teacher only facilitated the process by intervening when needed. This approach helped learners to construct their own learning with the assistance of the teacher. Integrating ICT in teaching shows positive results (3.2.2 & 3.2.3). An advantage of using simulations was also reported (see 3.8.3). Therefore, it is recommended that teachers use a blended approach by making use of simulation in combination with other teaching methods, such as direct instruction, problem-solving and inductive or deductive reasoning (see 2.6.1). Teaching with simulations also promotes inquiry-based teaching and stimulates active learning, during which learners can interact with each other while manipulating games (see 3.9.1). This approach will help to shift teaching and learning from a teacher-centred approach to a learner-centred approach (see 2.6.1.1).

A further recommendation is to provide teachers with appropriate in-service training on the use of technology for teaching. The TPACK of the teacher is very important when it comes to successfully using technology in teaching. Appropriate training in TPACK enables a teacher to integrate curriculum content knowledge, general pedagogy, technology and context, which all influence teaching and learning (see 3.3). Therefore, the teacher with the required TPACK, by integrating technology in teaching and learning, creates a learning environment where learners engage in activities by interacting with each other to construct knowledge.

A further recommendation is that principals of schools provide the necessary support and environment, and that departmental officials and lecturers at higher education and training institutions provide the necessary support through training for the successful integration of technology for teaching and learning.

The study has implications for physical sciences learners and teachers, physical sciences subject advisors, the Department of Basic Education and chemistry lecturers at tertiary institutions.

6.4. LIMITATIONS OF THE STUDY

- The quantitative instruments used for the study indicated whether improvement in performance took place. The instruments for the quantitative data collection used were not constructed to provide evidence of whether conceptualisation of the concepts took place. A well- designed quantitative questionnaire may have provided more evidence of the conceptualisation of stoichiometric chemistry.
- The topic of stoichiometric chemistry was dealt with at the school close to the June examinations. Hence, the teacher had to conclude the lessons and exposed learners to minimum practise in solving problems using computer simulations at different difficulty levels. This could have affected the slow learners in relation to conceptualisation of the topic.
- Other than the guidance given by myself, as the researcher, the teacher involved in the teaching of stoichiometric chemistry using computer simulation as a tool was not given formal training by professionals on using

computer simulation to teach. Formal training could have had an effect on the teacher, who may have explored simulation deeply, and used innovative ways to expose learners to the different difficulty levels of the games, while conducting the lessons.

- No data was collected from the teachers at the school about their experiences of teaching stoichiometric chemistry in previous years, and on any difference in teaching when computer simulation was used for the current study. This information could have given a better understanding of how conceptualisation of stoichiometric chemistry was affected by teaching with and without simulation, from the teacher's point of view.

6.5. FURTHER RESEARCH

Further research with respect to the following is recommended.

- Taking into consideration recent challenges due to the Covid-19 pandemic, where the learners cannot attend face-to-face lessons at schools, a study to determine the effect on learners of using computer simulation to learn stoichiometric chemistry without the physical assistance or presence of the teacher, could be conducted.
- The research can be extended to a larger sample size, involving more learners doing physical sciences in the province or country, with a quantitative questionnaire to collect data. This could assist to generalise findings.

6.6. SIGNIFICANCE OF THE STUDY

The study contributes to the improvement of learners' conceptualisation of stoichiometric chemistry at high school level, specifically in the South African context. Better conceptualisation of stoichiometric chemistry may contribute to improving learners' performance in the NSC chemistry examination. The study contributes to a better understanding of and improved learner participation in the learning process, which makes learning science fun. Doing so might reduce the number of learners who discontinue learning physical sciences in Grades 10, 11 and 12 due to their poor understanding and conceptualisation of stoichiometric chemistry and, hence, chemistry. The study contributes to promoting an innovative method of teaching stoichiometric chemistry, to achieve better conceptualisation at both high schools and tertiary institutions. Lastly, and most importantly, the study might contribute to producing more chemistry professionals for the chemical industry, to promote the economic growth and development of the country.

6.7. CONCLUDING REMARKS

The aim of the study was to determine the effect of computer simulation on Grade 11 learners' conceptualisation of stoichiometric chemistry. For the study, a literature review on the value and importance of teaching and learning chemistry in the South African context was conducted. It was found that teaching and learning chemistry contributed to the development of the chemical industry of South Africa. A second literature review was conducted to study the influence of computer simulation when it is integrated in the teaching of chemistry. It was found that using computer simulation to teach had a positive influence on learning various topics in chemistry. The empirical research conducted by using a mixed methods approach provided quantitative and qualitative data, which, in the current study, showed that, when computer simulation was used to teach, it improved Grade 11 learners' conceptualisation of stoichiometric chemistry. As the study showed computer simulation had a positive effect, teaching and learning of stoichiometric chemistry can, in the future, be improved by encouraging teachers to make use of computer simulation from Grade 10 onwards. Doing so would help learners to conceptualise the basic concepts of stoichiometric chemistry. Teachers can continue using simulation to teach Grade 11 learners to do complex stoichiometric calculations. This could have a positive effect on learners' performance in chemistry and, thereby, produce more tertiary-level students in the field of chemistry.

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Appendix A: Observation schedule

Surname & Initials of teacher: ....

Surname and Initials of observer: ....

Grade: ....

Date of observation ....

Criteria	A: Lesson design and implementation (What teacher intended to do)				
Instructional strategies & activities respected learners' prior knowledge and the preconceptions inherent therein	Never occurred 0	Lesson design informs the learners' prior knowledge 1	Lesson design checks on learner's prior knowledge based on their input without any adjustments 2	Lesson design makes use of prior knowledge for developmental part of lesson and adds value to content provided. 3	Lesson design activates learner's prior knowledge in the beginning and introduces content based on learner input and open for adjustments. 4
Lesson design to engage learners as members of a learning community.	No evidence 0	Lesson has limited opportunities for learners to be engaged. 1	Lesson design gives opportunities for continuous interaction between teacher and learners. 2	Lesson design includes both extensive teacher-learner and learner-learner interactions 3	Lesson design provided opportunity for gaining meaning of the content mainly through learner-learner interactions

Learner exploration prior to formal presentation	No exploration occurred 0	Lesson starts with an abstract exploration opportunity. Teacher just asks learner on what they think about the topic 1	Lesson designed with an initial short exploration opportunity with learners doing something 2	Lesson designed for learners to engage in active exploration experience 3	Learners spend sufficient and appropriate time exploring in detail prior to formal presentation 4
Design of lesson in encouraging learners to seek and value alternative modes of investigation or of problem solving	No encouragement for alternative modes 0	Lesson designed for teacher to ask divergent questions 1	Lesson designed for teacher to ask divergent questions, but not to investigate 2	Lesson designed for learner to engage in alternative modes of investigation but without subsequent discussion 3	Lesson designed to engage in alternative modes by having clear discussions 4
Focus and direction of lesson prioritising learner ideas	Lesson is teacher directed by all means 0	Lesson plan accommodates learners to ask questions 1	Lesson plan call for learner generated ideas 2	Lesson plan open for adjustments based on learner input 3	Lesson plan is entirely learner directed with content directed by teacher allowing learners to provide different ideas and questions 4
	B: Content knowledge of teacher, organisation and presentation of material				
Orientation of content with fundamental concepts	Teacher shows no clear focus, just a series of random facts delivered 0	A suggestion of concepts but not obvious and mostly delivering facts than concepts 1	Concept taught but not necessarily within a conceptual framework.	Concepts are taught within a conceptual framework but still contains miscellaneous details/facts 3	Teacher delivers concepts within a conceptual framework without any tangential material that potentially confounds 4
Presentation of content in a logical and clear fashion delivering	Not presented logically and lacks clarity and no	Lesson is disjoined and not consistent with the concepts	Lesson is clear and or logical but delivers	Lesson is clear and logical but relation of content with	Lesson presented clearly and logically with consistent relation of

strong conceptualisation of topic	connections between materials 0	1	inconsistently between concepts and content 2	concepts is not always evident 3	content and concepts throughout 4
Grasp of subject matter content inherent in lesson	No evidence of clear understanding of content by teacher 0	Teacher shows some understanding of the fundamentals but lesson gets wrought with errors 1	Mistakes are common but fundamentals are sound 2	Overall accurate delivery of content with minor errors 3	All information presented accurately 4
Variety in presentation	Delivers texts and facts directly 0	Teacher includes diagrams/ images in addition to text and do not explain them at all 1	Teacher uses variety of media for presentation but poor explanation to support and develop the content 2	Teacher uses variety of media for presentation but only occasional explanation to support and develop the content 3	Variety of ways used for presentation and builds the lesson properly to support/ develop the lesson 4
Integration with other content disciplines/ applications to real world phenomena	No connection to anything beyond a list of facts 0	Some connection to real world but mostly abstract or not helpful for content comprehension 1	Deliberate effort to connect to real world/ other disciplines is evident but teacher centred 2	Promotes learner thinking by deliberately making connections to real world/ other disciplines 3	Teacher sets up the concept, makes initial connections but provides enough opportunities for learners to explore 4
	C: Learner participation in the lesson (What the learners did)				
Use of a variety of media (models, drawings, graphs, symbols, materials) by learner to represent phenomena	Learners are not asked to do anything 0	Learners are asked to interpret phenomena by one means for the entire duration of the class 1	More than 2 different media are employed to assist learner learning 2	Learners manipulate more than 2 media for at least 25% of the class time 3	In any given moment during the lesson, learners are more likely given opportunity to work with a variety of media rather than just being passive listeners

					4
Learner involvement in making prediction, estimations and devising means for testing them	No opportunities for predictions 0	Teacher asks class to predict as a whole but do not wait for a response. No means for testing 1	Teacher asks class as a whole or as pairs to predict and waits for input. But no means for testing 2	Learners discuss predictions. Means for testing is highly prescribed 3	Learners guide questioning and can predict, explores a means for testing predictions 4
Learner engagement in thought provoking activities	Learners are completely passive 0	Learners engage in simple activities involving recalling/summarizing of facts 1	Learners engage in activities that involve some form of application 2	Learners engage in activities that involve analysis of a situation 3	Learner activities involve critical evaluation of content by negotiating meaning of content and/or synthesis something new 4
Learner reflection about their learning What did you learn, how do you know	No reflection 0	Learners ask questions that shows a thinking beyond immediate content 1	Teacher sets up opportunities for learners to reflect but doesn't follow through how it helped their connection to learning 2	Learners provided time to reflect on their learning, some limited connections to their learning, but not a follow through 3	Learners have specific opportunities/prompts from teacher to determine what they know, what they don't know and why 4

