An investigation into how two Grade 11 Physical Science teachers mediate learning of the topic chemical equilibrium: A case study

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by

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DECLARATION OF ORIGINALITY

I, **FUNGISISAI MILLICENT CHANI** declare that this thesis has not been submitted for a degree in any other university and that it is my original work.

Signature  Date: 10 November 2014

ABSTRACT

The Namibian Physical Science Higher Level Syllabus requires students to study the topic on chemical equilibrium. This section has proven to be one of the most difficult for Namibian learners as reflected by their poor responses to questions in the Grade 12 NSSC 'H' examinations.

Triggered by these discoveries, I decided to conduct a research on how teachers mediate learning of the topic on chemical equilibrium in a Namibian context. Conducted at a private school in Windhoek, the study involved two experienced Grade 11 Physical Science teachers renowned for good results.

I adopted a qualitative case study underpinned by an interpretive paradigm. Sense making of concepts on chemical equilibrium was my unit of analysis. To generate data, I used document analysis, semi-structured interviews, lesson observations, which were videotaped as well as stimulated recall interviews. Vygotsky's mediation of learning and social constructivism blended with Shulman's pedagogical content knowledge (PCK) were the theoretical frameworks adopted in the study. During the analysis process, there was grouping of data into categories. These included teacher-learner interactions as emphasized by Vygotsky's mediation of learning and learners' challenges according to PCK. I used an inductive approach to identify emerging themes from my data. The themes were colour coded and the developed into analytical statements.

Data triangulation, member checking, and peer review ensured data validity and trustworthiness. Stimulated recall interviews conducted while watching the videos with the two teachers, complemented these approaches.

My findings were that teachers extensively used various meditational tools such as prior knowledge, language, analogies and an equilibrium game to mediate learning. The teachers experienced numerous challenges during mediation of learning, including language difficulties and learners' failure to comprehend complex chemical equilibrium concepts. Notwithstanding, the teachers in this study managed to some extent to overcome the challenges by exhibiting facets of advanced PCK.

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I am indebted to my research participants and critical friend for being extremely cooperative. To all my colleagues at work, I value your encouragement.

My husband, Kuda, I appreciate all your invaluable support and for sitting long hours with me as I worked on my project. I am thankful to my children Sheunopa and Sarah for the gourmet meals they prepared while I conducted my research.

I am obliged to the Holy Spirit, the spirit of knowledge, wisdom and understanding.

DEDICATION

To all the Chemistry teachers who are passionate about education, I dedicate this thesis to you.

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LIST OF ABBREVIATIONS AND ACRONYMS

E	Excerpt
HPS	History and Philosophy of Science
L:	Learner
LLL:	Group of chorusing learners
LCP	Le Chatelier's principle
LCE:	Learner centred education
LTSM:	Learning and teaching support material
L1	Lesson 1
L2	Lesson 2
L3	Lesson 3
L4	Lesson 4
MEC:	Ministry of Education and Culture
M ED:	Masters in Education
NIED:	National Institute for Educational Development
PAR	Participatory action research
PCK:	Pedagogical content knowledge
SMK:	Subject matter knowledge
SRI	Stimulated recall interview
TIMSS:	Trends in International Mathematics and Science Study
T1:	Teacher 1
T2:	Teacher 2
ZPD:	Zone of proximal development

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Chapter 1

Situating the study

> *It is only, so the qualitative researcher argues, if one understands events against the background of the whole context and how such a context confers meaning to the events concerned, that one can truly claim to 'understand' the events (Babbie & Mouton, p. 273).*

1.1 Introduction

The main goal of my study was to discover how two Grade 11 teachers mediated learning of the topic, chemical equilibrium. In this chapter, the background of the study is described. As referred to in the epigraph, understanding the context of a study helps the reader to fully comprehend the research findings. A summary of the research goal and questions follows. The theoretical framework of the study is highlighted. In addition, the potential value of the study is suggested. Definitions of the key concepts are stated. The thesis outline is also discussed. The chapter culminates with some concluding remarks.

1.2 Background to the study

1.2.1 The international and regional context

According to Gonzales, Guzman, Partelow, Pahlke, Jocelyn, Katsberg and Williams (2004) in the Highlights from the Trends in International Mathematics and Science Study (TIMSS) 2003, there was a general decline in science achievement scores from 1995 to 2003. In a similar publication, TIMSS 2011 International Results in Science by Provasnik, Katsberg, Ferraro, Lemanski, Roey, and Jenkins (2012), the students performed much better in questions which required factual recall rather than those of reasoning and application. These facts show that learners are facing challenges in learning science particularly in areas where rationalisation is required.

Several studies in different parts of the world have shown that the topic, chemical equilibrium is one of the most important and yet challenging areas for both students and teacher (Chiu, Chou & Liu, 2002; Thomas & McRobbie, 2002; Bilgin & Geban, 2006; Quilez, 2006; Sarıçayır, Şahin, & Üce, 2006; Rudd, Greenbowe & Hand, 2007). As a result of this lack of understanding, students develop a considerable number of misconceptions about the subject (Voska & Heikkinen, 2000).

Based on their research conducted in Western Australia, Tyson, Treagust and Bucat (1999) posit that teachers experience difficulty with teaching chemical equilibrium for a number of reasons. These include, the language needed to explain concepts, which learners can easily misunderstand. Secondly, the content contains numerous abstract ideas that require very specific terminology. Furthermore, an attempt to simplify the challenging concepts often leads to misconstructions (ibid).

Agreeing with this, Van Driel (2002) postulates that the problems associated with the teaching of chemical equilibrium are perpetuated by conflicting prior knowledge. These ideas are introduced in the later years of learners' high school careers. By that time they would have accumulated a significant amount of prior knowledge in chemistry, so when learners are introduced to the principles of dynamic equilibrium, the concepts conflict with their existing knowledge, which makes it difficult for students to assimilate the concepts (ibid).

Similarly, in their study in South Africa, Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) found that both learners and teachers misunderstand the concepts pertaining to chemical equilibrium. They argue that teachers often lack the subject matter knowledge (SMK) coupled with the pedagogical content knowledge (PCK) to facilitate the mediation of learning this topic effectively. Consequently, they focus on procedural knowledge rather that conceptual understanding during teaching and learning (ibid).

Cheung (2009), reasons that there are limitations to the application of Le Chatelier's principle in predicting the changes that occur to systems in equilibrium. Consequently, the Le Chatelier's principle has contributed to the teachers' misconceptions in chemical equilibrium.

1.2.2 The Namibian context

After independence in 1990, the Namibian education system went through a major policy reform. This was a political initiative aimed at redressing the existing inequalities in access to education. As a way of guaranteeing social justice and democracy, a learner-centred education (LCE) approach was adopted (Namibia. Ministry of Education and Culture (MEC), 1993).

According to the MEC (1993), LCE is an educational approach positioning the learner at the centre of teaching. This implies that in lessons emphasis is on the learners' interests, active participation and prior knowledge. Within this paradigm, LCE teaching methods such as group work are prescribed. This is in contrast to traditional teaching strategies such as the lecture method. In the same vein, the teacher is viewed as a facilitator of learning, rather than as a mere transmitter of knowledge.

However, Nyambe (2008) suggests that LCE has not been successfully implemented in Namibia. In a study in the country, he found that teachers had difficulty in interpreting and practicing the learner-centred approach. Factors such as lack of skills, overcrowded classrooms and limited resources were some of the constraining factors. As a solution, he proposes a gradual transition from teacher-centred to learner-centred methods (ibid).

Notwithstanding, learner-centred approaches are prescribed in the Physical Science Higher Level Syllabus. In this course outline, the learners are required to study the concepts underlying chemical equilibrium. The topic connects to other major sections such as acids and bases, and industrial chemistry. Learners need to apply equilibrium concepts to these units of the syllabus.

Furthermore, the learners are expected to demonstrate certain competences after studying chemical equilibrium. The syllabus states that the learners should be able to:

- *describe chemical reactions that can be reversed by changing the reaction conditions;*
- *outline the principle that a system in equilibrium is subjected to change:*
  - *an increase in pressure favours the system which has the smaller volume; and*
  - *a rise in temperature favours the system which is formed with absorption of energy*
- *use this principle to determine the direction in which the reaction will go when changing concentration, pressure and temperature;*
- *construct an equilibrium constant expression for a simple homogeneous (gas phase or solution) reversible reaction;*
- *calculate an equilibrium constant by substituting given equilibrium partial pressures or concentrations (Kp and Kc) as well as deduce the unit of the constant;*
- *show qualitative understanding that the magnitude of an equilibrium constant indicates how far a reversible reaction proceeds towards completion*

(Namibian Institute of Education Department (NIED), 2009, p. 46).

At the end of Grade 12, learners schooled in Namibia sit for the Namibian Senior Secondary Certificate examinations. The assessments are written on two levels, Higher and Ordinary. The Namibian Higher Level Syllabus requires students to study the topic, chemical equilibrium. In

Namibia, this topic has proven to be one of the most difficult topics for science students. This is reflected in their poor performance in this section in the Grade 12 NSSC 'H' examinations.

The Physical Science NSSCH Examiners' reports reflect that learners in Namibia experience a significant challenge with chemical equilibrium concepts (2009-2012). To begin with, they do not understand Le Chatelier's principle and they are unable to apply it. Moreover, learners contradict themselves when answering questions. For example, they can predict a shift in the equilibrium which is opposite to the increase in concentrations. Questions which refer to changes in temperature are poorly answered. Learners refer to pressure in their responses instead of looking at whether reactions are exothermic or endothermic. In some cases, candidates are unable to answer questions which are regarded as straight forward by examiners. Their responses often lack the required scientific language to score marks. Conversely, learners generally answer equilibrium constant problems well. They are able to formulate the equilibrium expressions and derive the units. Yet, if any critical thinking is required, only the top students give correct answers (Namibia. MoE. Report on the Examinations NSSC (H), 2009, 2010, 2011, 2012)

As a concerned science teacher, I had discussions with markers, and they agreed with the examiners' reports. The markers alluded to the fact that students in Namibia generally find it problematic to explain the chemical equilibrium phenomena during examinations. Nevertheless, they pointed out that learners from a few schools do well in the topic. I selected one of these schools as my research site.

In an informal interview with the Chief Examiner, she confirmed that students' answers to the section often reflect an absence of conceptual understanding. She argued that the poor quality of the answers is as a result of how chemical equilibrium is taught in Namibia.

These findings and conversations aroused my curiosity to do my research on this seemingly problematic topic. I searched for studies done in Namibia on the teaching and learning of chemical equilibrium and could not find any. Consequently, I decided to conduct a qualitative study to gain insights into how two teachers in Windhoek actually mediate the topic on chemical equilibrium.

1.3 Research goal and questions

1.3.1 Research goal

To understand how Grade 11 Physical Science teachers mediate the learning of the topic chemical equilibrium.

1.3.2 Main research question:

How do Grade 11 Physical Science teachers mediate the learning of the topic chemical equilibrium during their lessons?

1.3.3 Sub-questions:

- What are Grade 11 Physical Science teachers' views and experiences of this mediation?
- How do Grade 11 Physical Science teachers provide a scaffold for learners to make sense of the concepts associated with the topic?
- What challenges do Grade 11 Physical Science teachers experience in teaching this topic?
- In what ways can Grade 11 Physical Science teachers be supported with the mediation of learning of the topic chemical equilibrium?

1.4 Theoretical framework

The theoretical framework adopted for the study was mediation of learning infused with social constructivism as defined by Vygotsky (1978) and blended with pedagogical content knowledge (PCK) (Schulman, 1987).

1.5 Potential value of my study

This research is a qualitative case study which aims at attaining an understanding of the teaching of the topic chemical equilibrium by two teachers.

- The study can inform science teachers about the complexities associated with equilibrium theories. At the same time, through being exposed to other teachers' classroom practices, they can reflect on their own and hopefully improve their practice. The teachers may also identify ways to help increase learners' conceptual understanding.

- A chemical equilibrium module was developed in collaboration with the research participants. The teaching resource takes into account the challenges learners face in understanding chemical equilibrium. For that reason, the module is capable of assisting me and other teachers during the mediation of chemical equilibrium.
- I could not find any published research on the topic of chemical equilibrium in Namibia; despite the fact that learners generally experience difficulties with the subject matter. Hence, this study may be used as a reference for further research and contribute to the alleviation of learners' problems in this area
- Curriculum developers may gain some understanding of the issues surrounding the teaching of chemical equilibrium. Consequently, they would be able to use this comprehension when developing resource materials.
- Lastly, the research findings may assist me in improving my own teaching practice.

1.6 Data gathering techniques

Different data gathering techniques were used to collect information. Triangulation of this data ensured its validity. These methods are:

- Document analysis;
- Observations;
- Semi-structured interviews; and
- Stimulated recall interviews.

1.7 Definition of key concepts

Some key concepts are repeatedly referred to in the study. These are chemical equilibrium, mediation, mediation tool, pedagogical content knowledge, prior everyday knowledge, learner support materials scaffolding, social constructivism, subject matter knowledge and teaching strategies. They are defined as follows:

1.7.1 **Chemical equilibrium:** is a state in which the concentrations of reactants and products are constant.

1.7.2 **Mediation of learning:** the process in which the teacher interacts with the learner in order to scaffold their intellectual development.

1.7.3 **Mediation tools:** the means through which mediation of learning is achieved, they can be physical or psychological.

1.7.4 **Pedagogical content knowledge (PCK):** a concept which describes the way in which teachers present and formulate subject content in order to make it understandable by students.

1.7.5 **Prior knowledge:** the information the learners bring with them into the classroom which can be scientific or non-scientific.

1.7.6 **Scaffolding:** is the assistance provided to learners during the teaching and learning process in order to help them make sense of ideas.

1.7.7 **Social constructivism**: a socio-cultural theory which advances that knowledge is acquired through interactions in a social context.

1.7.8 **Subject matter knowledge (SMK):** the possession of information relating to a topic.