	D: Classroom culture: learner-learner interaction				
Learner-learner involvement to communicate ideas in a variety of means and media	No learner communication, no ideas beyond teacher instructor are heard or accepted 0	At least one type of learner-learner communication (brainstorming, drawing pictures to convey ideas) The learner-learner are not accepted with each other 1	Either more than one type of learner-learner communication but not at a variety of scales (in pairs, small group, group to group, whole class). Some interactions are accepted and considered 2	Multiple types of learner-learner interaction at multiple scales but not at all scales of potential interaction ,most interactions are heard and considered 3	Focus of the class is on learner-learner interaction through a variety of scales and types (whole class processing). Every voice is equitable heard and respected 4
	E: Classroom culture: teacher-learner interaction				
Active participation of learners are encouraged and valued	Entirely teacher directed, no learner questions 0	Some learner questions, may be opportunities to shout out ideas 1	Some learner questions/input are accepted, and they appear to shift direction of the lesson. 2	Many learners engaged for some time for valuable inputs leading to class discussions that directs the lesson. 3	All learners actively engaged in meaningful interaction with teacher that guides the direction of the lesson throughout. 4
Teacher patience with learners	Teacher did not show any patience towards learners/ bad behaviour of learners tolerated or ignored 0	A bit of wait time after asking the question, teacher avoids answering his/her own questions, teacher works with learners to clarify their vague question 1	Waits for multiple learner thoughts, waits for all learners to have a chance to consider the question, not just taking the first raised hand or 'shout out' 2	Provides some time for learner-learner interaction, but may not be enough time for all to achieve goals 3	Teacher provides adequate time for meaningful conversations to occur between learners 4
Teacher as a resource person to support and enhance learner investigations	No activity to engage learners to apply content through problem solving 0	Very teacher directed, limited learner investigation, very rote learning. 1	Primarily directed by teacher with occasional opportunities for learner 2	Learners have freedom, but within the boundaries directed by teacher 3	Learners are actively engaged in learning process, learners determine what and how teacher could help 4

Appendix B: SCAT pre-test

Stoichiometric chemistry achievement Pre-test

Grade 11

Duration: 40 minutes

Question 1

The reaction of methane and water is one way to prepare hydrogen for use as a fuel.

The unbalanced chemical equation for the reaction is given below.

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + H_2(g)$$

A scientist in his laboratory begins with 995 g of CH_4 and 2510 g of water.

1.1 Write down a balanced chemical equation for the above reaction. (2)

1.2 One of the reactant in the reaction is the limiting reagent.

Define the term limiting reagent. (2)

1.3 By making use of a calculation determine the limiting reagent. (6)

1.4 What is the maximum mass of H_2 that can be prepared? (4)

1.5 What mass of excess reactant remains when the reaction is completed? (3)

[17]

Question 2

John collected some sea shells from the sea shore while he went for a trip to Cape Town.

His friend told him that sea shells contain calcium carbonate ($CaCO_3$).

When the sea shell is heated, $CaCO_3$ decomposes to calcium oxide and carbon dioxide.

2.1 Write down a balanced equation for the above reaction. (3)

2.2 If 20 g of $CaCO_3$ was heated, calculate the volume of CO_2 gas that will be produced at STP (5)

[8]

Total – 25 marks

$n=\frac{m}{M}$	$n=\frac{N}{N_A}$
$n=\frac{V}{V_m}$	$c=\frac{n}{V}$ OR/OF $c=\frac{m}{MV}$

KEY/ *SLEUTEL*

Atoomgetal
Atomic number

Elektronegatiwiteit
Electronegativity

Simbool
Symbol

Benaderde relatiewe atoommassa
Approximate relative atomic mass

29
1,9 Cu
63,5

1 (I)	2 (II)	3	4	5	6	7	8	9	10	11	12	13 (III)	14 (IV)	15 (V)	16 (VI)	17 (VII)	18 (VIII)
2,1 1 H 1																	2 He 4
1,0 3 Li 7	1,5 4 Be 9											2,0 5 B 11	2,5 6 C 12	3,0 7 N 14	3,5 8 O 16	4,0 9 F 19	10 Ne 20
0,9 11 Na 23	1,2 12 Mg 24											1,5 13 Aℓ 27	1,8 14 Si 28	2,1 15 P 31	2,5 16 S 32	3,0 17 Cℓ 35,5	18 Ar 40
0,8 19 K 39	1,0 20 Ca 40	1,3 21 Sc 45	1,5 22 Ti 48	1,6 23 V 51	1,6 24 Cr 52	1,5 25 Mn 55	1,8 26 Fe 56	1,8 27 Co 59	1,8 28 Ni 59	1,9 29 Cu 63,5	1,6 30 Zn 65	1,6 31 Ga 70	1,8 32 Ge 73	2,0 33 As 75	2,4 34 Se 79	2,8 35 Br 80	36 Kr 84
0,8 37 Rb 86	1,0 38 Sr 88	1,2 39 Y 89	1,4 40 Zr 91	41 Nb 92	1,8 42 Mo 96	1,9 43 Tc	2,2 44 Ru 101	2,2 45 Rh 103	2,2 46 Pd 106	1,9 47 Ag 108	1,7 48 Cd 112	1,7 49 In 115	1,8 50 Sn 119	1,9 51 Sb 122	2,1 52 Te 128	2,5 53 I 127	54 Xe 131
0,7 55 Cs 133	0,9 56 Ba 137	57 La 139	1,6 72 Hf 179	73 Ta 181	74 W 184	75 Re 186	76 Os 190	77 Ir 192	78 Pt 195	79 Au 197	80 Hg 201	1,8 81 Tℓ 204	1,8 82 Pb 207	1,9 83 Bi 209	2,0 84 Po	2,5 85 At	86 Rn
0,7 87 Fr	0,9 88 Ra 226	89 Ac															

58 Ce 140	59 Pr 141	60 Nd 144	61 Pm	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 163	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 173	71 Lu 175
90 Th 232	91 Pa	92 U 238	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Appendix C: SCAT post-test

Stoichiometric chemistry achievement Post-test

Grade 11

Duration: 40 minutes

Question 1

The reaction of methane and water is one way to prepare hydrogen for use as a fuel.

The unbalanced chemical equation for the reaction is given below.

$CH_4(g) + H_2O(g) \rightarrow CO(g) + H_2(g)$

A scientists in his laboratory begins with 995 g of CH_4 and 2510 g of water.

1.1 Write down a balanced chemical equation for the above reaction. (2)

1.2 One of the reactant in the reaction is the limiting reagent.

Define the term limiting reagent. (2)

1.3 By making use of a calculation determine the limiting reagent. (6)

1.4 What is the maximum mass of H_2 that can be prepared? (4)

1.5 What mass of excess reactant remains when the reaction is completed? (3)

[17]

Question 2

John collected some sea shells from the sea shore while he went for a trip to Cape Town.

His friend told him that sea shells contain calcium carbonate ($CaCO_3$).

When the sea shell is heated, $CaCO_3$ decomposes to calcium oxide and carbon dioxide.

2.1 Write down a balanced equation for the above reaction. (3)

2.2 If 20 g of $CaCO_3$ was heated, calculate the volume of CO_2 gas that will be produced at STP (5)

[8]

Total – 25 marks

$n = \frac{m}{M}$	$n = \frac{N}{N_A}$
$n = \frac{V}{V_m}$	$c = \frac{n}{V}$ OR/*OF* $c = \frac{m}{MV}$

KEY/ *SLEUTEL*

Atoomgetal
Atomic number

Elektronegatiwiteit
Electronegativity

Simbool
Symbol

Benaderde relatiewe atoommassa
Approximate relative atomic mass

29
1,9 Cu
63,5

1 (I)	2 (II)	3	4	5	6	7	8	9	10	11	12	13 (III)	14 (IV)	15 (V)	16 (VI)	17 (VII)	18 (VIII)
1 2,1 H 1																	2 He 4
3 1,0 Li 7	4 1,5 Be 9											5 2,0 B 11	6 2,5 C 12	7 3,0 N 14	8 3,5 O 16	9 4,0 F 19	10 Ne 20
11 0,9 Na 23	12 1,2 Mg 24											13 1,5 Aℓ 27	14 1,8 Si 28	15 2,1 P 31	16 2,5 S 32	17 3,0 Cℓ 35,5	18 Ar 40
19 0,8 K 39	20 1,0 Ca 40	21 1,3 Sc 45	22 1,5 Ti 48	23 1,6 V 51	24 1,6 Cr 52	25 1.5 Mn 55	26 1.8 Fe 56	27 1.8 Co 59	28 1.8 Ni 59	29 1,9 Cu 63,5	30 1,6 Zn 65	31 1,6 Ga 70	32 1,8 Ge 73	33 2,0 As 75	34 2,4 Se 79	35 2,8 Br 80	36 Kr 84
37 0,8 Rb 86	38 1,0 Sr 88	39 1,2 Y 89	40 1,4 Zr 91	41 Nb 92	42 1.8 Mo 96	43 1.9 Tc	44 2.2 Ru 101	45 2.2 Rh 103	46 2,2 Pd 106	47 1,9 Ag 108	48 1,7 Cd 112	49 1,7 In 115	50 1,8 Sn 119	51 1,9 Sb 122	52 2,1 Te 128	53 2,5 I 127	54 Xe 131
55 0,7 Cs 133	56 0,9 Ba 137	57 La 139	72 1,6 Hf 179	73 Ta 181	74 W 184	75 Re 186	76 Os 190	77 Ir 192	78 Pt 195	79 Au 197	80 Hg 201	81 1,8 Tℓ 204	82 1,8 Pb 207	83 1,9 Bi 209	84 2,0 Po	85 2,5 At	86 Rn
87 0,7 Fr	88 0,9 Ra 226	89 Ac															

58 Ce 140	59 Pr 141	60 Nd 144	61 Pm	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 163	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 173	71 Lu 175
90 Th 232	91 Pa	92 U 238	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Appendix D: Questionnaire

Thank you for participating in this questionnaire

Questionnaire

SECTION A : DEMOGRAPHIC INFORMATION OF LEARNER PARTICIPANTS

Instruction: For this section of the questionnaire please make a cross (X) in the box provided.

1. AGE (in years) ☐

2. HOME LANGUAGE

English	1
Afrikaans	2
Setswana	3
Sotho	4
Xhosa	5
Zulu	6
Other	7

If any other home language specify ....

3. Level achieved in Physical sciences in the November examination in 2018

1	2	3	4	5	6	7

4. Which discipline in physical science do you enjoy learning the most?

Physics	1
Chemistry	2

5. Are you interested in learning Physical sciences further?

Yes	1
No	2

SECTION B

Research title: The effect of computer simulation on grade 11 learners' conceptualisation of stoichiometric chemistry.

Your honest response to the questionnaire will be highly appreciated.

All answers to questions in this questionnaire will be treated confidentially.

Read through the instructions on how to approach each questions.

My teacher taught me the topic by (Tick in the appropriate box (either a or b))

a) only explaining and writing on the chalkboard ☐

b) explaining with computer simulation and writing on the chalkboard ☐

1. Fill in the spaces given below in one or two sentences for the questions. (1.1 – 1.6)

1.1. Write down what you understand about 'stoichiometric chemistry'.

....

....

....

1.2. What is the need of balancing chemical equations of a reaction in calculations based on stoichiometric chemistry?

....

....

....

1.3. What is the importance of a limiting reagent/reactant in a chemical reaction?

....

....

....

1.4. How confident are you in doing calculations based on stoichiometric chemistry?

....

....

1.5 Can you briefly explain a general method/steps that you will follow to answer a question to determine the limiting reactant?

………

………

………

1.6. What difference did the lessons you attended make in answering the post-test?

………

………

………

2. Make use of the keys given below to answer the following questions by writing a code in each of the boxes next to the questions. (e.g.1,2,3,4,5,6,)

Strongly disagree=1	**Diagree=2**	**Slightly disagree=3**	**Slightly agree= 4**	**Agree=5**	**Strongly agree=6**

2.1 I am now able to apply what I learnt through the lessons in more complex calculations of chemical reactions. ☐

2.2 The way the teacher guided us through the lessons helped me a lot to understand the concept of doing calculations with chemical reactions. ☐

2.3 I had very little understanding on the 'mole concept' last year but now I understand better. ☐

2.4 I feel more confident in learning chemistry than before. ☐

2.5 I feel that I can perform better for my Examinations on questions based on stoichiometric calculations. ☐

2.6 I agree that doing stoichiometric chemistry calculations be fun. ☐

Thank you for your valuable responses. Good luck with your future chemistry life!!

Appendix E: Interview

Instrument for conducting an interview for the research.

Title of research: The effect of computer simulation on grade 11 learners' conceptualisation of stoichiometric chemistry

The outcome of the quantitative study with the pre-test post-test experimental design will be verified and substantiated with an interview with nine learners totally from both control and experimental group by random selection. The interviews will include open ended questions focussing on the extend of conceptualisation of stoichiometric chemistry after treatment.

The following are the interview questions prepared by the researcher.

First of all I thank you for participating in my research on the effect of computer simulations on the conceptualisation of stoichiometric chemistry. Please feel free to ask if any of the questions are not clear or you do not understand them properly.

Question No.1

In grade 10 you were introduced with the quantitative aspects of chemical change. Briefly explain how well you understood the topic on mole concept and other calculations based on chemical reactions.

Question No.2

You were first given a pre-test on stoichiometric calculations, how did the understanding that you had in grade 10 about the moles help you in answering the pre-test?

Question No.3

You have now gone through a series of lessons with your teacher. What is your understanding about the term 'stoichiometric chemistry'?

Question No.4

You know that this topic deals with chemical reactions. What is the need of balancing chemical equations before attempting a calculation?

Question No.5

Your teacher might have introduced you with a new term 'limiting reagent' in the lesson. How important is identifying the limiting reagent in a chemical reaction?

Question No.6

Are there any way that you will use to determine the limiting reagent in a chemical reaction?

Question No.7

How confident are you in answering questions based on stoichiometric chemistry?

Question No.8

How did the teacher’s method of teaching help in your conceptualisation of stoichiometric chemistry?

Question No.9

How did the lessons you attended help in answering the post-test?

Question No.10

According to your understanding about stoichiometric chemistry calculations, can you give some basic steps that can be followed in doing calculations with chemical reactions.

Once again thank you for your co-operation and all the best wishes!!

Appendix F: Qualitative analysis of questionnaire

Themes, and examples of responses for qualitative section of questionnaire

Question no 1.1: Write down what you understand about stoichiometric chemistry	
Themes: Uncertainty Calculation of moles Calculations with ratios i	
Control group	Experimental group
Example of learner responses for the above themes *CG L20: know that it is about number of moles.* *CG L1: extremely difficult, only thing that I understand is it has to do with determining empirical formula.* *CGL16: I understand that in most cases you have to use moles to find the rest.* *CG L7: calculations to determine amount of products and reactants that are needed during a chemical reaction.* *CG L15: quantitative aspects of chemical changes….*	Example of learner responses for the above codes *EG L7: to be honest I do not remember much of stoichiometric chemistry because I did not revise.* *EG 32: has chemical equations, limiting reagents.* *EG L 3: it is all the calculations, …the mole…. the* *EG L10:* calculations based on reactions including moles and ratios. *EG L 11: using chemical reactions and ratios in balanced equations for calculations with moles, limiting reagents.*

CG L14: calculations between chemical reactions which involve ratios that has to do with atoms and molecules.	*EG L 31: calculations whereby we work with ratios to determine the amount of chemicals used in a reaction.*
Question 1.2: What is the need of balancing a chemical equation of a reaction based on stoichiometric chemistry?	
Themes: Uncertainty. Use of mole ratio	
Control group	Experimental group
<u>Example of learner responses for the above themes</u> *CG L1: left hand side equal to right hand side.* *CG L16: to conserve law of conservation of mass.* *CG L20: to see that your products can be equal to your reactants.* *CG L15: mol ratio in balanced equations used to calculate mass..* *CG L7: to determine the mole ratio and number of moles.* *CG14 to get accurate ratios on each molecules/atom in compounds.*	<u>Example of learner responses for the above themes</u>. *EG L7: making sure that both sides of the reactions are balanced.* *EGL3: mole ratios from balanced equations are always used.* *EG L32: for accuracy of calculations by knowing ratios of moles of reactant and products.* *EG L31: To get mass or mole ratio correct for accurate calculations.* *EG L10: because you always determine the mole ratio from the equation.*

•	*EGL11: so that the limiting reagent and the excess reagent can be determined using the mole ratio from the equation*
Question 1.3: What is the importance of a limiting reagent in a chemical reaction?	
Themes: Uncertainty Definition Determines products	
Control group	Experimental group
Example of learner responses for the above themes *CGL1: No response* *CGL20: To make a certain amount of products.* *CGL16: Gives an idea of the properties of the substance.* *CGL15: It is a reagent that is used up first within a reaction(definition)* *CGL14: So that we can know which one will be used first (definition)and use it in other calculations.* *CGL7: Determines the amount of the products.*	*Example of learner responses for the above themes* *EGL7: Because the reaction needs to be reduced.* *EGL32: To do some calculations.* *EGL3: To see which reactant is in surplus and what the reaction will produce.* *EGL31: Determines products of reaction.* *EGL10: To find which one is used up and use its ratio to find the amount of product formed and reactants used.* *EGL11: Limiting reactant slows down/stops a reaction. / how much the reaction will produce.*

<table>
<tr><td colspan="2">Question 1.4 How confident are you in doing calculations based on stoichiometric chemistry?</td></tr>
<tr><td colspan="2">Themes
Varied confidence</td></tr>
<tr><td>Control group</td><td>Experimental group</td></tr>
<tr><td>Example of learner responses for the above themes
CGL16: Not my favourite but fairly confident when doing revision, how and corrections.
CGL1: Not confident, do not understand the section, struggle a lot.
CGL7: Fairly confident
CGL20: I am not entirely confident but also really scared and some questions can be confusing.
CGL15: Slightly confident
CGL14: moderately confident</td><td>Example of learner responses for the above themes
EGL32: Not confident enough but through more practice can get there.
EGL7: I am not confident at all
EGL3: Slightly confident, needs to practice more often.
EGL11: Fairly confident
EGL31: I am not that confident but better than before.
EGL10: Moderately confident</td></tr>
<tr><td colspan="2">Question 1.5: Briefly explain a method that you will follow to answer a question to determine the limiting reactant?</td></tr>
<tr><td colspan="2">Themes
Misconception
Correct method for calculation</td></tr>
<tr><td>Control group</td><td>Experimental group</td></tr>
</table>

Example of learner responses for the above themes *CGL1: First find number of moles and the molar mass.* *CGL20: Write down balanced equation, determine mass of both agents and subtract.* *CGL16: Calculate the moles, use ratio, smaller is the limiting reactant.* *CGL15: Calculate number of moles, if actual is smaller than the mole ratio, it is the limiting reactant.* *CGL14: Balance the equation, find the ratio, calculate the moles, one with least number of moles is the limiting reactant.* *CGL7: Calculate moles, compare ratio, determine from ratio how many moles needed, reactant that cannot meet the need compared to how much is available is the limiting reactant*	*Example of learner responses for the above themes* *EGL7: Balance the equation, calculate moles, use mole ratio, determine limiting reactant using mole ratio.* *EGL32: Calculate the moles and find which has less moles.* *EGL3: Find moles, use mole ratio with smallest ratio and find how much of the other needed, then compare which one finishes first.* *EGL31: Find moles, use ratio and determine which one uses less than what is available.* *EGL10: Get the mole ratio from balanced equation, using mole ratio determine which reactant produces least product. It will be the limiting reactant.* *EGL11: Find moles, use mole ratio with smallest ratio and find how much of the other will be needed, then compare which one finished first.*
Question 1.6: What difference in the lessons you attended made in answering the post-test?	
Themes: Little understanding Improvement in understanding Simulations improved understanding	
Control group	Experimental group
Example of learner responses for the above themes	Example of learner responses for the above themes