1.7.9 **Teaching strategies**: The methods that a teacher uses to help learners to master concepts in the classroom.

1.8 Thesis outline

The study was conducted on two teachers at a private school in Windhoek and the thesis consists of six chapters. An outline of each chapter is given in the subsequent narrative.

Chapter 1 explains the aim, outline and structure of the study. A discussion of the background of the research is presented. The reasons for carrying out the study are outlined. In this chapter, the research goal and questions are specified. At the same time, the potential value of the study is proposed.

Chapter 2 provides an overview of the literature relating to mediation of the chemical equilibrium concepts in Namibia. All the factors which influence the teaching of the topic are explored. In addition, an account of the theoretical framework utilised in the research is described.

Chapter 3 clarifies the qualitative research methodology adopted in the study. The data gathering techniques and the rationale behind their use are portrayed. This chapter explains the qualitative research methodology used to answer the research questions. Thus, it answers why a qualitative research methodology was adopted. Further, the reasons behind the use of document analysis, interviews, lesson observations and participatory action research are explained. The use of the purposive sampling technique is discussed. Lastly, an overview of the data analysis procedures is presented.

Chapter 4 provides a narrative account of the data generated through document analysis, interviews and lesson observations. The presentation is from the perspective of the research participants and several direct quotes are included.

Chapter 5 summarises the results of the data collection. The chapter begins with a profile of the of the research participants, i.e. their qualifications and teaching experience. The highlights of the interviews, observations and document analysis conclude the chapter.

Chapter 6 is the data analysis section. In this chapter, the data presented in Chapter 5 is examined by means of the theoretical framework and literature. The data is sorted and presented under different categories. These are subdivided into various themes which emerged during the research. The themes encompass students' misconceptions, how the teachers deal with the alternative frameworks and teacher-student interactions.

Chapter 7 sums up the main findings. These comprise:

- Implications of the research outcomes;
- Suggestions for Physical Science teachers;
- Limitations of the study, and suggestions for further research;
- Lessons learnt from the study;
- Recommendations; and
- Personal reflections.

1.9 Concluding remarks

In this chapter the context of the study, research goals and questions, definition of concepts and the thesis outline were discussed. This will help the reader to navigate through the study with ease. Knowledge of the research background of the study will enable thorough understanding of the investigation. In Chapter 2 the literature relating to the mediation of chemical equilibrium concepts is reviewed.

Chapter 2

Literature review

> *Investigators who do not take time to find out what has already been thought or researched may be missing an opportunity to make a significant contribution to their field (Merriam, 2009, p. 72).*

2.1 Introduction

The main goal of my study is to investigate how two teachers mediate the learning of the topic of chemical equilibrium. A number of scholars have attempted to explore this seemingly challenging area. As suggested by Merriam (2009) in the epigraph, to ensure that my investigation would contribute meaningfully to the understanding of chemical equilibrium, it was mandatory to investigate what others have researched.

In this chapter, the literature relating to how teachers mediate the concepts of chemical equilibrium is discussed. Several studies and arguments are presented in order to illustrate the different factors influencing the mediation of the topic.

Firstly, the key equilibrium concepts covered by the Namibian Higher Level Physical Science syllabus are highlighted. The challenges faced when mediating the topic are discussed and possible solutions are explained as they are presented in different studies.

Secondly, a detailed analysis of mediation of learning is included and the origins of mediation are explained. This is followed by an analysis of the tools and strategies employed by teachers in the science classrooms.

Lastly, the theoretical framework adopted in this study is explored. In order to gain insight into how teachers mediate learning, I employed the theories of social constructivism and pedagogical content knowledge (PCK).

2.2 Mediation of key chemical equilibrium concepts as reflected in the Namibian syllabus: challenges and solutions

In the Namibian Higher Level Physical Science syllabus several key chemical equilibrium concepts are covered (Namibian Institute of Educational Development (NIED), 2010). These are: reversibility of reactions, dynamic equilibrium and the equilibrium constant (ibid).

Although the Namibian syllabus covers a number of concepts considered central to understanding chemical equilibrium, it has some deficiencies. Based on the literature explored, one of the shortcomings of the Namibian syllabus is that it does not mention the reaction quotient, Q (Tyson et al. 1999). Q represents the ratio between the products and reactants at a particular instant. It is considered a crucial concept in predicting changes in reaction mixtures and should be used in conjunction with the equilibrium law (ibid).

Cai and Ni (2011) in their investigation of the effect of the syllabi on mediation of learning in China, posit that the syllabus is central to mediation of learning. It determines what content is to be taught and how. They add that omissions in the syllabus can negatively influence learners' conceptual understanding and development of higher order thinking skills (ibid).

As I explained in the first chapter, in both Namibia and globally, the teaching of chemical equilibrium is the most difficult topic for teachers (Sarıçayır et al., 2006). However, in Namibia, not much research has been carried out on how this topic is mediated and the problems faced during the process. Consequently, I decided to investigate how two teachers in Namibia attempt to meet the challenge.

In the ensuing paragraphs, I will discuss the challenges encountered during the mediation of chemical equilibrium and some possible solutions.

2.2.1 Challenges associated with the mediation of the topic on chemical equilibrium

A number of gaps and difficulties are associated with the teaching of chemical equilibrium in different countries. Some of the problems include the abstract nature of the topic, the use of Le Chatelier's principle and the lack of teacher knowledge.

2.2.1.1 The abstract nature of concepts

The very nature of chemical equilibrium concepts is a source of difficulty during the mediation of learning. According to Tyson et al. (1999), chemical equilibrium theories are abstract in nature making them difficult to comprehend. At the same time, there are also very subtle differences between concepts causing learners to give incorrect explanations for phenomena (ibid).

According to the Namibian syllabus, one of the concepts learners have to study is reversible reactions (NIED, 2010). These are reactions, which do not proceed in one direction but backwards, and forwards (Tyson et al., 1999). A common misconception held by learners is that all reactions progress in a single direction only. The misunderstanding is compounded by explaining reactions in terms of reactants and products (ibid).

In addition, the Namibian Physical Science syllabus requires learners to predict changes in the equilibrium system (NIED, 2010). Chemical equilibrium is established when two reactions occur concurrently and at equal rates (Petrucci, Harwood, Herring & Madura, 2002). Bilgin and Geban (2006) submit that there are a number of alternative conceptions based on the equilibrium concept. For instance, at equilibrium, a system does not seem to be changing, whereas at the sub-microscopic level, bond breaking and formation will be taking place. Learners often use what they see to explain sub-microscopic changes resulting in a failure to appreciate the dynamic nature of equilibrium. They erroneously assume that as a reaction approaches equilibrium it causes the rate of the forward reaction to increase. Moreover, learners separate the components of equilibrium mixtures, that is, they perceive reactions to be occurring in distinct compartments instead of in the same system (ibid).

Furthermore, learners are required to study the Equilibrium Law and write an expression for the equilibrium constant. Van't Hoff derived the Equilibrium Law in 1884 after a series of observations on reversible reactions (Quilez, 2006). The principle outlines the mathematical relationship between concentration of reactants and products at equilibrium (ibid).

Tyson et al. (1999) recommend the use of the equilibrium constant in predicting changes in equilibrium systems. They argue that it provides accurate predictions for changes in conditions such as pressure, which are difficult to explain by other methods. In support of teaching the Equilibrium Law, they further state that it results in fewer misconceptions than using the commonly used Le Chatelier's principle (ibid).

In contrast, Voska and Heikkinen (2000), in their study of chemistry second year university students in the United States found they had different conceptual problems relating to the equilibrium constant. 40% of the students were unable to asertain the conditions affecting the value of the equilibrium constant. As a result they could not determine when the constant remained constant or changed. This limited the students' ability to answer equilibrium questions using the equilibrium law and constant (ibid).

2.2.1.2 The use of Le Chatelier's Principle

The Namibian syllabus recommends the use of Le Chatelier's Principle (LCP) when explaining changes in equilibrium (NIED, 2010). According to Petrucci et al. (2002), LCP states that if a system is subjected to a change in conditions, the system will respond by partially counteracting the imposed change to re-establish equilibrium (p. 641). The principle aims at explaining changes in equilibrium conditions such as temperature, pressure and concentration of reacting species.

Hillert (1995) posits that Le Chatelier's principle is important in explaining and predicting various disturbances in equilibrium. Since the principle is qualitative in nature, it can be used in instances when mathematical formulations are not possible (ibid). Similarly, Tyson et al. (1999) explain that teachers and textbooks continue to use the principle because they find it is easier and more straightforward than other methods.

Nevertheless, there are numerous critiques against the use of the LCP when mediating the chemical equilibrium topic. Quilez (2004) argues that the LCP uses demanding language, which students do not easily understand. The vocabulary is vague and difficult to explain thereby strengthening the possibility of misconceptions. As an illustration, students may find it problematic to distinguish between the 'change', the 'response' and what is being 'opposed' (ibid).

Similarly, Kousathana and Tsaparlis (2002) carried out research in Athens using learners from various secondary schools. They discovered that the majority of learners applied LCP to heterogeneous systems. As a result, they made wrong predictions about the effect of adding a solid reactant to a gaseous system in equilibrium. Thus, the researchers posit that learners do not understand the conditions under which the principle is applied.

Cheung (2009) agrees that the use of LCP in predicting the effect of changes in equilibrium conditions regularly generates alternative conceptions. He developed a misconception test to probe the adequacy of LCP in Hong Kong. Cheung (2009) found out that most teachers in his study failed to make accurate explanations because of using LCP. They could not describe accurately the effect of changes in temperature, pressure and concentration on the equilibrium mixture. For one particular question, only two teachers out of thirty-three gave the correct answer because they used the Equilibrium Law instead of LCP. This strengthened Cheung's (2009) argument that the LCP has flaws that limit its applicability. However, the learners may not have the mathematical capacity to use the law correctly, for instance the ability to understand fractions well enough in the case of large numerators or denominators (Voska & Heikkinen, 2000).

2.2.1.3 Inadequate teacher knowledge

Apart from the difficulties associated with nature of equilibrium concepts and the use of LCP, inadequate teacher knowledge also hinders the effective mediation of the topic. Cheung (2009) assessed teachers in Hong Kong with Bachelor of Science degrees, majoring in Chemistry, for alternative conceptions. He found that the majority of the educators held mistaken beliefs about equilibrium principles. Similarly, Quilez (2004) found that some teachers in Spain misunderstood the effect of changes in pressure and concentrations on reversible reactions. They subsequently passed on these errors to their students (ibid).

To add weight to the argument, Rollnick et al. (2008) argue that teachers in South Africa use simple and inadequate explanations in chemical equilibrium due to their limited subject matter knowledge (SMK). The limited SMK negatively affects their pedagogical content knowledge (PCK) which constrains students' comprehension of this topic (ibid).

There are, however, possible interventions, which can assist teachers to overcome the challenges they face when mediating the topic of chemical equilibrium. I elaborate on these in the subsequent discussion.

2.2.2 Interventions for mediating the topic on chemical equilibrium

Several interventions deal with the complexities associated with teaching chemical equilibrium. Tyson et al. (1999) suggest that multiple explanations can improve the solving of chemical equilibrium problems. For example, a combination of the equilibrium law and the reaction quotient can result in accurate predictions for changes in equilibrium conditions. These highlight that the quantitative characteristics of equilibrium helps learners to make accurate predictions (ibid).

Correspondingly, Van Driel (2002) discovered that studying reversibility by using the cobalt complex system (pink-and-blue) assists learners to interpret reversible chemical reactions. Their written answers showed that experiments using cobalt complexes experiments help learners to understand reversibility. As an added bonus, learners find the colour changes which occur during the reactions to be fascinating.

In addition, Chiu et al. (2002) in their study conducted in Taiwan found that the use of Cognitive Apprenticeship (CA) improved students' construction of equilibrium mental models. CA is a method of teaching which consists of aspects such as scaffolding, coaching and exploration. Chiu et al. (2002) add that CA promotes conceptual development of learners. They further described that the process begins with the modelling phase in which the teacher does some experiments for the students. This is followed by the coaching phase in which the teacher tutors learners and directs them towards new activities. Then during the scaffolding phase, the teacher gives suggestions to help the learners to carry out a task. The learners are then asked to articulate their thoughts relating to the task. For example, the teacher may ask the learners what changes they would expect when red and white ink were mixed together and ask then to draw the distribution of molecules.

Likewise, Bilgin and Geban (2006) maintain that out-dated teaching methods such as lecturing do not promote conceptual understanding in chemical equilibrium. They propose that cooperative learning methods improve learners' achievement in chemical equilibrium. These approaches assist learners to improve their grasp of concepts.

In the same vein, Quilez (2006) advises teaching chemical equilibrium from a historical/philosophical point of view. The History and Philosophy of Science (HPS) approach involves teaching equilibrium concepts in conjunction with their historical and theoretical development. Quilez (2006) recommends that the HPS method has several advantages. It assists students to advance their conception of the nature of chemical equilibrium. Teachers may be able to understand students' alternative conceptions better because they are similar to those held by some scientists in the past. Lastly, HPS method helps students understand the equilibrium law more clearly as they trace its derivation (ibid). In the next section, I will discuss my theoretical framework in detail.

2.3 Theoretical framework

Merriam (2009) explains that a theoretical or conceptual framework is the structure on which a research project is based. The framework influences every aspect of the research which includes the research problem, methodology, data analysis and interpretation. The theoretical framework is derived from concepts, theories and literature of a particular discipline (ibid).

My theoretical model consists of three components: mediation of learning, social constructivism and pedagogical content knowledge (PCK). Mediation of learning and social constructivism are intertwined with social constructivism acting as a broader learning model that includes mediation of learning as an integral component. Because of its importance to this study, I will discuss social constructivism in detail. Similarly, PCK is essential in the mediation of learning; as a result, it is infused into my theoretical framework, which I will now elaborate on.