CGL1: I felt more confused, it gave me some sort of knowledge, but I do not know where to apply things. *CGL15: I understand better than before.* *CGL20: I could understand some questions a bit better than before.* *CGL14: My understanding of stoichiometric chemistry was refreshed and also enhanced.* *CGL16: It gave more insight and a better and a clearer understanding of the moles and formula.* *CGL7: A lot of work was similar to the grade 10 work. The lessons made a difference with regards to the limiting reagent.*	*EGL32: I can do some of the calculations better than before.* *EGL7: It helped slightly.* *EG L3: It helped but I forgot some and did not know how to answer things.* *EG31: I knew some of the work on the post- test than before because much could remember the visual lessons with simulations.* *EGL10: The lessons attended with simulations made answering the test much easier to understand and gave me more confidence.* *EGL11: I could answer better as the lessons with simulations helped me to understand better.* *EGL20: The lessons we had with simulations helped a lot and it is seen by the difference in the pre-test and post-test where most of us were not able to answer.*

Appendix G: Qualitative analysis of interview

Question 1: In grade 10 you were introduced with the quantitative aspects of chemical change. Briefly explain how well you understood the topic on mole concept and other calculations based on chemical reactions	
Themes Moderate understanding	
Control group	*Experimental group*
Example of responses:	*Example of responses:*
CGL16: I was confused. I didn't understand properly. *CGL15: In gr10 I would say I understood 60-65% but then I learned in gr11 more by going through the work and of course with the help of teachers.* *CGL1: I understood it well.* *CGL7: I think in grade 10 it was introduced; I didn't understand it well as it was new but after a while I could understand well and perform better.*	*EGL7 I think I didn't understand it well in gr 10* *EGL32: In grade 10 I didn't understand this well, but now after mam did it this way, she did it, I understand it better. Last year I didn't really understand how to do the things and but yes now at least I know what the formulas is properly now, Yeah.* *EG L3: Hhmm, not that well. It was very complicated; I did not understand the elements and the numbers on it I needed to understand before I could do any calculations.*

<table>
<tr>
<td>CGL 20: To be honest in gr10, I actually liked chemistry up till we learned this stoichiometry… what what, I was like ehhhh I am not quite fond of it so at that time I am not sure if I understood it well but it was hhhhmm eh......
CG L14: Hhmm, in grade 10 it was a little bit difficult because it was new. But as I got hold, I had to practice it more because I had to be familiar with the reactions, how to put it and how to structure the equations as well so.... it went well</td>
<td>Moles can be calculated from the formula in gr10, that was my understanding.
EG L10: I had very little understanding on quantitative changes, the aspects of chemical change in gr10. I did not understand what a mole is. I just used the formula mam, check what I was given and what I needed to find, I just depended on the formula.
EGL11: It wasn’t that well, becoz it was new concept, becoz of the different changes from subject NS to physical science, so it wasn’t an easy progression between the two phases. So mole calculations were not easy as it was the first time. I understand the definition what a mole is but not specifically practically what it is and the calculations we have to go by.
IEGL31: Hmm mam, I did not understand at all. It was a disaster.</td>
</tr>
<tr>
<td colspan="2">Question no 2 You were first given a pre-test on stoichiometric calculations, how did the understanding that you had in grade 10 about the moles help you in answering the pre-test.</td>
</tr>
</table>

Theme Forgetting Balancing equation Calculate moles Learning method	
Control group	*Experimental group*
Example of responses: *CG16: I could calculate only the calculation on number of moles.* *CGL1: I remembered a few things in gr10, so that helped.* *CGL14: It helped me a lot becoz if I did not know what to do then I would not have answered those questions. So, the knowledge that I had in gr 10 helped me to answer those questions really well.*	*Example of responses:* *EGL32: Well.... not as well, not as good as I didn't remember most of the things, so it didn't help me as well in the pre-test. Yeah* *EGL3: Okay mam, I don't think I remembered that well, the work and all that. So, I had to go back and start from over. But think from gr10 it was the basics it helped a little bit.*

CG L7: It did help to a certain extend where it was just calculating the moles and basic steps but afterwards (laughing)...I did not know what to do. *CG L20: I think they helped me; it is just that I forgot. (laughs)* *CG L15 When I wrote the pre-test I understood here and there I didn't have a lot of understanding, but...I could....understand a few..... to write the test*	*EGL31: I could remember only that there are moles and formula to calculate moles.* *EG L7: I don't think it helped me well, because I forgot some of the stuff, I was uncertain about it.* *EG L10: The only thing that I could do in the pre-test was balancing the equation. So, it did not help at all.* *EG L11: It made me realise that we don't know much about stoichiometry and that we need to focus on it and learn every day and then we should change the way that we learn it because we can't recall it on how we did it in gr10.*
Question no:3: You have now gone through a series of lessons with your teacher. What is your understanding about the term 'stoichiometric chemistry'?	
• Themes • Calculation of moles, • Calculations with ratios.	
Control group Example of responses:	*Experimental group* Example of responses:

CGL1: I do understand it better. I can calculate concentration, volumes, moles. *CG L16: Calculating the no of moles and to identify the mass used, identifying the limiting reagent.* *CGL20: I think stoichiometry neh.. is like .... calculating the moles like how much this element is made out of something or how much is needed.... yes, basically that.* *CGL15: I have more understanding now... about stoichiometric chemistry....Ahh according to my understanding, stoichiometry...stoichiometric chemistry is calculating the number of moles in a reaction, the limiting reagent and yeah* *CGL7: I think I understand everything that we covered, so far of the topics that we done...... we usually work out in a given reaction, using the number of moles of the compounds to calculate for example, either the mass of the reactants or working out the composition of the reactant that was added*	EGL31: Stoichiometric chemistry has to do with calculations in a reaction with moles and ratios. EGL32: Ehhmmm like I have to calculate the moles, molar mass, finding the concentration and yeah. EG L10: Calculate the moles, use them to calculate mass or volume at STP, find concentration, % purity. I know how to do calculations concerning stoichiometry other than just balancing the equation. EG L7: We are learning about number of moles and then also calculating the quantitative composition of a given chemical substance and then breaking down into a ratio and comparing the answer that you got, stoichiometric chemistry is basically the ratio in a balanced equation. EGL3: understand that it is calculating this one substance from the reaction that you will need to find out and why the outcome of the reaction is that. Stoichiometry means finding the mass or moles of a substance using the ratio.

CGL14 eehhm basically it's all about calculating the mass, but most importantly it's about the moles as well because in order to calculate the mass you need to know the moles of the substance as well and the limiting reagents as well which was new I mean am in grade 11 but before in gr 10, we did not do the limiting reagent, I learnt it as well, also the concentration and to structure the equation, I did learnt about it last year but this year we got more deep with it.	EGL11 Calculating of moles in compounds and substance. So, through the process that we went through it is easier to understand where it comes from and why we are asked to calculate certain mass of things using the volume and stuff
Question 4 You know that this topic deals with chemical reactions. What is the need of balancing chemical equations before attempting a calculation?	
Themes Misinformation To calculate moles To use ratio for calculations	
Control group Example of learner responses	*Experimental group* *Example of learner responses*

CG L1 You need it to calculate the moles, quantity, balanced equation makes sure that both sides are equal. *CGL16: To calculate the number of moles.* *CGL14: Ehmm you need to balance the equation becoz you need to do the mole ratio in order to find like your mass or concentration.* *CGL20: Eehhm becoz the one side you see there is a law that says that I don't know that it has to be equal, I feel that the number of moles or something has to be equal, so they have to be equal eh yes.* *CG L15: Balancing chemical equations you need to.... see...how do I put this?? When you balance an equation, you need to see the number of moles to calculate let's say the limiting reagent, something to see which reactant is used up and yeah.* *CG L7: With the balanced equation you use the ratio between, so you need to know how much of each ehm element in a compound is in the reactants and products so that when you*	*EGL31: I need to balance the equation for calculations. I will need the ratio for calculations. Hhmm Yeah.* *EG L7: You can get an accurate amount; you break it down to a ratio to know the amount in the substance. We get the ratios in the reactants react and products from the coefficients in the balanced equation.* *EG L10: So that you can get the correct ratio, if your mole ratio is wrong, the number of moles formed calculated becomes wrong. All your answers calculated automatically becomes wrong.* *EGL11: It is going to affect my calculation. I use the mole ratio in the balanced equation, so it is for the right ratios for the moles.* *EGL32: In a balanced equation you see how, how much much you use, how much of the element of the periodic table was used and yeah. The coefficients in the equation shows the ratio in which they react. Yeah*

do the calculations your calculation or what you are working out is accurate.	*IEGL3: A balanced equation is telling us how many/how much of the substance do we have in a reaction. So, we need to know about it in doing a calculation, for finding how much of the product will be produced*
Question 5 Your teacher might have introduced you with a new term 'limiting reagent' in the lesson. How important is identifying the limiting reagent in a chemical reaction?	
- Themes - Uncertainty Calculation of products.	
Control group	Experimental group
Example of learner response *CGL 14: Eh It is very important becoz u need to know which amount was used in order to find the limiting reagent.* *CGL1: It would be the one that is used up first so for calculating concentration you would use it as volume, amount or like the substance that you would use as the chemical formula for calculation.*	Example of learner response *EG L3: Limiting reagent is the one that is used up in a reaction. By knowing the limiting reagent, we will know how much of the other substance will react and how much of the substance will be formed.* *EG L11: To know when the reaction will end up, because if there is no sufficient supply of a certain compound in the*

CGL20: We need to find out the limiting agent so that we know to calculate the other becoz the other limiting one is the one that is going to be used up first, so u need to find out how the other... the other, is it a compound???Oh ya *CGL15: In such calculation identifying the limiting reagent you have to see which substance has been used up so that yoi can be able to calculate the other.......how do you say this.... you use the molecular formula to calculate the lining reagent to see which substance is used up, yes.* *CG L16: To know which chemical or substance is going to be used up first. I cannot answer it, I am not sure, I think it is how much at the end you gonna get for the reaction. We have been calculating number of moles for substances and then the lowest one will be your limiting reagent. Then you know that when you calculate the mass, that reaction, that chemical is going to be used up first, so you need to know if it is sufficient or correct for the reaction.* *CG L7: Once you know the limiting reactant you know how much of the other reactant was needed for the products to*	*reaction, the reaction will stop. The limiting reagent decides on how long the reaction will continue and limit the product.* *EGL7: You need the limiting reagent to see if there is any excess of the reactants and how much of the products can be formed. The limiting reagent decides on how much of the product will be formed.* *EGL10: The limiting reagent in a reaction is important because it tells you how much of a product you can expect.* *EG31: Limiting reactant is the one that finishes first right, so I will need to know which one finishes first for other calculations with mole ratio.* *EGL32: Limiting reagent is that that is being used up and excess is the one that has been left. Yeah ...So you can know which one has been used up, which one does not have that much and hence find how much products can be formed*:

form. So, u need to know which one was used so that u can find the moles of the reactant to work out the moles of the other one to find like the overall.	
Question 6 Is there any specific steps that you will use to determine the limiting reagent in a chemical reaction.	
• Themes • Misconception • Calculation of moles • Mole ratio	
Control group	Experimental group
Example of learner responses	Example of learner responses
CG L15: Yes, I would use the one we calculate the number of moles which number of moles equal to the mass given over the molar mass.	*EGL31: Hohm. You need to first know the moles of each, then use ratio and…. apply ratio to find which one finishes first and which one is excess.*
CGL16: You find the moles of the reactants, and the one with the lowest will be the limiting reagent.	*EGL15: Yes, from the balanced equation you get the ratio, and you work out the amount of moles and then compare with how much is available and the formula will help you.*

CGL20: You calculate the number of moles of each compound and see which one has the lowest and the lowest is your limiting reagent. *CG L7: Yes mam, you first calculate the number of moles of each reactant and you see the ratio in which the reactants make with one another and you apply the ratio to see if there is ....ok then you see how many moles there for each are and the one with the least moles will be the limiting reactant.* *CG L14: Ahh yes, what I normally do is... I do the mole ratio of one substance and then I calculate the moles and then I compare with the number of moles that I was given to the number of moles I calculated and if I see that it is smaller then I know that it is the limiting reagent because it was all used up.* *CG20: You calculate the number of moles of each compound and see which one has the lowest and the lowest is your limiting reagent*	*EG L3: Firstly, I have to balance the equation, the I find the ratio between the substance. Then I used the mole ratio and I compare the original to the one that I calculate. Then I see which one is less than, if it is less than......it is the limiting reactant.* *EG L10: Start by balancing your equation, then you use the mole ratio to find the number of moles of each reactant using the mass and molar mass. The you compare the ratio and from that you can see the one that is finishing first and the other is the limiting reagent and which one is in excess can be got.* *EG L11: I need to first get the ratios from the balanced equation, see the number of moles of one, and see how much of the other will be needed from the ratio, and you comparing what is exceeding form the available one.* *EGL32: Yes, from the balanced equation you get the ratio, and you work out the amount of moles and then compare with how much is available and the formula will help you.*

Question 7 How confident are you in answering questions based on stoichiometric chemistry.	
Themes Improvement in confidence Method of learning	
Control group	Experimental group
Examples of learner responses	Examples of learner responses
CGL20: To be honest I am not that confident. Compared to other topics in chemistry, I am not that confident	*EG L7: Not much...but if I can get more practice, I can be better in the calculation.*
CGL1: Ahhmm, I think I am a bit more confident.... Yes	*EG L10: I am very confident now; I actually enjoy stoichiometry and it is much easier now with its understanding.*
CGL14: I am definitely more confident because I know more, I know how to do, and I know how to attack the problem.	*EG L3: Compared to then, Okay I am a bit confident becoz I understood more when to do what in a calculation.*
CG L15: I am much more confident than in gr10....because I have had more understanding of it and after the test as well. It has given me that boost to understand how to calculate stoichiometric chemistry.	*EG L11: My confidence level has increased because of the process of the lessons because we understood how the*

<table>
<tr><td><i>CGL7: I think I am quite confident about it.... better</i>
<i>CGL16: Very confident…. hhmmm…. I am glad</i></td><td><i>reaction happens through the simulation. It’ s just that I need more practice to increase the skill.</i>
<i>EGL31: I think I am more confident now after the classes.</i>
<i>EGL32: Better than last year, I feel bit more confident, not yet there, but now it is better and more confident that last year</i></td></tr>
<tr><td colspan="2">Question 8 How did the teacher’s method of teaching help in your conceptualisation of stoichiometric chemistry?</td></tr>
<tr><td colspan="2">Themes
Application of steps
Visualising using simulations
Sandwich simulations</td></tr>
<tr><td>Control group
Example of learner responses
<i>CGL1: It helped a lot like to work out the first steps like the number of moles... then like seeing what you have and writing</i></td><td><i>Experimental group</i>
<i>Example of learner responses</i>
<i>EG L32: It did the best, I could at least visualise the thin.gs that were done in class, saw the way that mam presented the things, so it helped me better than the normal way.</i></td></tr>
</table>

it down and then seeing what you don't have and calculating that with the formula. *CGL16: Mam, because my teacher in the class that I am she went day by day into the steps that we had to use, I did not understand any in Grade 10, but when I got in to Grade 11 started doing with stoichiometric chemistry... okay maybe I could do this.* *CGL14: The teacher showed us the steps to approach while doing the calculations, so it was easier to understand.* *CG L15: That one helped me a lot because, while I was given the formula, I was also given what the letters in the formula means so that I understand and in class we usually write it in steps, this is the molar mass , this is the mass so when I substituted , it is very easier and much better for me to understand.* *CG L7:. I didn't really understand the way that she taught it, to me...i don't know I think maybe it is the explaining of the way, the approach that was taken. In class I did not really grasp what she was trying to say.*	*EGL7: I enjoyed working on how to balance equations and finding the limiting reactants with simulations, sandwiches.* *EG L10: It gave me a visual understanding of what actually happens during a chemical reaction and how the limiting reagents affects the products that you get. I remember the bread and sandwiches in place of reactions.* *EG L11: It helped me understand because we used with the bread and the sandwiches which we were able to see the more every day and then we were able to understand what is required from us when we are doing the moles and especially the limiting reagent that I could understand it more with the simulation.* *EGL31: Mam, I was able to see how reactants look like and products also. The sandwich game was so new for us. I think it helped a lot for me to understand.* *EGL3: The lesson was nice because it was visual, I enjoyed it than other lessons that we attended*

CG L20: To be honest, the class that I am in..... i feel like it did gave me a concept but didn’t really help to understand. But rely a lot on YouTube videos to help me understand , the reason why I have the knowledge I have is because of the YouTube videos that I watched and yes I also had a few extra lessons, because I did not understand stoichiometry at all.	
Question 9: How did the lessons you attended help in answering the post-test?	
Theme Improved understanding Simulated lessons	
Control group	*Experimental group*
Examples of learners’ responses *CG L1: It helped a little to understand the moles and its calculations.* *CG L14: As I said it helped me how to start and how to carry on the calculations. I went through it much easier than I did*	*Example of learner responses* *EGL7: It helped a little better.* *EGL31: It helped me to perform better.* *EG L32: It did help me to write the post-test better. At least I could remember what I saw and how the problems were solved, my memory was freshened a little and again with*

the pre-test, so I felt more confident and i could do the questions. *CGL16: It helped me to answer the post-test better.* *CGL7: I went through it much easier than I did the pre-test, so I felt more confident and I could do the questions.* *CGL15: I could answer the questions better in the post test* *CGL20: It helped…I think it helped.*	*the way that mam presented things I could at least visualise it I could at least apply that understanding.* *EG L10: Thinking back in the simulation helped me to remember that I need to first find the limiting reagent and how it will affect your product and the agent in excess and it also helped me to balance the equation before I do the calculation.* *EGL3: We could understand how and see the reactions in a different way it helped one to understand better and answer the post-test better* *EGL11: It helped really well in the post- test, I assume my calculations went well and I have improved. Because my understanding was better in the post-test*
Question 10 According to your understanding about stoichiometric chemistry calculations, can you give some basic steps that can be followed in doing calculations with chemical reactions?	
• Themes • Use of formula • Calculation of moles	

• Comparison of ratio • Limiting reagent and leftovers • Conceptualisation of method	
Control group Example of responses *CG L1: First you get the equation you have to balancethe equation perfectly, secondly you have to calculate number of moles always and then based on the calculation you find out the concentration or volume.* *CGL16: You first calculate the moles of each substance and then convert it into other quantities.* *CG L15: In doing a stoichiometric chemistry calculation I would first calculate the moles by using the n=m/M and then I would use, sometimes they ask... let's say for the concentration, you use one of the two formulae c= n/v or c=m/MV and then calculate the concentration* *CGL14: Ok, let's say they give you the mass, an d the question is to calculate the moles, you are already given the*	*Experimental group* *Example of responses* *EG L32: I will find the moles and then use the formulae to find what is asked. Yeah, I will use the mole ratio from the balanced equation.* *EG L3: Use the mass of the given substance and convert to moles and also use the other formulae to do the calculations. Also use the mole ratio for the calculations.* *EG L10: We use the ratio compare the ratio of the limiting reactant to the ratio of the product and then calculate the moles of the product.* *EG L11: As I said it is the ratios first getting the number of moles, Balance the equation first and then take the ratio and find the number of moles of the one after that*

periodic table, so you calculate the moles, and then you gonna balance the equation and use the mole ratio and from there you calculate the ,you have your moles and there you can calculate the mass of the substance *CG L7: I will calculate the moles, see the equation if it is balanced, then I always do the moles because that's the basic, then you can use the ratio and see of the other reactant and its moles.* *CGL20: I am not sure, but I know I use some formula and do calculations.*	*compared to the other and you divide and see how much is there?* *EGL7: I will use the balanced equation and use the mole ratio to find how much of the other substance is used and also find the products.* *EGL31: First you must calculate moles from mass, then use ratio and find the products. Also find limiting reagent and leftovers with ratio and moles*

Appendix H: Permission from district office to conduct research

Permission from Frances Baard District office to conduct the study in the school

Northern Cape
Department of Education

FRANCES BAARD DISTRICT

9 Hayston Road
Hadison Park
Kimberley 8301

Private Bag X5041
Kimberley 8300
Republic of South Africa

Tel: 053 830 1600
Fax: 053 830 1629

DEPARTMENT OF EDUCATION

Enquiries: L. Monyera
Contact No: 053 830 1602
Ref No: L4.3.4
Date: 12 April 2019

Mrs. A.J. Philip
School of Education
Sol Plaatje University
Scanlan Street
KIMBERLEY
8301

SUBJECT: REQUESTING PERMISSION TO CONDUCT RESEARCH AT KIMBERLEY GILRS' HIGH SCHOOL

The Northern Cape Department of Education encourages research, which is in the best interest of education and will consider any meaningful research project in this regard. The Department therefore supports the conducting of high quality research that enables the Department to make evidence based policy decisions, and to enhance delivery of quality education to our learners.