2.3.1 Theory of mediation of learning

My research goal is to understand how Grade 11 Physical Science teachers mediate learning of the topic 'Chemical Equilibrium'. Related to this main research question is 'how do Grade 11 Physical Science teachers mediate learning of chemical equilibrium during their lessons?' Therefore, it is imperative that I discuss and expand on the mediation of learning, that is, the origins of the idea and other aspects associated with the notion.

The concept of mediation of learning is attributed mainly to Vygotsky (1978) and Feuerstein (1991) (Presseisen & Kozulin, 1992). In my study, I focused on Vygotsky's mediation of learning because it incorporates social constructivism based on a fundamental concept known as the 'zone of proximal development' (ZPD). This term explains how learning takes place and is one of Vygotsky's most important theories (Daniels, 2004). Vygotsky (1978, p. 86) defines the ZPD as the difference between the actual development reflected by individual problem solving and the level of potential development as mirrored by what a learner can do under teacher guidance or in collaboration with more able peers. According to Thompson (2013), "the most powerful forms of learning take place when students are working within a Zone of Proximal Development (ZPD)" (p. 247).

Vygotsky (1978) posits that mediation of learning is a process in which an adult or more competent peer intervenes between the child and their environment to enable improved mental development. The existence of an indirect relationship between the child and their surroundings necessitates this intervention (ibid). In agreement with Vygotsky, Presseisen and Kozulin (1992) define mediation of learning as the connection between the teacher and learner which results in effective acquisition of knowledge. Doehler (2002) articulates corresponding views. He postulates that the expert guiding the learner during 'collective' activities achieves cognitive development. In essence, mediated learning is a product of the interaction between a teacher (more competent) and a learner (less competent) in a social setting.

Vygotsky (1978), furthermore, proposed that mediation is achieved using signs and tools. Presseisen and Kozulin (1992) identify two types of tools namely psychological and physical. Psychological tools or signs are culturally determined symbols concerned with mastering inner functions such as memory (Deutsch, 2003). Examples are symbols, formulae, graphs and most importantly, language. Physical tools such as pen and paper are externally oriented. They are aimed at physical procedures and abilities. These tools have an indirect effect on psychological functions.

Human mediation involves another person purposefully intervening in the learning process (ibid). Presseisen and Kozulin, (1992) suggest that in Vygotsky's mediation an individual mediates meaning by acting as a medium of symbolic mediation.

Vygotsky (1978) highlights the importance of social relations in mediation of learning. Barcelos, Batista and Passerino (2011) support the assertion that learning involves the construction of knowledge through social interactions. They add that shared exercises such as group problem solving and teamwork are crucial for intellectual development (ibid).

Although I discuss Vygotsky's concept in more detail, I will also give a brief overview of Feuerstein's mediated learning experience (MLE).

Presseisen and Kozulin (1992) explain that Feuerstein's theory differs from Vygotsky in some aspects. Feuerstein disputes that the mere presence of a task and aligned cognitive function results in mediation of learning. He proposes that other factors constitute the mediated experience such as the presence of shared meaning. Adding weight to Feuerstein's argument was a study by Presseisen and Kozulin (1992) in America that proved his claim. They found that of the students tested only 12% were able to give correct answers after undergoing an exercise which used Vygotsky's mediation of learning, while the rest held on to their misconceptions.

As an alternative, Feuerstein presents the Mediated Learning Experience (MLE) theory (Fraser, 2006). This is based on Feuerstein's Structural Cognitive Modifiability (1979) which suggests that human thinking can be changed through learning. This acquisition of knowledge concurrently requires the intervention of a more experienced human being. Thus, in a MLE classroom the teacher plays a central role in mediation (ibid).

Feuerstein (1991) identified twelve structures that make up the MLE. Of these, three should be present in every mediated experience. He identified intentionality, transcendence and mediation of meaning as three essential qualities of effective mediation. Intentionality is the deliberate action of the teacher aimed at helping the learner to understand. Mediation of meaning refers to the mediator helping the learner to understand the meaning and importance of what they are doing, while transcendence describes how new knowledge is applied to novel situations (ibid).

Doehler (2002) explained that in both Vygotsky's and Feuerstein's mediation of learning, the teacher plays a vital role. The teacher acts as a facilitator of knowledge and not simply a provider of information. Instead, the teacher ensures that learners are actively involved. This means that learners are at the centre of teaching. Accordingly, the teacher does not ignore learners' prior knowledge but uses and incorporates it as a basis for acquiring new knowledge (ibid).

Additionally, teachers as mediators of learning play various roles in the classroom (Roth & Stith, 2010). For instance, teachers give feedback, encourage reflections and challenge the learners to reason. They question, give explanations, demonstrate, facilitate investigations and negotiate conflicts. Teachers are responsible for covering the contents of the curriculum; in addition, they act as leaders, managing the classroom. They determine the time to take on a particular topic. Lastly, teachers select the appropriate signs and tools to use in the learning process (ibid).

This means that throughout the mediation of learning, the teacher utilises various tools. These include prior knowledge, increase of language skills, practical activities, laws, principles and analogies. The following discussion outlines these mediating tools in detail.

2.3.1.1 Prior everyday knowledge as a tool for mediating learning

The Namibia Curriculum prescribes that learning must proceed from what the learners already know, which is one of the foundational tenets of constructivism (Namibia. MoE, 1993). This recommendation is based on the understanding that learners do not come into the classroom as empty vessels, they bring not only the information that they have gathered from earlier classes but also possess knowledge accumulated from outside the school environment which can and must be used during learning.

There are numerous arguments in support of including learner contexts in the classroom. Roschelle (1995) confirms that everyday experiences are the main source of learning rather than new material presented by the teacher. This indicates that learning is not possible without incorporation of prior knowledge into learning. He further argues that everyday knowledge is crucial for conceptual change, thus pre-existing ideas are refined over time and act as raw materials for conceptual change. As prior knowledge is transformed, new ways of knowing emerge. Oloruntegbe and Ikpe (2011) express similar opinions. They argue that conceptual achievement increases when learners' experiences are included in the classroom. They reason that learners' prior everyday knowledge assists them in developing an in-depth understanding of concepts during the mediation of learning.

Likewise, Stears, Malcolm and Kowlas (2003) propose that a greater connectedness between school science and learners' everyday knowledge facilitates mediation by promoting greater learner involvement. Learners enjoy linking their experiences to classroom science. As a result, they are engrossed by science relating to their everyday experiences. Kuhlane (2011) in her case study based in Grahamstown, Eastern Cape, has reported similar findings. She established that Grade 7 learners appreciated using their everyday knowledge of acids and bases during lessons. Kuhlane (2011), for that reason reckons that everyday experiences must be included in teaching so that learners become comfortable with science. In the same vein, Rennie (2011) claims that projects which enable schools to work with scientists in the 'real world' promote better student engagement and attentiveness in science.

In spite of these perceived advantages, Taylor (1999) criticizes the use of prior everyday knowledge during the mediation of learning. He maintains that everyday knowledge is unstructured and wide. Hence, it is difficult to develop an organized and in-depth understanding of scientific knowledge when incorporating individual experiences. Taylor (1999) deduces that the inclusion of everyday knowledge during learning mediation is at the cost of a logical and deep understanding of concepts. Another point raised by Taylor (1999) is that learners are confused when the curriculum's structure does not include their everyday contexts.

During the mediation of chemical equilibrium, there are a number of difficulties linked to learners' everyday knowledge. Researchers such as Tyson et al. (1999) report that learners may have misconceptions in their existing knowledge which prevent them from comprehending the new material. For example, the knowledge of collision theory can cause confusion in equilibrium mixtures containing solids. According to collision theory, an increase in the surface area of a solid reactant increases the rate of a reaction. However, this is not the case when a solid is added to a system in equilibrium. As result, learners reason incorrectly that the addition of a solid disturbs equilibrium. The effect of the addition of a catalyst to a reaction is also problematic for learners. Using the collision theory, they incorrectly believe that an enzyme increases the rate of forward reaction. Yet, an enzyme will increase the rates of both the forward and backward reaction (ibid). In agreement, Quilez (2004) contends that when learners apply the principle that forces can oppose each other, they erroneously believe reverse reactions proceed to counter the effect of forward reactions. In the same vein Cheung (2009), comments that the use of mechanical laws causes the students to incorrectly reason that at equilibrium the concentrations of reactants and products are equal.

In addition to everyday prior knowledge, language is another essential mediation tool. In the ensuing discussion, the role of language is explained.

2.3.1.2 Language as a tool for mediating learning

Vygotsky (1978) identifies language as the most important psychological tool in the mediation of learning. He explains that mental development occurs in two dimensions dependent on language. These are the social and psychological phases. At the social level, information is passed through social interactions, such as between the teacher and learner, by means of language. In this way, the child develops reasoning tools and cultural skills. The psychological stage involves using language to assimilate the cultural tools into thinking structures. This means that language enables external experiences to be organised into thought. The process whereby what is learnt through the social interactions is assimilated into the psychological plane is termed internalisation (Vygotsky, 1978). In short, Vygotsky (1978) claims that language is the medium through which concepts are acquired into the human intellect. One can only grasp these theories when they are explained by using language in a suitable context.

Hodson and Hodson (1990) concur with Vygotsky that language is central to the mediation of learning. They illustrate that language assists the learners to co-construct knowledge as they work in groups. In the course of these collaborations, teacher-student talk is most essential in helping learners understand concepts (ibid). Similarly, Lemke (1990) posits passing on of communal meanings in subjects is through language. Science, as a specialized subject has its own language. Consequently, in the classroom, teachers should spend a considerable amount of time on teaching the language of science (ibid).

In contrast, Kocakulah, Ustunluoglu and Kocakulah (2005) postulate that learning science in a foreign language limits comprehension of scientific concepts for high school learners. In their study, conducted in Turkey, two science teachers taught Energy in Turkish, the native language. The other two taught the topic in English, the language of instruction. Kocakulah et al. (2005) found that students taught in English had more difficulty in explaining scientific concepts. They claim that the lack of language proficiency acted as a barrier to conceptual development. Similarly, Brock-Utne (2001) states that language rather than content is the major learning problem in science classrooms.

In the same way, the language used in chemical equilibrium is a source of many problems. Pedrosa and Dias (2000) propose that the terms and phrases used in chemical equilibrium are complex. The expressions such as ‘reversible’, ‘equilibrium shift’, ‘dynamic’, ‘closed systems’ are not easily grasped by some students (ibid). Moreover, learners may have difficulty in distinguishing similar terms with different meanings such as concentration and amount of substance (Rudd, Greenbowe & Hand, 2007).

Correspondingly, some terms used in chemical equilibrium have different meanings to everyday language resulting in misunderstandings. According to Bilgin and Geban (2006), learners understand equilibrium to mean equal or a balanced system that is not moving. Therefore, they wrongly assume that at equilibrium the concentrations of reactants and products are identical. Both students and teachers also misconstrue the equilibrium position. Many view it as the same as equilibrium constant (ibid).

Similarly, Marais and Jordaan (2000) theorise that the symbols used in equilibrium are often a source of confusion for students. They add that the mathematical language used in the topic is extremely difficult to learn. For instance, a typical examination question is as follows:

‘Ammonia is produced by the Haber process according to the reaction

$$N_2\,(g) + 3H_2\,(g) \leftrightarrows 2NH_3\,(g)$$

Explain how equilibrium is affected by a change in temperature.’

Marais and Jordaan (2000) argue that this question contains a number of icons and letters. The student is required to first interpret the problem through a long chain of mental steps before being able to respond to the question. They have to name the elements and understand the double arrow. What is more, the student has to recognise that the reaction consists of a homogenous mixture from looking at the state symbols written in brackets. Generally, students have problems with comprehending different types of symbols encountered in chemical equilibrium. This inhibits their performance in the topic (ibid). Chiu et al. (2002) express the same opinion. They posit that poor achievers are unable to translate English into appropriate chemical language. Yet, high achievers are exceptionally competent at using symbols (ibid).

In conclusion, the language difficulties, experienced during the teaching of the topic on chemical equilibrium, can be minimised by the use of other mediating strategies. Lemke (2001) maintains that allowing for extended learner talk is pivotal in developing proficiency in the language of science. This is particularly essential for second language speakers (ibid). Probyn (2004) agrees with this view and advocates that teachers must employ approaches aimed at developing learners' language skills when teaching science. She suggests the use of the chalkboard, whole class question and answer activities, practical work and code switching as approaches since these all cater for language needs. Code switching involves the teacher shifting from the language of instruction to the home language of the learners for several reasons such as helping them understand a concept. Probyn (2004) claims that effective mediation will only occur if teachers give language support to their learners. Rudd et al. (2007) support the use of practical activities during mediation of chemical equilibrium as I discuss below.

2.3.1.3 Practical activities as tools for mediating learning

There are no fixed rules for classifying practical activities. Nevertheless, Roberts (2004) organises practical activities into five different categories. These are skill practical activities, observation, technological, investigations and exploratory tasks. Maselwa and Ngcoza (2003) refer to 'hands-on', minds-on' and 'words-on' practical activities.

Practical activities are of educational value in the classroom. According to Millar (2004) the practical work helps learners to understand concepts better. When learners are able to visualise phenomena, there is enhancement of their conceptual understanding. During these activities, alternative concepts are confronted and replaced (ibid). However, there is a mistaken tendency to equate any activity to learning. Therefore, Rudd et al. (2007) recommend that practical activities must be properly administered to be effective.

A second point supporting the inclusion of practical activities in the mediation of learning is the enjoyment dynamic. In their research project in the Eastern Cape, Maselwa and Ngcoza (2003) reveal that most learners enjoyed practical tasks. The Grade 9 learners in their study identified practical work as one of the aspects, which made them, enjoy how science is taught at their school. In agreement, Hattingh, Aldous and Rogan (2007) submit that, from their experience, learners are enthusiastic about carrying out meaningful 'hands-on' practical work.

In the same way, Rudd et al. (2007) suggest that laboratory activities can help reduce confusion in the teaching of chemical equilibrium. In their study in California, they found that students taught equilibrium concepts using Science Heuristic Writing (SHW) outperformed those students instructed using traditional methods. This approach requires students to answer questions as they carry out their practical activities. The learners draw conclusions based on experimental work.

In contradiction, Hodson (1990) disputes the educational value of practical work. Based on his twenty years in education, he concluded that the practical work carried out in schools is 'ill-conceived, confused and unproductive' (Hodson, 1990, p. 33). In his opinion 'hands-on' practical work does not necessarily improve learner motivation in science lessons, he contends that learners may find some practical activities to be extremely boring. Hodson (1990) further refutes claims that practical activities improve acquisition of laboratory skills. He maintains that the laboratory skills are only useful if they can advance learning. For that reason, teachers must concentrate on skills allowing learners to be involved in useful activities.

On the argument that practical work improves the learning of science, Hodson (1990) proposes that there is no conclusive evidence to support these claims. He sees no value in carrying out practical work structured in the same way as one follows a recipe. According to Hodson (1990), such practical activities are unproductive and a waste time. In agreement, Roberts (2004) warns that unsuccessful experiments can retard learning. They can actually generate alternative conceptions. Besides, practical tasks are ineffective if the link between the activity and theory is not clear (Miller, 2004). Analogies, discussed in the next paragraphs, can supplement practical activities.

2.3.1.4 Analogies as tools for mediating learning

Analogies are parallels drawn to help the students to understand a concept (Treagust, 1993). They can be from real life experiences (ibid). Analogies can be useful in science classrooms but at the same time, they have their limitations.

According to Bilgin and Geban (2006), analogies can mediate learners to acquire the required concepts of chemical equilibrium. The learners can understand new ideas by drawing parallels with existing knowledge. When they compare abstract equilibrium concepts with tangible experiences, it results in a better understanding of the topic (ibid).

Treagust (1993) outlines some of the criticisms levelled against the use of analogies in science classrooms. He proposes that when learners do not know how to reason by using comparisons, learning is constrained. This implies that learners struggle to discriminate between the important aspects being represented by the analogy. Analogies and the real concepts have similarities but are not identical. The learners may not be able to distinguish between the resemblances and differences. This causes transfer of incorrect information. Analogies are often easier to remember than the real phenomena. Thus, learners may end up remembering analogies at the expense of the actual concepts. Lastly, students may take the associations between analogies and real phenomena too far. As a consequence, students give incorrect answers to questions posed by the teacher (ibid).

2.3.2 Social constructivism

According to Moll (2002), social constructivism is a sociocultural theory, which advocates that mediation of learning occurs as a result of social interaction with a knowledgeable individual. This perspective highlights that knowledge is socially constructed within a community (ibid). In this sense, the classroom is a community or specifically a community of practice (Lave & Wenger, 1991). A community of practice is a joint enterprise that binds members through shared repertoires and resources. Learning occurs because of full participation within these communities (ibid).

Moll (2002) advances that social constructivism places the learner at the center of the mediation of learning. It takes into account their everyday experiences. In this way, social constructivism moves from memorization to understanding by relating content to learners' experiences (ibid).

Furthermore, McRobbie and Tobin (1997), posit that the social constructivist perspective on learning environments stresses three crucial components, involvement, autonomy and relevance. Active involvement during the mediation of learning contributes to better understanding of science. Autonomy refers to students having control over their own learning, for example, choosing their own procedures in problem solving. Giving learners freedom during learning is thought to enhance their understanding. Relevance means in-cooperating learner contexts in teaching and learning (ibid.).

According to Goos (2004), the ZPD is linked to two pivotal aspects, namely, scaffolding and collaboration. Wood, Bruner and Ross first used the term 'scaffolding' in 1976 (cited in Hodson & Hodson, 1998). Scaffolding is the interaction between the teacher and the learner in which the teacher structures a task and allows the learner to carry out the assignment whilst the teacher gradually withdraws his/her support. Scaffolding occurs in the zone of proximal development and helps learners to learn. In this manner, education is enculturation whereby a teacher leads the learner to new levels by interaction and gradually transferring responsibility to them (ibid). Vygotsky (1978) proposes that while solving scientific problems, a child is able to do more when working in partnership as opposed to working alone.

Additionally, collaboration is essential in the mediation of learning. Vygotsky (1978) reasons that scientific concepts are not learnt through direct instruction. He insists that cooperative instructional practices achieve effective teaching (ibid). Tudge (1990) agrees with Vygotsky and asserts that collaborations in the ZPD can lead to development in a culturally acceptable manner. However, he cautions that peer collaboration does not always ensure learning. For that reason one needs to pay close attention to the interactions taking place during the process (ibid). In consensus, Moll (2002), states that the emphasis should be on construction of meaning through collaborative processes. This is opposed to the mere transfer of skills from the more to the less knowledgeable partner (ibid).

Several criticisms have been leveled against social constructivists. Namely, they are viewed as anti-realists who believe that everything is socially constructed and therefore no knowledge exists outside these constructions thus ignoring natural forces (Moll, 2002). Moreover, social settings may constrain learning as the actions of others shape individual learning (McRobbie & Tobin, 1997). Lastly, time constraints, prioritizing passing of exams and the belief system of the teacher can limit the application of social constructivism ideas (ibid).

In my study, I focused on mediation of learning, which includes how the teacher scaffolds the learners to make sense of chemical equilibrium. Consequently, I took note of the nature of classroom interactions, the methods of instruction and the tools used during mediation. Social constructivism in conjunction with PCK was the theoretical framework. Accordingly, an explanation of PCK follows.

2.3.3 Pedagogical Content Knowledge

Schulman (1987) identifies PCK as one of the seven categories of knowledge a teacher has to possess in order to mediate learning. He explains that PCK is a concept describing the way in which teachers present and formulate subject content in order to make it understandable i.e. how concepts are presented during lessons to suit the abilities and interests of students. Thus, PCK is a blend of content knowledge and pedagogy. Pedagogy refers to the general strategies and principles of classroom organisation employed across educational disciplines (ibid). Consistent with Schulman's views Loughran, Mulhall and Berry (2004) describe PCK as the information that educators use in the teaching process, that is, the professional knowledge peculiar to teaching (ibid).

Furthermore, Kind (2009) purports that, within PCK, mediating factors such as presentation of content, goals and students' contexts are taken into account. This knowledge is a combination of subject matter knowledge (SMK) and effective teaching skills. Kind (2009) continues to explain that PCK integrates numerous aspects such as instructional approaches, subject specific learning, learners' difficulties, the nature of science, curriculum knowledge, SMK, context and sociocultural factors (ibid). This view is in agreement with Geddis, Onslow, Beynon and Oesch (1993) who reported that PCK involves an understanding of student misconceptions, approaches for changing these misconceptions as well as alternative forms of presentations.

In addition, Schulman (1987) puts forward the notion that the mediation of learning involves the processes of comprehension and transformation. Comprehension refers to how the teacher understands the subject matter to be taught to the learners. The route by which this knowledge is made accessible to students is called transformation. The process of transformation consists of four procedures: preparation, representation, instruction and adaptation. The teacher starts by preparing for a lesson. Preparation entails selecting a suitable text for teaching followed by the structuring and sequencing of the teaching material. Once in the classroom the teacher has to present the material. Representation comprises the methods used by the teacher to present key ideas. For example, demonstrations, explanations and analogies which are used to enhance students' conceptual understanding. During the presentation, the teacher also tutors or instructs learners. Instruction comprises classroom management and effective interactions through questions, reactions and feedback, as well as the teaching strategies employed. Lastly, adaptation is the process of tailoring the presentation to the learners' needs so that it is relevant and meaningful. Students' prior knowledge, misconceptions, difficulties and motivations are taken into account (ibid).

Teachers need PCK to be the best possible practitioners (Schulman, 1987). Concurring with Schulman, Loughran et al. (2004) note that teachers can be academically qualified but this does not guarantee that they will be effective teachers. Hence, PCK is essential in the mediation of learning and is identified when the process is unfolding (ibid).

In my study, I used a variety of data collection instruments namely document analysis, interviews and classroom observations. There are several reasons for using this multifaceted approach. Loughran et al. (2004) suggest that PCK is complex and tacit. It has no common language resulting in teachers being unable to articulate its principles. For that reason, PCK is investigated through a number of ways or methodologies (ibid). Van Driel et al. (2001) concur that various methods of data collection and triangulation should be used when investigating teacher knowledge because of its multidimensional nature.

In this research, an in-depth study of the mediation of learning is carried out to understand the presence and extent of the teachers' PCK. This includes how the teachers present the lesson, their teaching strategies, analogies, alternative explanations and how they deal with students' misconceptions.

2.4 Concluding remarks

The aim of this chapter was to review the literature relating to the mediation of learning the topic of chemical equilibrium. I investigated several ideas that had been previously researched and questions were highlighted and critiqued. These studies were from different parts of the world.

The problems experienced by learners and teachers when mediating equilibrium concepts were discussed. The literature showed that there are numerous difficulties that are faced by both learners and teachers. These include the abstract nature of concepts, inadequate teacher knowledge, the language difficulty and the use of LCP.

Literature dealing with ways in which teachers can improve the mediation of equilibrium theories were deliberated. Studies suggest the use of practical activities, analogies, history and the philosophy of science, and cooperative learning methods to improve the teaching of chemical equilibrium.,

In addition, the literature involving mediation of learning and scaffolding was critically discussed. This included examining the role of language, prior knowledge and other mediation tools. It was found that, according to various studies, there are problems associated with the use of some meditational tools in the classroom.

To conclude my literature review chapter, I elaborated on the literature linked to my theoretical framework namely PCK and social constructivism. The origins and meaning of PCK and social constructivism were explained from the perspective of various scholars. The shortcomings of these philosophies were also reviewed. In the next chapter, I describe my methodology in detail.

Chapter 3

Methodology

> *To answer some research questions, we cannot skim across the surface. We must dig deep to get a complete understanding of the phenomenon we are studying. In qualitative research, we do indeed dig deep: We collect numerous forms of data and examine them from various angles to construct a rich and meaningful picture of a complex, multifaceted situation (Leedy & Ormrod, 2014, p. 141).*

3.1 Introduction

I set out to understand how teachers mediate the topic of chemical equilibrium. In order to accomplish the task I needed to 'dig deep' as pointed out in the epigraph (Leedy & Ormrod 2014, p. 141). It was mandatory to analyse various types of data. To generate significant information, I had to find a suitable procedure. After reading widely, I established that the qualitative research approach was the most appropriate for my investigation.

In this chapter, I elaborate on the methodology adopted in my enquiry. To begin with, I explain the research design and orientation. A profile of the research goal and questions follows. I then provide a narrative of the research participants as well as describe my data gathering and analysis techniques. Finally, I discuss the validity and ethical issues, which I considered.

3.2 Research design and orientation

My research was in two phases. The first phase was a qualitative case study underpinned by an interpretive paradigm. In the second phase, I co-designed a chemical equilibrium module with my research participants.

I began by piloting my interview guide. A pilot test of the interview schedule allows the researcher to change the instrument based on the feedback from a small representative sample (Creswell, 2012). I tested the research questions on a fellow MEd student to ensure that the questions were clear and unambiguous. It was also necessary to ensure that the interview questions were in line with my research goal and questions. Likewise, I had to familiarise myself with the interview schedule to guarantee that the interview would flow smoothly.

When I interviewed my classmate, I realised that some questions had to be changed. Specifically, the terminology in the schedule of questions needed to be simplified. For instance, instead of asking how teachers provide a scaffold for learners, I had to ask how they help the students to understand concepts.

At the beginning of the pilot interview, I attempted to record the dialogue on my mobile phone. Unfortunately, the phone malfunctioned at the beginning of the interview. This meant that I had to resort to taking field notes, which did not capture all the data. I realised I had to utilise a more reliable device to record my data. During the actual interviews, I used a tablet because it had a better working memory. I checked it several times before the conversations to make sure it was operational.

In the following paragraphs, I discuss my research orientation. The rationalisations behind adopting a case study approach within an interpretive paradigm are explained.

3.2.1 Interpretive paradigm

The interpretive approach was utilised in my study for a number of reasons. Terre Blanche, Durrheim and Painter (2009) clarify that an interpretive paradigm is characterised by its focus on the individual and their encounters. Its purpose is to understand how people interpret the world around them. Reality comprises of people's involvements and perceptions (ibid). My objective was to gain insights into the mediation of the chemical equilibrium topic. Therefore, it was critical to comprehend the teachers' experiences and views.

Additionally, the interpretive framework uses methodological approaches such as observation and interviews to obtain the personal reasons behind actions (Terre Blanche et al., 2009). In order to answer my research questions, it was necessary to carry out lesson observations and interviews. These methodologies are consistent with the interpretive framework.

Similarly, social constructivism resonates with the interpretive method (Merriam, 2009). Social constructivism implies that generation of knowledge occurs by interaction between the researcher and participants in a social milieu. In order to obtain data, it was necessary to work collaboratively with the two teachers. For instance, during the first phase, the teachers' responses to interview questions were a vital source of information. In the second phase, I developed the module in partnership with the participants.

3.2.2 Phase 1: Qualitative case study research

My investigation was a case study. In the following account, I explain the meaning of research in general. A more detailed discussion of qualitative research and case studies follows to substantiate my research approach.

Merriam (2009) defines research as a process of exploring occurrences in a methodical way. The need to increase the comprehension of a particular subject or to improve practice motivates a study (ibid). I embarked on the research to appreciate the mediation of chemical equilibrium. My anticipation was that my research would contribute to improving the teaching of the topic.

Merriam (2009) posits that qualitative researchers investigate occurrences in their natural setting to capture the complexities behind the events. I undertook the task of unravelling the teaching of chemical equilibrium. Therefore, I had to observe lessons in the classroom where the teaching occurs which meant that a qualitative research approach was suitable for my study.