When preparing your questionnaires, you must take the sensitivity of the contents, learners, since respondents such as the Northern Cape Department of Education, educators, learners, governing bodies and parents may not be offended or embarrassed by them.

You must obtain consent from participant categories, such as Principals, parents, teachers and learners. After approval has been granted by the Northern Cape Department of Education, the following conditions would be applicable.

1. There must not be any financial implications for the Northern Cape Department of Education.
2. Institutions and respondents must not be identifiable in any way from the result of the investigation.
3. The researcher must make all the arrangements concerning his/her investigation.
4. Prospective researchers must present a copy of the written approval of the Northern Cape Department of Education to the head of the institution concerned before any research may be undertaken.
5. In case of some research projects it will be necessary for the applicant to obtain the written permission of the parents or legal guardians concerned personally before learners/ learners are involved.
6. Research may not be conducted during official contact time, as educator programmes should not be interrupted.
7. The research may not be conducted during the fourth term.

Page **1** of **2**

8. The research will be limited to those schools or institutions for which approval has been granted.
9. A copy of the completed report, dissertation or thesis, accompanied by a separate synopsis (maximum 2-3 typed pages) of the most important findings and recommendations if it does not already contain a synopsis, must be provided to the Frances Baard District Director.

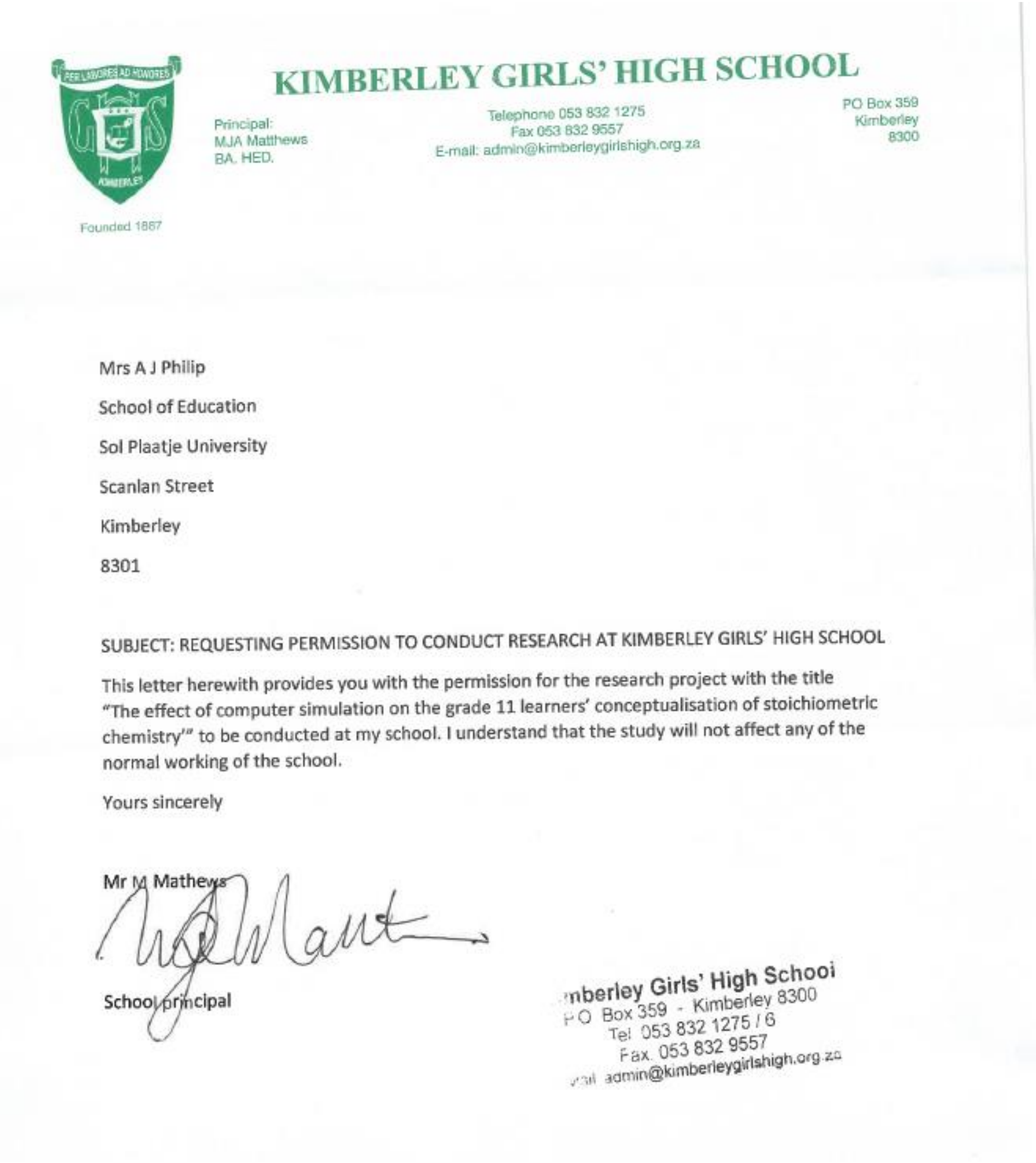
This letter herewith provides you with permission for the research project to be conducted at Kimberley Girls' High School within the Frances Baard District in the Northern Cape Province on condition the above are adhered to.

Yours sincerely

12/04/2019.

L. MONYERA
DISTRICT DIRECTOR: FRANCES BAARD DISTRICT

Appendix I: School permission to conduct research



PER LABORES AD HONORES
KIMBERLEY
Founded 1887

KIMBERLEY GIRLS' HIGH SCHOOL

Principal:
MJA Matthews
BA. HED.

Telephone 053 832 1275
Fax 053 832 9557
E-mail: admin@kimberleygirlshigh.org.za

PO Box 359
Kimberley
8300

Mrs A J Philip

School of Education

Sol Plaatje University

Scanlan Street

Kimberley

8301

SUBJECT: REQUESTING PERMISSION TO CONDUCT RESEARCH AT KIMBERLEY GIRLS' HIGH SCHOOL

This letter herewith provides you with the permission for the research project with the title "The effect of computer simulation on the grade 11 learners' conceptualisation of stoichiometric chemistry'" to be conducted at my school. I understand that the study will not affect any of the normal working of the school.

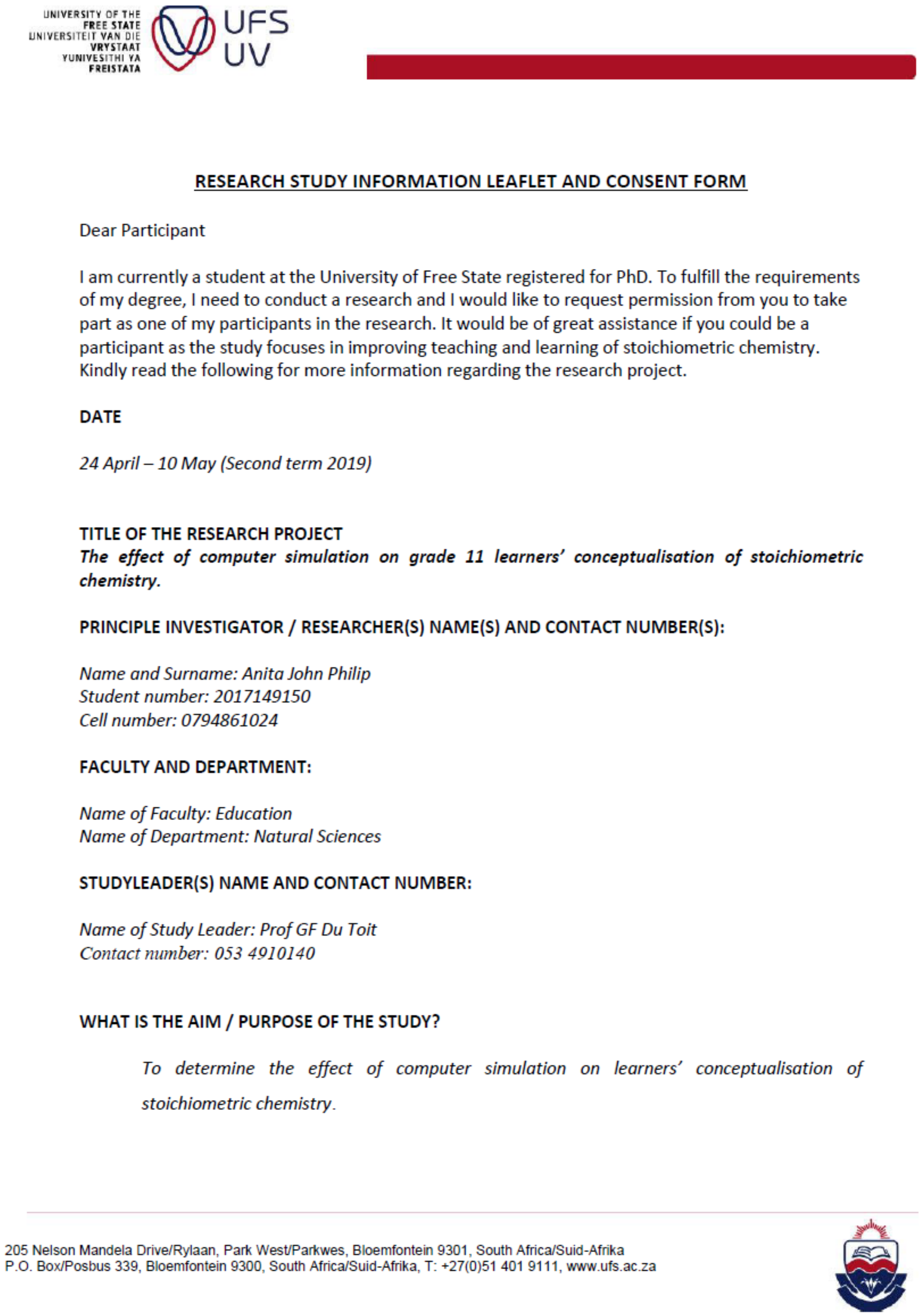
Yours sincerely

Mr M Mathews

School principal

nberley Girls' High School
PO Box 359 - Kimberley 8300
Tel 053 832 1275 / 6
Fax. 053 832 9557
ail admin@kimberleygirlshigh.org.za

Appendix J: Teacher consent form



RESEARCH STUDY INFORMATION LEAFLET AND CONSENT FORM

Dear Participant

I am currently a student at the University of Free State registered for PhD. To fulfill the requirements of my degree, I need to conduct a research and I would like to request permission from you to take part as one of my participants in the research. It would be of great assistance if you could be a participant as the study focuses in improving teaching and learning of stoichiometric chemistry. Kindly read the following for more information regarding the research project.