Creswell (2007) notes that researchers frequently use case studies in qualitative research. He explains that a case study is a comprehensive investigation of a confined system centred on extensive collection of data. Case studies analyse phenomena from the perspective of the participants. The actions of the participants and their corresponding feelings and thoughts are emphasised. The aim is to grasp how individuals interpret and make sense of their experiences. Consequently, case studies produce penetrating accounts of real life occurrences (ibid).

The mediation of the topic chemical equilibrium is a multifaceted phenomenon. As discussed in the literature review, mediation includes classroom interactions, scaffolding and challenges faced by learners when acquiring these concepts. Hence, a case study approach was most appropriate because it enabled a full exploration of the complexities of mediation of learning. Merriam (2009) posits that case studies are holistic as they capture the various variables affecting a single case

Researchers differ in their conceptualisation of case studies (Trochim, 2006), however, they agree that case studies always have a case and unit of analysis. The case is the focus of the study. The unit of analysis is the most important entity examined to generate descriptions (ibid). In my study, the two Grade 11 Physical Science teachers were my case and sense making of equilibrium concepts was my unit of analysis.

3.2.3 Phase 2: Collaborative approach to designing a teaching module

The concept of professional learning communities is gaining momentum in educational settings (Thompson, Gregg & Niska, 2004). The idea involves teachers teaming up to create solutions to educational problems. This leads to greater levels of collaboration among the teachers leading to results that are more effective. Consequently, an improvement in the performance of both students and teachers ensues (ibid).

In my research, I designed a teaching module together with my research participants to answer my last research question, specifically, how can Grade 11 Physical Science teachers improve learners' sense making of the concepts underlying the topic chemical equilibrium?

It was a challenge for all three of us to meet at the same time. Consequently, I met with the teachers separately and I had to go back and forth from one teacher to another. I found this process to be extremely time consuming. Notwithstanding, there was there was a teaching resource which was in place which I found to be a good starting point for developing the module.

Participatory action research (PAR) is a method which produces knowledge by collaboration between the researcher and participants in order to improve educational practice (Bhana, 2006). It involves the development of an intervention for an identified problem, carrying it out and assessing its effectiveness (ibid.). One of the benefits of PAR is that it promotes community participation. Lave and Wenger (1991) explain that learning occurs as individuals participate in societies called communities of practice. The members of these communities advance their knowledge by jointly pursuing a common goal. As a result, they are able solve problems faster and more effectively than they would as individuals (ibid).

After developing the module described above, one of the teachers used an equilibrium game from the unit of work for revision purposes. Insights on the usefulness of the game were drawn thus there was integration of an element of (PAR) into the second phase. In designing the module, the participants and I formed a community of practice. As a community, we were able to provide an answer for my fourth research question.

3.3 Research goal and questions

3.3.1 Research goal

To understand how Grade 11 Physical Science teachers mediate the learning of the topic, chemical equilibrium.

3.3.2 Research question

Main research question:

How do Grade 11 Physical Science teachers mediate learning of the topic chemical equilibrium during their lessons?

Sub-questions:

- What are Grade 11 Physical Science teachers' views and experiences of mediating the topic chemical equilibrium?
- How do Grade 11 Physical Science teachers provide a scaffold for learners to make sense of the concepts associated with the topic chemical equilibrium?
- In what ways do Grade 11 Physical Science teachers deal with the challenges faced by learners in making sense of the concepts underlying the topic chemical equilibrium?
- How can Grade 11 Physical Science teachers improve learners' sense making of these concepts?

3.4 Research sites and participants

I conducted the investigation on two teachers from the same school. In the subsequent paragraphs, I expound on the research site and participants.

3.4.1 Research site

My research was at a private school in Windhoek, the capital city of Namibia. Windhoek is located in Khomas, one of the thirteen regions in the country. Private schools, largely, are among best performing schools in Namibia. They are characterised by high school fees, well- trained teachers, low student-teacher ratios and adequate resources. In general, students at these schools come from stable, well to do families.

The selected school aims to provide students with the best academic education possible. Students are encouraged to strive for excellence in mind, spirit and body. The institute maintains a rigorous academic program. Learners have to write a series of entrance exams to gain admission. Those who do not meet the required standards are not selected. The teachers at the school are highly qualified by Namibian standards. They are drawn from around the globe.

The student population is very diverse in terms of their social background. There are Asians, Australians, Americans, Europeans, and Africans among the students. English, Afrikaans and German are the dominant home languages.

3.4.2 Sampling

In my research, I used a combination of purposive and convenience sampling. According to Cohen et al. (2011), purposive sampling is closely associated with qualitative research. In this method, the research participants are selected for a particular reason. There are several rationalizations for using purposeful sampling. For example, a sample is purposefully selected to allow for the investigation of cases that are critical for the study (ibid.). I used the purposive sampling strategy to decide on the grade, research participants and school.

There were several justifications for carrying out purposive sampling. Grade 11 Physical Science teachers were chosen because chemical equilibrium is covered in this grade. Cohen et al. (2011) points out that comprehensive information is obtained from those who possess it.

In addition, to select the individual teachers, I utilised the purposive sampling anticipating in-depth insights. Mrs Focus has twelve years' teaching experience. She holds a BSc degree in Chemistry and Biochemistry and a post-graduate teaching certificate. Mr Humour has an engineering degree and has taught at the school for ten years. These teachers shared the Khomas Region Science Teacher Award for the previous year. Furthermore, examiners echoed that the students from their school performed well in chemical equilibrium questions in earlier public examinations. Hence, both teachers were extreme cases i.e. individuals with diverse characteristics which are outstandingly good. Creswell (2012) explains that these atypical cases are able to shed light on the deeper sources of a problem by providing illuminating perceptions.

Furthermore, the same school was selected because the two teachers formed a homogenous sample. Homogenous sampling refers to selecting individuals because they are in the same environment or belong to a particular group (Creswell, 2012). It helps to inform an in-depth analysis of that particular association. At the same time, it makes the study more controlled by eliminating some variables (ibid). According to Maxwell (2005), a small homogenous sample that has been systematically selected is more likely to yield more illuminating insights than a random one.

Convenience sampling refers to when individuals are selected because they are easily accessible or available (Creswell, 2012). This is the most common type of sampling in qualitative research (ibid). Leedy and Ormrod (2014) propose that convenience sampling is an appropriate strategy depending on the purpose of the research. However, appropriate measures have to be taken to ensure the trustworthiness of conclusions drawn from the study (ibid).The location of the research site constitutes the convenience-sampling component. A school in Windhoek was chosen because of easy access. This made the data collection process more convenient.

Mertens (2005) advises that the sample sizes are determined by the nature and purpose of research. It is also dependent on the amount of time in the field. She adds that for a case study research, studying a single case is sufficient (ibid). As I was carrying out a case study research for a half- thesis, a sample size of two teachers was adequate. To increase the validity of my findings, I employed several data gathering techniques in my study.

3.5 Data gathering techniques

In the first phase of my investigation, I used document analysis, observations, interviews (semi-structured and stimulated recall interviews) to gather my data. In the second phase, a collaborative approach to data gathering was utilised. The table below outlines the various stages of my research process.

Table 1: Phases and stages in the data gathering process

Stage/ Phase	Method used to gather data	Data to be gathered	Purpose
Phase one Stage 1	Pilot study of interview questions	Colleague's perceptions and experiences	To assess suitability and quality of questions
Stage 2	Pre-test	Learners' prior knowledge	To determine if learners have the prerequisite knowledge for the topic To find out if there are any existing preconceptions
Stage 3	Document analysis	Contents of : The syllabus	To find out the outcomes and objectives of the chemical equilibrium topic
		Learner support materials (LTSMs)	To answer the following questions: Do the LTSMs clearly explain the topic? Do they adequately cover the content? Do they use language which is easy to understand?
		Examiners' reports	To find out how students have been performing in examinations
Stage 4	Semi-structured interview	The teachers' views and experiences	To answer research question 1
Stage 5	Observation of lessons and field notes, recording of videos	How the teacher mediates	Record teachers' practices and categorize them into emerging themes such as teaching strategies and prior knowledge
Stage 7	Document analysis	Students' work	To assess the work completed by students
Stage 8	Stimulated recall interview while watching the video together with the teachers	Teachers' views	To seek further clarifications and validate my data
Phase two: Development of module	Participating teachers	Ways to improve learning of equilibrium	To answer research question 4

The following paragraphs discuss my data gathering techniques in detail. An exploration of the rationale behind the use of each procedure is given.

3.5.1 Document analysis

Creswell (2008) defines documents as 'public and private records that qualitative researchers obtain about a site or participants in a study, and they can include newspapers, minutes of meetings, personal journals and letters' (p. 230). Documents are valuable because they are found in all organisations (ibid).

In qualitative research, documents are commonly used because they have several advantages. Creswell (2012) asserts that records can save the researcher a large amount of time. They are easily accessible, free and contain information that would take a long time to gather. Careful thought is given to preparation of official documents. Therefore, they use language, which does not require any transcription. This makes them ready for analysis (ibid).

Secondly, records are a rich source of historical and current data (Mertens, 2005). They provide the researcher with vital background information and are able to produce descriptive data to allow deeper comprehension of a scenario (ibid). Moreover, some explanations are found only in documents (Davies, 2007). As an illustration, I obtained the information on how learners perform in chemical equilibrium questions only in examiners' reports.

Lastly, documents have a major advantage of constancy (Merriam, 2007). Unlike observations and interviews, the contents of a document are not altered by the presence of the researcher. They depend on the context in which they were generated and are therefore not affected by the research process (ibid).

In my study, I analysed the syllabus, hand-outs and examiners' reports. I used the syllabus and examiners' reports to describe the context of the study in the first chapter. Detailed information of the general problems encountered by learners was acquired from the examiners' reports. Equally, I examined the teaching resources to be aware of their content. All these documents were easy to access and contained a large amount of information. The documents were in formal English; therefore, I could use direct quotes from them. However, I could not obtain all the evidence from documents alone so I conducted several interviews to augment my data.

3.5.2 Interviews

Interviews are conversations used to understand peoples' thoughts and feelings (Kelly, 2006). These conversations consist of different types of interviews depending on their structure (ibid.). In my study, I carried out semi-structured and stimulated recall interviews (SRI). I employed interviews to gain perceptions on the teachers' views on teaching chemical equilibrium issues such as the challenges they face during mediation of learning.

Creswell (2012) points out that an interview is a useful source of information because it provides data, which might not be observable. He adds that the interviewer can also control the facts they gather by asking particular questions (ibid). Conversely, interviews have their drawbacks. Interviewees may not express themselves adequately or they may only say what they think is expected of them (ibid).

3.5.2.1 Semi-structured interviews

Semi-structured interviews utilise an interview guide with open-ended questions. An interview guide is a schedule of questions, which the interviewer intends to ask (Leedy & Ormrod, 2014). These questions relate to the research goal and are prepared in advance (ibid.).

I carried out a semi-structured interview with each teacher. The interview schedule directed me during each interview. I prepared six open-ended questions in advance. Open-ended questions allow interviewees to express their opinions without any feeling of restraint (Leedy & Ormrod, 2014).

Furthermore, I asked follow up questions. These are sub-questions used by the researcher to obtain additional details (Creswell, 2007). I used probing to clarify what the interviewee had said and to make sure that they had answered the questions fully. However, after my first pre-interview with Mrs Focus, I realised that my first inquiry was not giving me the information I needed to answer my research questions. Therefore, I changed the wording during my next interview with Mr Humour.

In addition, I audio taped the interviews. The main advantage of audio tapes is that they provide a detailed account of an interview which can be replayed (Davies, 2007). I found that although I could not capture all the information in my field notes, the details were available on the recording. Moreover, I could play the audio tape numerous times when I was transcribing the interviews.

However, in my interviews with Mr Humour I found the recorder to be intrusive. The participant kept glancing uneasily at the recorder, so the conversation did not flow very smoothly and it ended earlier that anticipated. When I switched off the device, Mr Humour started talking freely. I took down some notes as he conversed.

An observational protocol captures the data gathered during an interview (Creswell, 2008). The form is designed in advance to ensure an organised way of recording data (ibid). Nonetheless, during my interviews I did not use any form because I found it easier to scribble notes and write them neatly later.

3.5.2.2 Stimulated recall interviews

After the lesson observations, I carried out stimulated recall interviews (SRI). These are processes in which video recordings are replayed to participants to recall their thinking during events (Lyle, 2003). An SRI allows for the analysis of cognitive reasoning. However, they may not reflect the cognitive processes occurring at the time of the event (ibid).

I watched selected videos recordings with each of the teachers. During this time I asked questions on areas requiring clarification. At the same time I noted the comments made by the teachers. However, I did not manage to watch all the videos as intended due to time constraints. The teachers were busy with marking of examination scripts. To get around this problem, I focused on clarifying issues I had picked up when I was transcribing the lesson observations and pre-interviews. The procedure was quite insightful as I managed to fill in gaps existing in my data. For example, I learnt why the teachers use their own teaching resource rather than textbooks. The teachers were delighted to see how they teach and made some comments on how they would improve their teaching in future. This exercise was of great mutual benefit to my research participants and myself.

3.5.3 Observations and field notes

I observed four of Mrs Focus’ lessons and three of Mr Humour’s on the topic chemical equilibrium. Observations are one of the main sources of data in case studies (Merriam, 2009). Kelly (2006) explains that observations occur in the natural setting of the participants. They aim to understand a situation from the perspective of the participant. In addition, they bring the researcher close to the phenomena thereby producing a first-hand account (ibid).

During the observations, I was able to see how the teachers actually teach. I gathered much more data on both teachers while in the classroom. As an illustration, there were some strategies that

Mrs Focus used which she had not mentioned in the interview. A number of spontaneous questions from learners changed the direction of some lessons providing unpredicted data. According to Leedy and Ormrod (2014), the main advantage of using observations is their flexibility. An observer is able to gather unanticipated data as it unfolds.

Nevertheless, observations have some limitations. The presence of the researcher may alter the behaviour of participants. As a result, the data collected gathered by this method can be biased (ibid). I found this be true, Mrs Focus admitted that in her first lesson, she felt uneasy as the students were unusually quiet.

As mentioned above, I observed several lessons. My protracted presence ensured that the participants became accustomed to my being there and started acting normally I found that the atmosphere was more relaxed in the later lessons. Creswell (2008) agrees that a better understanding of situations is gained by prolonged observations (p. 223).

To reduce any bias, I tried to be a non-participant observer (Maxwell, 2008). A non-participant observer is not involved in the activities of the participants. The observer sits at a strategic position to view and record the phenomenon under investigation. Although I tried not to participate in most of the lessons, sometimes a teacher would refer to me and I had to respond.

Notes record participants' actions and words during an observation (Kelly, 2006, p. 314). They can also be comments to analyse and reflect on events as they occur (ibid.). During the lesson observations, I made some field notes of my personal reflections. I recorded the notes on the observational forms.

Leedy and Ormrod (2014) posit that field notes may not sufficiently capture all the data as it unfolds, hence the need for recording. Video recording enables one to capture events as they occur (Merriam, 2009). It also allows for capturing of other non-verbal communication such as movements and facial expressions (ibid.). I video recorded all the lessons and was be assisted by a colleague who was my critical friend

Video recording can be intrusive, that is, it can disturb the natural flow of events (Davies, 2007). It also involves the attendance of an additional person (ibid). To minimise the disruption, my colleague sat at the back of the classroom while recording.

During lesson observations, there were two cameras in the classroom. My colleague operated the main camera and I had the second one. I used the camera to record information such as students' written work during discussions.

In summary, the aim of the observations was to find out how teachers actually mediate learning. The information obtained from observations was compared to the interview data during my analysis. There were no notable discrepancies between data from these two sources.

3.6 Data analysis

Merriam (2009) defines data analysis 'as the process of making sense of data' (p. 175). It is the procedure used to answer research questions. Qualitative data analysis aims at deriving meaning from data by placing it into themes and categories. During the process, any emerging patterns and consistencies are noted. This facilitates the interpretation of data.

To begin with, I transcribed the audiotaped interviews. Transcription is the practice of converting the audio tape recording into text (Creswell, 2008). This text is an accurate and reliable source of detailed information (ibid). However, I found the process to be extremely time-consuming.

Furthermore, I used an inductive approach to identify emerging themes from my data. The themes were colour coded. Coding is the process of classifying data according to a particular theoretical outline (Babbie & Mouton, 2006). A code can be a phrase, sentence or a paragraph used to describe a text. However, codes can change during the analytical process (ibid.). I used my computer to highlight data from a particular code with the same colour.

Similar codes were grouped together into themes by cutting and pasting to create analytical memos. The data was organised into four themes namely meditational tools, PCK, challenges faced and development of the module. Out of these themes, four analytical statements were drawn.

My theoretical framework guided the entire data analysis process. I employed the mediation of learning infused with social constructivism according to Vygotsky coupled with Pedagogical Content Knowledge (PCK) (Schulman, 1987) as lenses. Mediation of learning emphasises teacher-learner interactions therefore during my analysis I focused on instances where there was evidence of these exchanges. It was necessary to include social constructivism because of the interrelationship between social constructivism and mediation of learning.

One of the key aspects of social constructivism is prior everyday knowledge. Hence, as I carried out my data analysis, I concentrated on how teachers incorporated learners' prior knowledge during mediation. Similarly, as I used PCK as part of my theoretical framework, when I analysed my data, I was interested in how teachers dealt with the problems faced by learners and the ways in which they made concepts understandable to learners, for instance, the teaching strategies they used.

3.7 Validity

Internal validity refers to how close the findings of a study are to reality (Merriam, 2009). Triangulation of data and member checking are often employed as ways to ensure that the data is valid. Other strategies involve spending sufficient time in collecting data, providing detailed descriptions to contextualise the study and reviews by peers (ibid).

Cohen et al. (2011) define triangulation as the use of different methods of data collection. The data from the different sources were checked and compared (ibid.). In my study, I evaluated all the data collected by the different data gathering tools.

Member checking also known as 'respondent validation' is when interviewees are asked for feedback (Merriam, 2009, p. 217). This is the main way to identify the researcher's misunderstanding and biases (ibid). The transcripts of interviews were handed back to the respondents so that they check for the accuracy of the recorded information. However, the participants indicated that they trusted me and did not need read the transcripts. They felt that I would not falsify any information. Being concerned about the issue of content validity, I gave the videos and transcripts to my critical friend, who made the necessary corrections. In addition, I utilised stimulated recall interviews as a means of data validation.

Peer review refers to discussions carried out with a critical friend to study how well matched findings are to the raw data (Merriam, 2009). In my case, a colleague, who also happens to be a science teacher, assisted me with video recording the lessons and I discussed my interpretations with him.

In essence, I used various strategies to ensure validity. These were piloting, triangulation, member checking, 'rich and thick descriptions', ample time in data collection and peer examination (Merriam, 2009).

3.8 Ethical considerations

Informed consent is the process of obtaining permission from institutions providing amenities for research and all persons involved (Cohen et al., 2011). Written consent was sought from the principal of the school involved and the two teachers. The copies are attached in appendices A. Permission to audio record interviews and video tape lessons was requested in advance. Consent from parents was obtained through the teachers.

A research study should not harm the participants. This refers to ensuring that no endangering of the participants, whether physically or psychologically occurs (Babbie & Mouton, 2005). In my study, I endeavoured not to cause any harm to my participants by revealing any information that would cause them to be embarrassed. At the same time, in my analysis, I did not characterise participants in any damaging way to their self-image.

The participants were guaranteed confidentiality and anonymity. Confidentiality ensures that the report is not traceable to an individual (Mertens, 2005). While anonymity ensures that, the information provided leads to the identification of a participant (ibid.). Confidentiality and anonymity were ensured by the use of pseudonyms. The participants were known as Mrs Focus and Mr Humour. In addition, I did not disclose the name of the school.

3.9 Limitations of the study

Due to the small sample size, my results cannot be generalised, that is, they do not represent the population of teachers in Windhoek. However, I drew insights on how teachers mediate the topic chemical equilibrium. I found that the use of recording devices altered the behaviour of participants, particularly in the first lesson and during Mr Humour's interview. The use of various data generating methods counteracted the possible biases.

3.10 Concluding remarks

In this chapter, I described my methodological orientation, namely, a case study approach underpinned by an interpretive paradigm. I outlined my research questions. I described the research site, sampling procedure and the data gathering techniques. I explained how the data was analysed. Issues of validity and ethics are discussed. To conclude, I summarised the limitations of my study. In the following chapter, I present the data I collected.

Chapter 4

Data presentation and analysis

> *To analyse is to find some way or ways to tease out what we consider to be the essential meaning in the raw data; to reduce and reorganise and combine so that the readers share the researcher's findings in the most economical, interesting fashion. The product of the analysis is a creation that speaks to the heart of what was learnt (Ely, Anzul, Friedman, Garner & Steinmetz, 1991, p. 140).*

4.1 Introduction

As mentioned in the previous chapters, the main goal of my research was to find out how teachers mediate the topic chemical equilibrium in a Namibian context. To achieve this objective, I utilised several data gathering techniques as elaborated on in the methodology chapter. These were document analysis, semi-structured interviews and lesson observations. Using these tools, I managed to gather a considerable amount of information. The aim of this chapter is to present a summary of the data in a way that conveys what I discovered as described by Ely, Anzul, Friedman, Garner and Steinmetz (1991) in the epigraph.

In the study, my research participants were two experienced Grade 11 Physical Science teachers who are renowned for obtaining good results at the school. I begin with a profile of these teachers. The outline focuses on the teachers' qualifications and experience in order to contextualise my findings. This is followed highlights of the data from the document analysis, lesson observations and interviews. I end the chapter with some concluding remarks.

4.2 Teachers' profiles

A sample of two grade 11 Physical Science teachers was selected for the study. By Namibian standards, both teachers are highly qualified and very experienced. Mrs Focus (pseudonym) (T1), for example, has a Bachelor of Science degree majoring in Biochemistry and Chemistry from the University of Sydney in Australia. She is in possession of a teaching diploma and has more than ten years of teaching experience. She gained most of her teaching experience at a private school in Sydney. Mrs Focus has been teaching in Namibia for approximately three years. During this time, she received a teacher's award in recognition of her learners' outstanding Grade 12 results in the national examinations.

Mr Humour (pseudonym) (T2) holds a Bachelor of Chemical Engineering degree from the National University of Science and Technology (NUST) in Zimbabwe. He studied Chemistry as one of his major subjects when he was completing a University of Cambridge Advanced Level course. Although he does not have a formal teaching qualification, he has participated in various staff development seminars offered by his school. These seminars aim at equipping teachers who had not received any teacher training with the necessary skills to mediate learning in the classroom. He has more than ten years of experience as a Physical Science teacher. At the time of the study, he was teaching Grades 9 to 12 Physical Science and Grade 10 Mathematics. Mr Humour feels he teaches Physics better than Chemistry; as a result, he had a strong preference for teaching the Physics section to the Chemistry one. Similar to Mrs Focus, he has received prizes for outstanding learner results in Grade 12.

4.3. Phase 1

In the first phase of my study, I analysed documents, observed lessons and interviewed my research participants. Samples of the analysed data are presented in the subsequent paragraphs.

4.3.1 Document analysis

I analysed data from several documents, namely, the Namibian Higher Level Syllabus, LTSMs and learners' activities. A detailed discussion of the analysis follows.

4.3.1.1 The Namibian Physical Science Higher Level Syllabus

As outlined in the syllabus for Namibian Physical Science, learners study reversible reactions, changes in equilibrium systems and the equilibrium constant. From my analysis, there are shortcomings in the syllabus. After studying reversible reactions, learners are required to jump to explaining changes in equilibrium systems. In the syllabus there is no mention of chemical equilibrium itself, for example, learners are not required to learn the meaning of equilibrium. There seems to be an assumption that learners already know what chemical equilibrium entails. One would expect learners to learn the equilibrium concept first before proceeding to looking at changes in equilibrium.

4.3.1.2 Learner support materials

During their mediation, both teachers made use of a chemical equilibrium module they had developed. In the stimulated recall interview, Mrs Focus explained that they used their own materials because none of the textbooks covered the topic adequately. She commented, *"I developed my own resource so that it was syllabus specific and covers all aspects of the syllabus"*. The information that was in the module was gathered from various textbooks most of which are prescribed for levels above Grade 11.

On the front page of the hand out, there was an outline of the syllabus learning outcomes. Space was left for the learners to indicate when they had studied a section as shown in Fig 4.1 below:

Fig 4.1 An example of the front page of the notes showing the outcomes of the syllabus

At the end of this unit students should be able to:		Textbook pages	Studied
31.	outline the principle that when a system in equilibrium is subjected to change: - an increase in pressure favours the system which has the smaller volume - a rise in temperature favours the system which is formed with absorption of energy		
32.	use this principle to determine the direction in which the reaction will go when changing concentration, pressure and temperature		
33.	construct an equilibrium constant expression for a simple homogeneous (gas phase or solution) reversible reaction		
34.	calculate an equilibrium constant by substituting given equilibrium partial pressures or concentrations (Kp and Kc) as well as deduce the unit of the constant		
35.	show qualitative understanding that the magnitude of an equilibrium constant indicates how far a reversible reaction proceeds towards completion		

In my opinion, this was a good practice as it helped the learners to know what they were required to know. It also proved that the teachers had knowledge of the curriculum.

In the unit of work, there were different tools such as symbols, words and diagrams. Included in the teaching resources were numerous exercises with questions, which varied from simple and straightforward to complex problems.

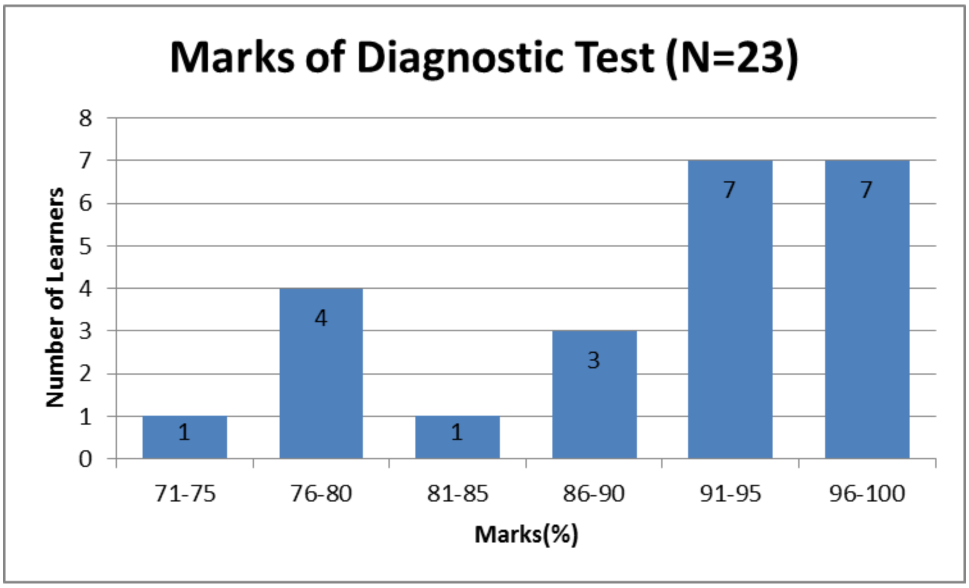
In my opinion, the module was quite comprehensive and contained sufficient information for the topic chemical equilibrium. The explanations were clear and appropriate. The language used was able to convey the meaning of the concepts. The subsequent quote shows an example of the exceptional clarification found throughout the notes:

Previously we have viewed reactions as proceeding from reactants to products. In many reactions, however, there is a significant reaction in the opposite direction in which the product molecules react to regenerate the reactants. Because of this, the terms 'forward reaction' and 'reverse reaction' are frequently used.