DATE

24 April – 10 May (Second term 2019)

TITLE OF THE RESEARCH PROJECT
The effect of computer simulation on grade 11 learners' conceptualisation of stoichiometric chemistry.

PRINCIPLE INVESTIGATOR / RESEARCHER(S) NAME(S) AND CONTACT NUMBER(S):

Name and Surname: Anita John Philip
Student number: 2017149150
Cell number: 0794861024

FACULTY AND DEPARTMENT:

Name of Faculty: Education
Name of Department: Natural Sciences

STUDYLEADER(S) NAME AND CONTACT NUMBER:

Name of Study Leader: Prof GF Du Toit
Contact number: 053 4910140

WHAT IS THE AIM / PURPOSE OF THE STUDY?

> *To determine the effect of computer simulation on learners' conceptualisation of stoichiometric chemistry.*

205 Nelson Mandela Drive/Rylaan, Park West/Parkwes, Bloemfontein 9301, South Africa/Suid-Afrika
P.O. Box/Posbus 339, Bloemfontein 9300, South Africa/Suid-Afrika, T: +27(0)51 401 9111, www.ufs.ac.za

WHO IS DOING THE RESEARCH?

I am Anita John Philip, a lecturer at Sol Plaatje University. I am conducting this research to fulfill the requirements for my PhD studies and also to make a contribution in the teaching and learning of stoichiometric chemistry in the Northern Cape Province schools.

HAS THE STUDY RECEIVED ETHICAL APPROVAL?

This study has received approval from the Research Ethics Committee of UFS. A copy of the approval letter can be obtained from the researcher.

Approval number: UFS-HSD2018/1292

WHY ARE YOU INVITED TO TAKE PART IN THIS RESEARCH PROJECT?

I was informed by the provincial co-ordinator for physical sciences that you have a large enrollment in physical sciences in grade 11 and have interest in improving physical sciences education at your school. Therefore to determine the effect of computer simulation on learners' conceptualisation of stoichiometric chemistry you are chosen to teach stoichiometric chemistry by either using the traditional method of teaching or computer simulation.

WHAT IS THE NATURE OF PARTICIPATION IN THIS STUDY?

The study involves an experimental pre-test post-test design, where the learners in the control group will be taught stoichiometric chemistry using the traditional method and learners in the experimental group will be taught the same topic using computer simulation. The role of the teacher as the participant is to conduct the teaching using anyone of the teaching methods and to conduct the pre-test and post-test. During your normal teaching time for physical sciences, according to the timetable of the school, the participant will be teaching his/her own learners in grade 11 the topic of stoichiometric chemistry either by using the traditional method or by making use of computer simulation. Both group of learners will write a pre-test set by the researcher and thereafter the intervention, they will write the post-test under the supervision of the participant teacher. These results will be compared and analysed later. Your learners will then participate in a questionnaire and interview. The duration of the participation will be the same as prescribed in the work schedule for teaching the topic send by the Department of Northern Cape education. No anticipated risks are foreseen for the participant. The researcher will explain all the details to the participant as the teacher before starting with the data collection.

CAN THE PARTICIPANT WITHDRAW FROM THE STUDY?

Participation in this study is voluntary and there will be no penalty or loss of benefit for not participating. You are under no obligation to consent to participation. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a written consent form. You are *free to withdraw any time without giving a reason before the learners have taken part in the questionnaire and interview. But kindly note and accept that once your learners have taken part in the questionnaire and interview you may not withdraw from the research.*

WHAT ARE THE POTENTIAL BENEFITS OF TAKING PART IN THIS STUDY?

Stoichiometric chemistry is always a topic that is least attractive to learners as they do not perform well in tests / examinations for questions based on it. By conducting this study the researcher aims to determine the effect of computer simulation in the conceptualisation of stoichiometric chemistry by grade 11 learners. The findings of the study could propose a new pathway for the teaching of stoichiometric chemistry. The participation in the study will be strictly kept confidential.

WHAT IS THE ANTICIPATED INCONVENIENCE OF TAKING PART IN THIS STUDY?

No potential inconvenience or discomfort are foreseen for the participants

WILL WHAT I SAY BE KEPT CONFIDENTIAL?

All information will be kept confidential. Names of the teachers participating will not be recorded anywhere in the research report, only codes will be used to refer to the participants in the data, any publications or research reporting methods such as conference proceedings. A transcriber will have access to the data, but the individuals will sign an agreement of confidentiality. Otherwise, records that identify you will be available only to people working on the study, unless you give permission for other people to see the records. A report of the data will be submitted for publication, but the individual participants will remain anonymous. While every effort will be made by the researcher to ensure that they will not be connected to the information that they may share during meetings, I cannot guarantee that other participants in the meetings will treat information confidentially. I shall, however, encourage all participants to do so. For this reason I will advise them not to disclose personally sensitive information during the study. The participants may withdraw themselves from the study any time that they feel so. Records that identify you will be available only to people working on the study, unless you give permission for other people to see the record.

HOW WILL THE INFORMATION BE STORED AND ULTIMATELY DESTROYED?

Hard copies of all answers made by learners will be stored by the researcher for a period of five years in a locked cupboard for future research or academic purposes; electronic information will be stored on a password protected computer. Future use of the stored data will be subject to further Research Ethics Review and approval if applicable. Information will be deleted from any computer and all hardcopies will be burned after a period of time.

WILL I RECEIVE PAYMENT OR ANY INCENTIVES FOR PARTICPATING IN THIS STUDY?

Unfortunately, there will be no payment or financial reward for taking part in the study.

HOW WILL THE PARTICIPANT BE INFORMED OF THE FINDINGS / RESULTS OF THE STUDY?

If you would like to be informed of the final research findings, please contact Anita John Philip on 0794861024 or anita.philip@spu.ac.za. The findings are accessible for a year. Should you require any further information or want to contact the researcher about any aspect of this study, please contact on above contact detail. Should you have concerns about the way in which the research has been conducted, you may contact Prof GF Du Toit, 0534910140 or email at Gawie.dutoit@spu.ac.za.

Kindly attach your signature below if you agree to be a participant

Teacher Signature:

Thank you for taking time to read this information sheet and for participating in this study.

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA
UFS
UV

CONSENT TO PARTICIPATE IN THIS STUDY- Teacher consent form

I, ______________________________________ (participant name), confirm that the person asking my consent to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read (or had explained to me) and understood the study as explained in the information sheet. I have had sufficient opportunity to ask questions and am prepared to participate in the study. I understand that my participation is voluntary and that I am free to withdraw at any time without penalty (if applicable). I am aware that the findings of this study will be anonymously processed into a research report, journal publications and/or conference proceedings.

I agree to the recording of the pre-test and post-test that was conducted before and after my teaching for *data collection*.
I have received a signed copy of the informed consent agreement.

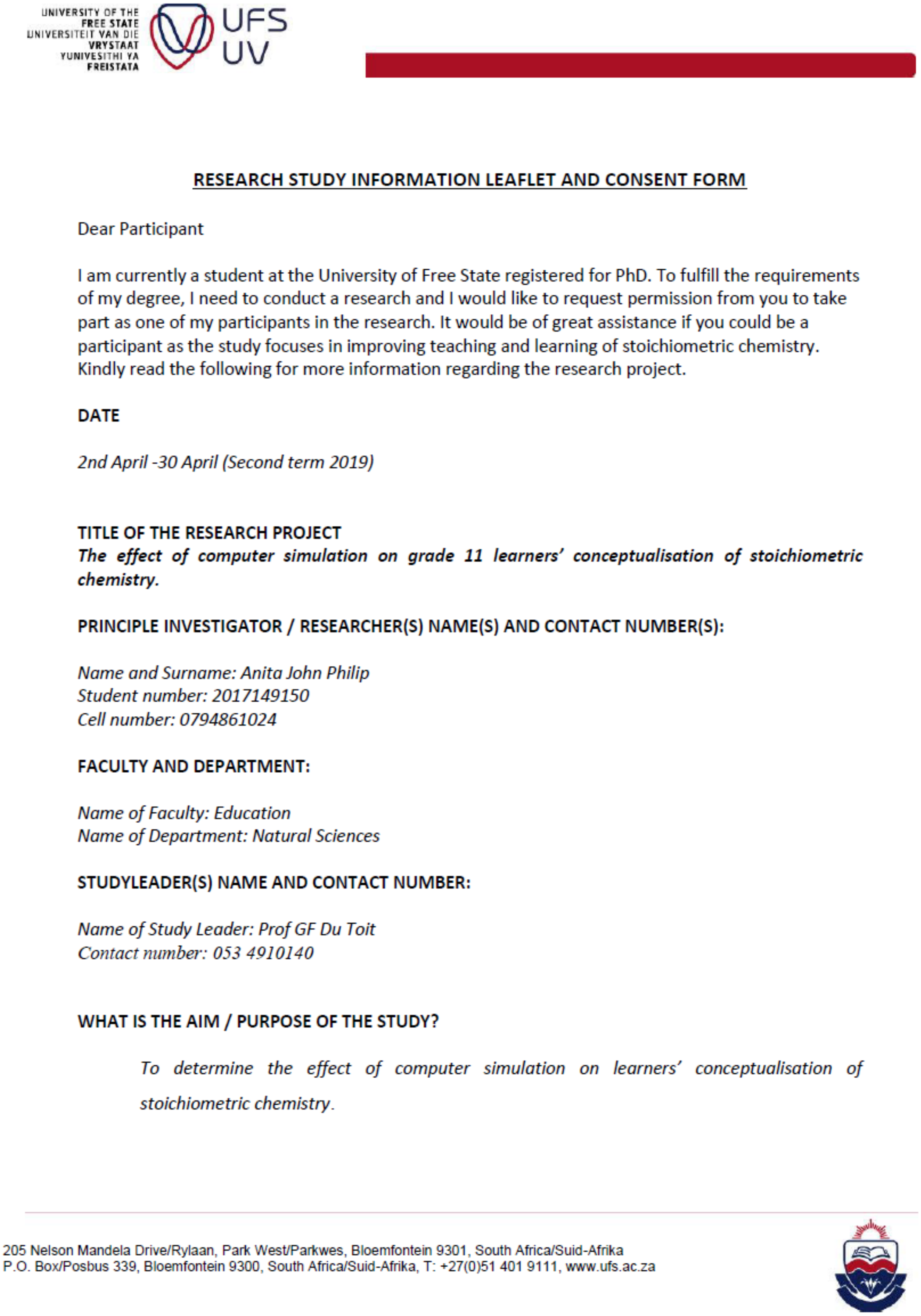
Full Name of Participant: ____

Signature of Participant: ____________________________________ Date: ____________________

Full Name(s) of Researcher(s): ____

Signature of Researcher: ____________________________________ Date: ____________________

Appendix K: Parent/learner consent form



UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA
UFS
UV

RESEARCH STUDY INFORMATION LEAFLET AND CONSENT FORM

Dear Participant

I am currently a student at the University of Free State registered for PhD. To fulfill the requirements of my degree, I need to conduct a research and I would like to request permission from you to take part as one of my participants in the research. It would be of great assistance if you could be a participant as the study focuses in improving teaching and learning of stoichiometric chemistry. Kindly read the following for more information regarding the research project.