4.3.1.3: Learner's activities: Diagnostic test

At the start of the topic, I gave the learners a diagnostic test (Appendix C). My aim was to assess their prior knowledge. As described in the literature review, the absence of prerequisite prior knowledge is as a problem when teaching chemical equilibrium concepts. I tested the learners on their understanding of chemical reactions, symbols, pressure and volume. Learners scored high marks for the test. The distribution of marks is shown in the following graph, Fig 4.2.

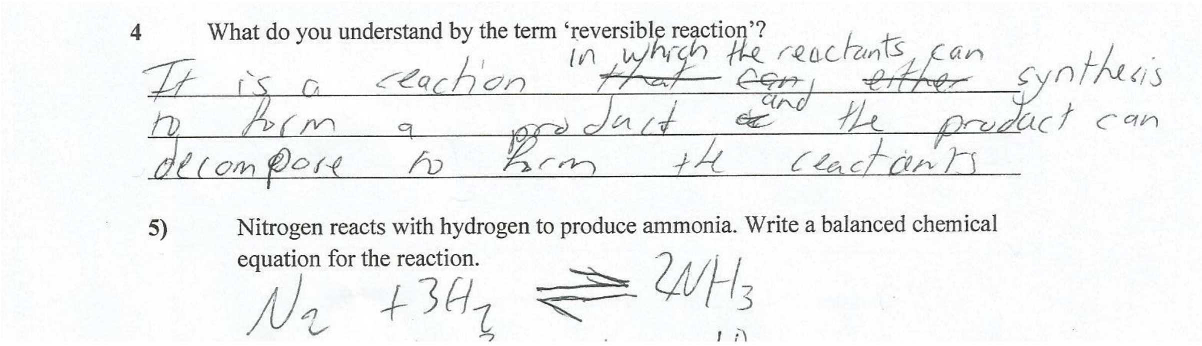
Fig 4.2: Analysis of marks for the diagnostic test



The scores reflect most learners had the pre-knowledge to study chemical equilibrium.. Learners explained the meaning of a reversible reaction well. They could relate the change of volume to pressure and concentration. Generally, learners could interpret the symbolic language.

Although, only a few learners held alternative conceptions, a number of them left out the states of matter in their equations. The teachers dealt with the omission by insisting that learners should write the states of matter every time they wrote a chemical equation as shown in Fig 4.3

Fig 4.3: Shows well answered questions from the diagnostic test, with omitted states



4 What do you understand by the term 'reversible reaction'?

It is a reaction in which the reactants ~~that~~ can ~~can~~, ~~either~~ synthesis to form a product ~~or~~ and the product can decompose to form the reactants

5) Nitrogen reacts with hydrogen to produce ammonia. Write a balanced chemical equation for the reaction.

$N_2 + 3H_2 \rightleftharpoons 2NH_3$

During the lessons, learners were required to answer various questions from their handbook. . From what I examined, learners gave correct responses. However, some struggled with predicting changes in equilibrium gave incorrect answers or made contradictory statements. The teacher went through the questions with the learners so that they could correct their answers.

The teachers dealt with this problem in the same way as they tackled the omission of states of matter. They revised the questions and discussed the correct answers with the learners. However, some learners, as in the example above (Fig 4.3), did not make the necessary corrections.

The teacher asked learners questions, which assessed knowledge with understanding, handling information, application and problem solving. I established that there was a gap in questions assessing learners' practical skills. The learners did not carry out any practical activities on their own.

4.4 Lesson observations

As explained in Section 3.5.3, observations enabled me to gather data in their natural setting which results in a first-hand account of phenomena. The lesson observations enabled me to experience how the teachers actually mediate learning as opposed to what they say they do.

During the lesson observations, I was able to witness teacher-learner interactions, challenges faced, how teachers were providing a scaffold for the learners to allow them to make sense of chemical equilibrium concepts and how they dealt with learners' difficulties.

Seven lessons were observed, four from Mrs Focus and three from Mr Humour. All the lessons were video recorded and transcribed verbatim (see Section 3.5.3). As the lessons progressed, I made field notes of any aspect that I found to be interesting. The data sets presented in the following section were from the video tapes and the field notes.

4.4.1 Lesson observations for Mrs Focus (T1)

The following outline is a summary of the four lessons observed for Mrs Focus.

Lesson 1 (45 minutes): Reversibility of reactions

Mrs Focus started by welcoming us to the lesson and explaining to the learners about our research. She made of use of clear and accurate explanations in her lesson. She augmented her descriptions with the use of symbols and diagrams drawn on the whiteboard. For instance, when referring to reversible reactions she stated "*in some reactions reactants can make products and also products can reverse to make reactants"*. In reference to equilibrium, she clarified that "*the rate of the forward reaction is equal to the rate of the backward reaction. One is not faster than the other". Once the balance is reached, it maintains the balance'.* This demonstrated her sound subject matter knowledge (SMK) and her English language proficiency. Being a native English speaker, she was able to expound on concepts easily.

Throughout the course of the lesson, there were recurring teacher-learner interactions as exemplified by the subsequent excerpt:

E1: T1L1

T1: What is an equilibrium reaction?

L: Balanced.

T1: Balanced, good. It is an equilibrium reaction. What about the reaction is balanced?
L: It is the amount.
T1: It is not usually the amount. I am going to tell you an example of that in a moment. What would it be if not the amount? There is not necessarily the same amount of product as it is the reactant.
L: What happens is the products are continuously forming reactants, as soon as it forms they break down, they from products. They happen at the same time.

The teacher-learner interactions were mainly in the form of dialogues in which the teacher asked leading questions. The teacher used questions as a way of providing a scaffold for learners to make sense of concepts, clearing up misconceptions as well as soliciting learners' prior knowledge. In some instances the learners themselves would ask questions which were answered by the teacher.

E2: Examples of questions asked by learners.

L: *For the last question in number 3, is there anything to indicate that this reaction is in equilibrium?*

L: *If I increase the concentration of nitrogen obviously at some point the hydrogen will get finished, what happens then?*

Mrs Focus employed various tools and strategies throughout the mediation process. She used a practical demonstration of the dehydration and hydration of copper (II) sulfate to illustrate the concept of reversible reactions as shown in Fig 4.4.1.1. The learners were amazed at the colour changes and watched the process.

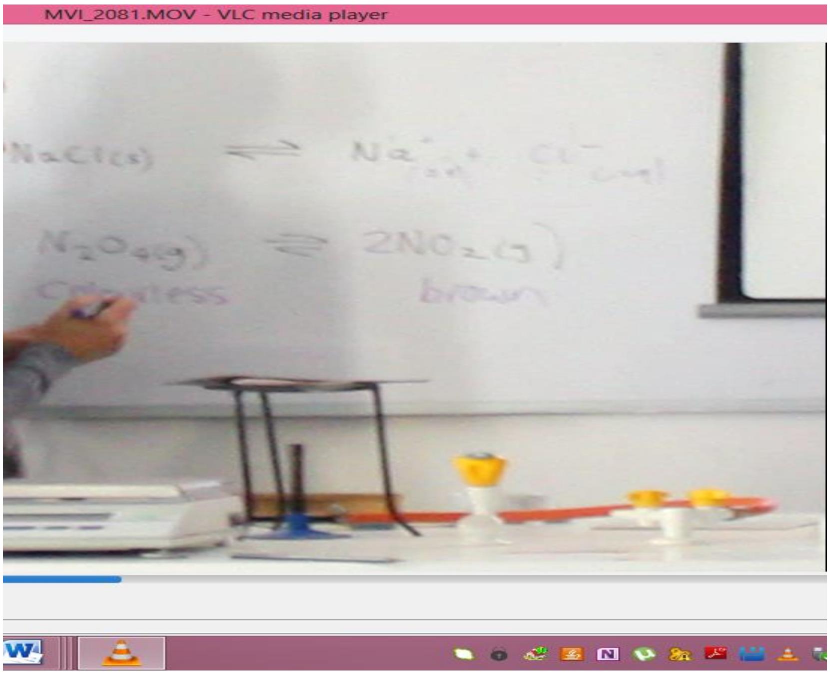
Fig 4.4: A snapshot showing the teacher's demonstration of white copper (II) sulfate turning blue after addition of water

Mrs Focus gave various examples throughout her teaching, such as the equilibrium between solid and aqueous sodium chloride as well as liquid water in equilibrium with its vapour. The di-nitrogen tetra-oxide and nitrogen dioxide equilibrium was used as an example of a chemical system.

The learners watched a You-tube clip of this equilibrium system, in which test-tubes were placed in hot and cold water. This resulted in colour changes. The teacher occasionally put the clip on pause to make clarifications such as "*By doing something to the reaction the lady says we can favour, we can push the equilibrium if you like, further or push the reaction and make it go forward*".

In addition to the video clip, notes and demonstration, Mrs Focus wrote on the whiteboard the key points as well as balanced chemical equations for all the reactions as shown in Fig 4.5

Fig 4.5: A snapshot showing examples of balanced chemical equations written on the whiteboard.



Lesson 2 (45 minutes): Le Chatelier's Principle

The lesson was on predicting the effects of changes in conditions of equilibrium by using Le Chatelier's principle. The teacher introduced the lesson by establishing learners' prior knowledge as follows:

E3: T1L2

"T: In the last lesson we started talking about reversible reactions. Can someone please tell me what a reversible reaction is?
L: A reaction in which products are formed and the products react to form reactants.
T: Good, that's a perfect answer"

The main part of the lesson consisted of a significant amount of lecturing interspaced with oral and written questions. She explained the effect of changes in concentration, temperature, pressure on a system in equilibrium.

At the end of the lesson, Mrs Focus encouraged the learners to revisit concepts and made a summary on the whiteboard. This points to the effective use of LTSMs as discussed in Section 5.3.2.2.

The teacher-learner interaction consisted mainly of Mrs Focus asking questions requiring the learners to give short responses such as in the following excerpt:

E4: T1L2

"T: Which way will this reaction go?
L: Backward
T: Why backward?
L: Because it will use up the energy".

Furthermore, Mrs Focus utilised several analogies during the process of mediation of learning. She applied the principle of the seesaw to illustrate why a system at equilibrium readjusts itself when encountered with a change by mentioning

> "*Imagine we have a see-saw and I am on this side and there are two small children on the other side but we have reached a point where we are balanced. How do I get the balance off the see-saw?"*

Likewise, to describe pressure she alluded to ping pong balls which she compared with chemical equilibrium as follows

> "*Think about ten ping pong balls in a container. They will exert a certain amount of pressure…Yes, less amount of ping pong balls, less pressure. Make sure you have that concept, less moles less pressure"*

There were a number of hurdles, which learners faced during the lesson. One of them related to equilibrium and reversibility. This is exemplified by a question a learner asked towards the end of the lesson "*Sorry mam, what exactly is the difference between a reversible reaction and a reaction at equilibrium?"*

Another learner incorrectly stated that a reaction is at equilibrium by arguing "*Ma'am they are at equilibrium because it says nitrogen and hydrogen produce ammonia. And ammonia produces nitrogen and hydrogen"*. The teacher responded by clarifying, *"Both can go both ways, ok. Both can go from left to right and right to left, ok. In equilibrium, they can occur at the same time. They occur at the same rate."*

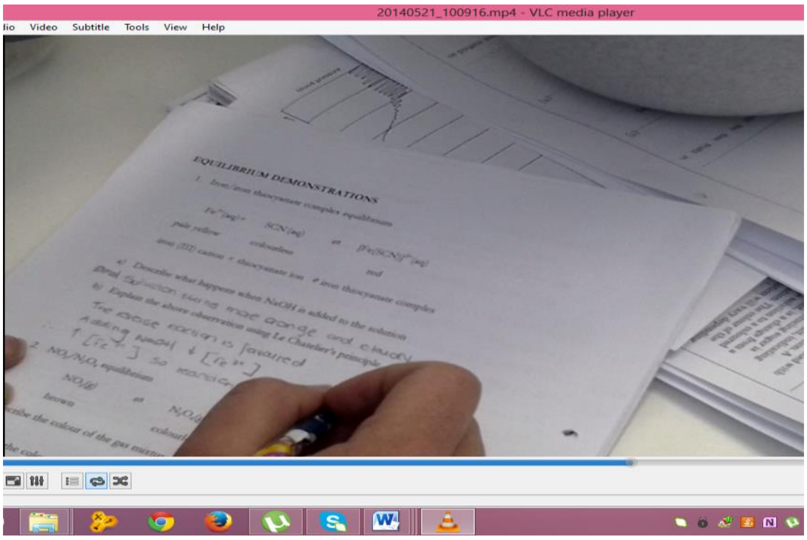
Learners often confused whether the backward reaction or forward reaction is favoured when there were changes in pressure, temperature and concentration for a system in equilibrium. Some learners simply guessed without having a plausible explanation for their answer. The teacher dealt with each problem by using various examples during the entire lesson. She also asked the learners follow-up questions in order to clear up misconceptions.

Lesson 3 (45 minutes): Changes in conditions of systems at equilibrium

Mrs Focus introduced the lesson by going back to equilibrium shifts, covered in the previous lesson. She then carried out two demonstrations to show the effect of changes in concentration and temperature. The two equilibrium systems were of iron/iron thiocyanate complex and NO_2/N_2O_4.

Mrs Focus explained each step as she carried out the demonstration. In the meantime, the students wrote answers to the questions relating to the demonstration. The teacher assisted the students with answering the questions by telling them the answers and then giving them an opportunity to write them in their own words. Some learners seemed to follow the discussions, while a few struggled to keep up with the pace. The learners seemed to enjoy the lesson as they exclaimed as colour changes occurred. There was a calm atmosphere and more laughter than in previous lessons. Fig 4.6 shows a learner completing an exercise during the lesson.

Fig 4.6: A snapshot of a learner writing answers on a worksheet during the teacher demonstrations.