DATE

2nd April -30 April (Second term 2019)

TITLE OF THE RESEARCH PROJECT
The effect of computer simulation on grade 11 learners' conceptualisation of stoichiometric chemistry.

PRINCIPLE INVESTIGATOR / RESEARCHER(S) NAME(S) AND CONTACT NUMBER(S):

Name and Surname: Anita John Philip
Student number: 2017149150
Cell number: 0794861024

FACULTY AND DEPARTMENT:

Name of Faculty: Education
Name of Department: Natural Sciences

STUDYLEADER(S) NAME AND CONTACT NUMBER:

Name of Study Leader: Prof GF Du Toit
Contact number: 053 4910140

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205 Nelson Mandela Drive/Rylaan, Park West/Parkwes, Bloemfontein 9301, South Africa/Suid-Afrika
P.O. Box/Posbus 339, Bloemfontein 9300, South Africa/Suid-Afrika, T: +27(0)51 401 9111, www.ufs.ac.za

WHO IS DOING THE RESEARCH?

I am Anita John Philip, a lecturer at Sol Plaatje University. I am conducting this research to fulfill the requirements for my PhD studies and also to make a contribution in the teaching and learning of stoichiometric chemistry in the Northern Cape Province schools.

HAS THE STUDY RECEIVED ETHICAL APPROVAL?

This study has received approval from the Research Ethics Committee of UFS. A copy of the approval letter can be obtained from the researcher.

Approval number: UFS-HSD2018/1292

WHY ARE YOU INVITED TO TAKE PART IN THIS RESEARCH PROJECT?

The participants of the study needs to be two physical sciences teachers and their usual physical sciences learners in grade 11. Your teacher was identified to be the appropriate participant to teach stoichiometric chemistry. The study will be conducted during normal contact time according to the timetable of the school and hence you as the learner of the teacher was chosen as the participant.

WHAT IS THE NATURE OF PARTICIPATION IN THIS STUDY?

The study involves an experimental pre-test post-test design, where the learners in the control group will be taught stoichiometric chemistry using the traditional method and learners in the experimental group will be taught the same topic using computer simulation. The role of the teacher as the participant is to conduct the teaching using anyone of the teaching methods and to conduct the pre-test and post-test. During your normal teaching time for physical sciences, according to the timetable of the school, your teacher will be teaching the learners, the topic of stoichiometric chemistry either by using the traditional method or by making use of computer simulation. Both group of learners will write a pre-test set by the researcher and thereafter the intervention, they will write the post-test under the supervision of the participant teacher. These results will be compared and analysed later. The learners as participants will also answer the questionnaire and nine randomly selected learners will be interviewed. The duration of the participation will be the same as prescribed in the work schedule for teaching the topic send by the Department of Northern Cape education. No anticipated risks are foreseen for the participant. The researcher will explain all the details to the participant as the teacher before starting with the data collection.

CAN THE PARTICIPANT WITHDRAW FROM THE STUDY?

Participation in this study is voluntary and there will be no penalty or loss of benefit for not participating. You are under no obligation to consent to participation. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a written consent form. You are free to withdraw any time without giving a reason during the pre-test post-test experimental design.

But kindly note and accept that once you have taken part in the questionnaire and interview you may not withdraw from the research.

WHAT ARE THE POTENTIAL BENEFITS OF TAKING PART IN THIS STUDY?

Stoichiometric chemistry is always a topic that is least attractive to learners as they do not perform well in tests / examinations for questions based on it. By conducting this study the researcher aims to determine the effect of computer simulation in the conceptualisation of stoichiometric chemistry by grade 11 learners. The findings of the study could propose a new pathway for the teaching of stoichiometric chemistry. The participation in the study will be strictly kept confidential.

WHAT IS THE ANTICIPATED INCONVENIENCE OF TAKING PART IN THIS STUDY?

No potential inconvenience or discomfort are foreseen for the participants

WILL WHAT I SAY BE KEPT CONFIDENTIAL?

All information will be kept confidential. Names of the learners participating will not be recorded anywhere in the research report, only codes will be used to refer to the participants in the data, any publications or research reporting methods such as conference proceedings. A transcriber will have access to the data, but the individuals will sign an agreement of confidentiality. Otherwise, records that identify you will be available only to people working on the study, unless you give permission for other people to see the records. A report of the data will be submitted for publication, but the individual participants will remain anonymous. While every effort will be made by the researcher to ensure that they will not be connected to the information that they may share during meetings, I cannot guarantee that other participants in the meetings will treat information confidentially. I shall, however, encourage all participants to do so. For this reason I will advise them not to disclose personally sensitive information during the study. The participants may withdraw themselves from the study any time that they feel so except after taking part in the questionnaire and interview. . Records that identify you will be available only to people working on the study, unless you give permission for other people to see the record.

HOW WILL THE INFORMATION BE STORED AND ULTIMATELY DESTROYED?

Hard copies of all answers made by learners will be stored by the researcher for a period of five years in a locked cupboard for future research or academic purposes; electronic information will be stored on a password protected computer. Future use of the stored data will be subject to further Research Ethics Review and approval if applicable. Information will be deleted from any computer and all hardcopies will be burned after a period of time.

WILL I RECEIVE PAYMENT OR ANY INCENTIVES FOR PARTICPATING IN THIS STUDY?

Unfortunately, there will be no payment or financial reward for taking part in the study.

HOW WILL THE PARTICIPANT BE INFORMED OF THE FINDINGS / RESULTS OF THE STUDY?

If you would like to be informed of the final research findings, please contact Anita John Philip on 0794861024 or anita.philip@spu.ac.za. The findings are accessible for a year. Should you require any further information or want to contact the researcher about any aspect of this study, please contact on above contact detail. Should you have concerns about the way in which the research has been conducted, you may contact Prof GF Du Toit, 0534910140 or email at Gawie.dutoit@spu.ac.za.

Thank you for taking time to read this information sheet and for participating in this study.

CONSENT TO PARTICIPATE IN THIS STUDY- Parent/Learner consent form

I, ____________________________________ (participant name), confirm that the person asking my consent to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read (or had explained to me) and understood the study as explained in the information sheet. I have had sufficient opportunity to ask questions and am prepared to participate in the study. I understand that my participation is voluntary and that I am free to withdraw at any time without penalty (if applicable). I am aware that the findings of this study will be anonymously processed into a research report, journal publications and/or conference proceedings.

I agree to the recording of the pre-test and post-test , questionnaire and interview that was conducted with me for *data collection*.
I have received a signed copy of the informed consent agreement.

Full Name of Participant: ____

Signature of Participant: ____________________________________ Date: ____________________

Full Name(s) of Researcher(s): ____

Signature of Researcher: ____________________________________ Date: ____________________

Appendix L: Ethics statement

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA
UFS·UV
EDUCATION
OPVOEDKUNDE

Faculty of Education

16-Apr-2019

Dear **Mrs Anita Philip**

Ethics Clearance: **The effect of computer simulation on grade 11 learners' conceptualisation of stoichiometric chemistry.**

Principal Investigator: **Mrs Anita Philip**

Department: **School of Education Studies Department (Bloemfontein Campus)**

APPLICATION APPROVED

With reference to you application for ethical clearance with the Faculty of Education, I am pleased to inform you on behalf of the Ethics Board of the faculty that you have been granted ethical clearance for your research.

Your ethical clearance number, to be used in all correspondence is: **UFS-HSD2018/1292**

This ethical clearance number is valid for research conducted for one year from issuance. Should you require more time to complete this research, please apply for an extension.

We request that any changes that may take place during the course of your research project be submitted to the ethics office to ensure we are kept up to date with your progress and any ethical implications that may arise.

Thank you for submitting this proposal for ethical clearance and we wish you every success with your research.

Yours faithfully

Prof. MM Mokhele Makgalwa
Chairperson: Ethics Committee

Education Ethics Committee
Office of the Dean: Education
T: +27 (0)51 401 3777| F: +27 (0)86 546 1113 | E: MokheleML@ufs.ac.za
Winkie Direko Building | P.O. Box/Posbus 339 | Bloemfontein 9300 | South Africa
www.ufs.ac.za

Appendix M: Turnitin report

Anita

ORIGINALITY REPORT

10%	10%	4%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	uir.unisa.ac.za Internet Source	1%
2	www.tandfonline.com Internet Source	1%
3	hdl.handle.net Internet Source	1%
4	moam.info Internet Source	<1%
5	2019.fmgtegitimikongresi.com Internet Source	<1%
6	epdf.pub Internet Source	<1%
7	dokumen.pub Internet Source	<1%
8	silo.pub Internet Source	<1%
9	iisit.org Internet Source	<1%

Appendix N: Language editing

Declaration

26 February 2021

PO Box 4
Otjiwarongo
Namibia

Student: Anita Philip

Thesis: The Effect of Computer Simulation on Grade 11 Learners' Conceptualisation of Stoichiometric Chemistry

I confirm that I edited this thesis and checked the references. I made suggestions for changes, which the student accepted or rejected.

HSHuman

MA Language Practice

Hettie Human
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