Lesson 4 (45 minutes): Effects of temperature, pressure and concentration

The fourth lesson was on predicting the effect of temperature, pressure and concentration on the equilibrium reaction between hydrogen and nitrogen to produce ammonia. In the lesson, Mrs Focus explained point by point what happens when there is a change in the conditions of an equilibrium system. For instance, when explaining changes in temperature the following conversation occurred:

E5: TIL4

"T: Ok, let's make sure that everyone agrees to that. So, if I decrease the temperature, what I am really doing? So, if I pull that out which I pull that out, which way would the equilibrium shift?
L: To the right.
T: Why?
L: Because when you remove heat, the system will try and bring back the heat and it would shift to the right".

She took time to introduce the students to the terminology needed to answer related questions. In discussing pressure changes, she recalled her previous analogy of ping pong balls in a small area to clarify that when the volume is decreased pressure increases. As in previous lessons, the learner-learner interactions consisted mainly of the teacher asking questions and the learners supplying brief answers or chorusing. The example above demonstrates that some learners clearly understood equilibrium shifts and were able to use the correct terminology. Similarly, the next excerpt displays a clear grasp of equilibrium concepts by a learner:

E7: T1L4

T1: Let's look at ammonia, why would you like to take it out, when you make it?
L: It would create an imbalance in the equilibrium, so more ammonia will be formed.
T1: So if we leave the ammonia to collect and collect, what will happen?
L: Then it will start to decompose and produce hydrogen and nitrogen.

Still, there were some moments when learners were confused between exothermic and endothermic reactions as well as changes in pressure. However, the teacher did not refer to ΔH when greater and less than zero. On some occasions, learners gave incorrect predictions for pressure changes such as the system would shift to the left instead of saying it will shift to the right. The teacher dealt with these by going back to the reaction and asking the learners questions until they realised their mistake as reflected by the subsequent conversation:

E8: T1L4

"L: Increase the pressure.
T: So which way would it shift?
L: To the left.
T: Is that what we wanted?
L: No".

Best practices and missed opportunities for lessons 1-4

In summary, the best practices observed for the lessons were the clear and accurate explanations, varied teaching strategies, multiple examples and constant teacher-learner interactions. Showing learners the colour changes occurring during reaction was a good practice.
There were some missed opportunities during the lessons. The teacher could have asked more questions that are open-ended. Likewise, she could have redirected some of the questions to the class. This would have balanced learner talk and teacher talk. In this case, the teacher talked more than the learners did. To encourage the learners to be more actively involved, learners should have carried out some practical activities. There were few learner-to-learner interactions, thus, limiting opportunities to co-construct knowledge.

4.4.2 Lesson observations for Mr Humour (T2)

I observed three of Mr Humour's lessons. They covered reversibility of reactions, Le Chatelier's principle and the equilibrium constant.

Lesson 1(45 minutes): Reversibility of reactions

Mr Humour started the lesson by explaining that my critical friend and I were conducting research on how he taught the topic, chemical equilibrium. He assured the learners that they did not need to be overly concerned about our presence as the study was targeted at him as the 'rat' under investigation. The students found this amusing and it helped to make the atmosphere more relaxed.

The lesson was on reversibility of reactions and the teacher introduced the lesson by tapping into the learners' prior knowledge. The learners had already studied reversible reactions in Grade 9, which the teacher was aware of. So, he started off by enquiring "*Today's lesson is reversible reactions. Ok, reversible reactions, reversible reactions. Is there anybody who recalls a reversible reaction from Grade 9?"* One of the learners correctly responded '*A reaction in which reactants can form a product and products can react to form reactants'.* He continued to ask the learner for an example and the learner said '*Ammonia which is formed from nitrogen and hydrogen'.* All through the lesson, the teacher integrated learners' prior knowledge when he explained concepts. By analysing the learners' responses, I concluded that their everyday prior knowledge concerning reversible reactions was scientific and accurate.

Similar to Mrs Focus, most of teacher-learner interactions consisted of question and answer exchanges as exemplified by the following:

E1:T2L1

"T2: Is this a gaseous reaction?
L: Yes
T2: How do I balance it?
LLL: Put a 3 in front of H and 2 in front of N.
T Wow, yes put a 3 here and a 2 here"

A number of times the learners chorused the answers as most questions were closed and did not require in-depth explanations.

Similarly, Mr Humour used various analogies when mediating the topic. He described reversibility as similar to students entering and leaving a school by expressing,

> "*Suppose here at school every time you were getting ready to leave and go to another school, there was another student coming in, we would sent another student to immediately come in".*

The teacher also used the pumping of water in a swimming pool as an illustration of a system at equilibrium by informing the class.

> *The water is pumped, is circulated, again it is pumped, and its circulated and keeps being pumped and comes back and pumped out…….So I am saying technically, the water stays the same although there is water coming in and water going out. So we say when we have such a system, we say the rate of the forward reaction is equal to the backward reaction.*

He further explained Le Chatelier's Principle by comparing to the body in this way "*let's talk about your body, have you ever, eh eh eh, swallowed something that's not good for your body? What does your body do? You feel sick isn't it?"* He continued "*that's you reacting. That's your body trying to counter the wrong thing that you have put in up there. So your body starts sweating or you start having a running tummy or you start other things, having fevers and so on. It's our natural LCP".*

In addition, Mr Humour gave detailed and occasionally lengthy explanations of reversible reactions and made use of several examples. These included the production of ammonia and hydrogen iodide. When clarifying these concepts, he wrote the main points and chemical equations on the board. He would ask questions on how to balance the equations. Mr Humour's explanations were very accurate reflecting a sound subject matter knowledge and mastery of the language of instruction. He even 'borrowed' some terms from Physics to compare the difference between dynamic and static equilibrium. This confirmed that Physics is closer to his heart as well as reflecting integration within the same subject.

The learners seemed to have difficulty in understanding why not all reactions were reversible as typified by one question "*could water be a reversible reaction when it decomposes?"* The teacher handled this difficulty by clearing up "*No, no, the reaction between the oxygen and hydrogen is one directional equation. Hydrogen and oxygen you get water"*. There was also a concern on when reversibility occurs as the same learner asked *"Does it occur when products are decomposing naturally?"* However, there was no feedback from the teacher to address this question.

Furthermore, the learners found the concept of an increase in concentration to be problematic. The teacher explained that if you increase the concentration of one of the reactants the forward reaction is favoured. He used the production of hydrogen iodide and expounded that an increase in hydrogen will cause the forward reaction to be favoured. The learners did not agree and argued that this was only possible if iodine was also increased. One learner correctly pointed out:

> *But sir, with the equation you gave us, that if you pump in more hydrogen then the forward reaction will increase, but wouldn't more iodine be required as well, because for that as well the amount of iodine must increase.*

This issue caused a considerable amount of debate until the teacher concluded the discussion by stating "*our theory just accept, let's take an ideal situation where there is enough iodine"*. The learners were not completely satisfied with and one learner responded "*sir, will we be tested on this?"* This was greeted by laughter from the other learners.

Lesson 2 (45 minutes): Le Chatelier's Principle

Mr Humour began the lesson by reminding the learners what he had taught them in the previous lesson. He repeated in detail the effects of temperature on the ammonia equilibrium. The lesson was on the effect of concentration, pressure and a catalyst on an equilibrium system.

Mr Humour employed mainly the lecture, question, and answer methods as his teaching strategies. Comparable to Mrs Focus, he used short answer questions and probing as a way of scaffolding the learners to make sense of concentration. As a result, the teacher-learner interactions consisted of question- answer dialogues such as:

E2: T2L2

"T2: If you increase the amount of concentration of nitrogen gas, what do you think will happen? Describe in full.

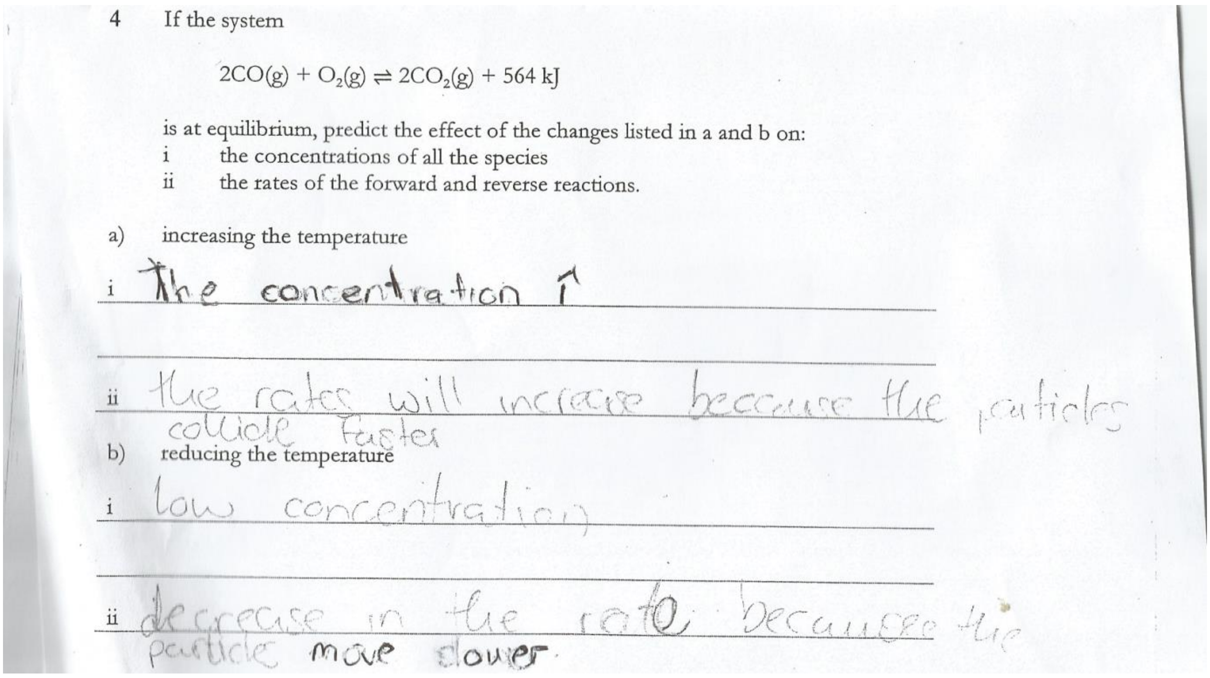
L1: We will increase the concentration of hydrogen.
T2: How do we do that, how will that affect equilibrium, describe in full.
L1: More nitrogen will be used.

The preceding conversation highlights one of the problems encountered during the lesson. The teacher and the learners frequently did not seem to follow each other. The learners would give answers appearing to be tangential to what the teacher required. All the same, the teacher continued to probe until they reached a common understanding. Sometimes they would make contradictory statements when answering questions as one learner said "*more ammonia will be produced, because the backward reaction will be favoured to make more ammonia"* instead of the forward reaction is favoured.

The terminology used during the lesson was a source of difficulty for some learners as illustrated by this question which was asked at the end of the lessons "*sir, what does it mean when you say a reaction is favoured?"* The teacher addressed such language concerns by explaining further.

However, there were instances when prior knowledge was a hindrance to learning as reflected in Fig 4.7 below.

Fig 4.7: Shows an example of a learner who struggled with explaining changes in equilibrium because they misapplied the collision theory


4 If the system

$$2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g) + 564\ kJ$$

is at equilibrium, predict the effect of the changes listed in a and b on:
i the concentrations of all the species
ii the rates of the forward and reverse reactions.

a) increasing the temperature
i The concentration ↑
ii the rates will increase because the particles collide faster
b) reducing the temperature
i low concentration
ii decrease in the rate because the particle move slower

Lesson 3 (45 minutes): The equilibrium constant

This lesson was on the equilibrium constant. Mr Humour commenced the lesson by discussing the concept of the equilibrium constant. He explained the equilibrium constant in words as a' *comparison of the concentration of the products raised to their powers and the reactants raised to their number of moles'. Using symbols he wrote on the chalkboard:*

‘$K = \frac{[products]^x}{[reactants]}$

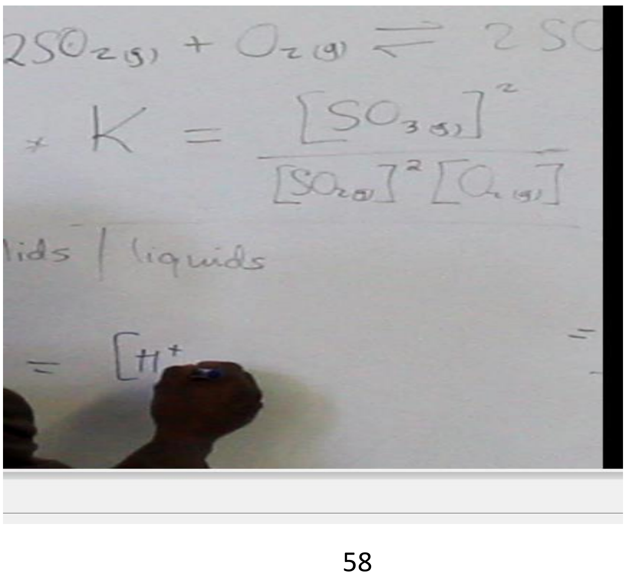
Firstly, he used a general equation to show how to work out the equilibrium constant and then he went on to use the hydrogen iodide equilibrium by stating *"Suppose hydrogen reacts with iodine gas this way and give us, the equilibrium balanced*, whilst writing $H_{2(g)}$ + I_2 to give $2HI_{(g.)}$ He continued *K expression or the equilibrium expression would be HI to the power of 2 divided by the power and to the power and indicated on the whiteboard that K would be equal to*

$\frac{[HI]^2}{[H_2][I_2]}$*"*

He pointed out that "*the squared brackets mean the concentration of the species".*

Similar to the previous lessons, the whiteboard and a worksheet were the LTSMs. Mr Humour made effective use of the whiteboard by writing neatly, clearly and in an organised manner. One could easily follow the progress of the lesson by looking at what was written on the board. He also left the main ideas visible for the duration of the lesson as shown in Fig 4.8.

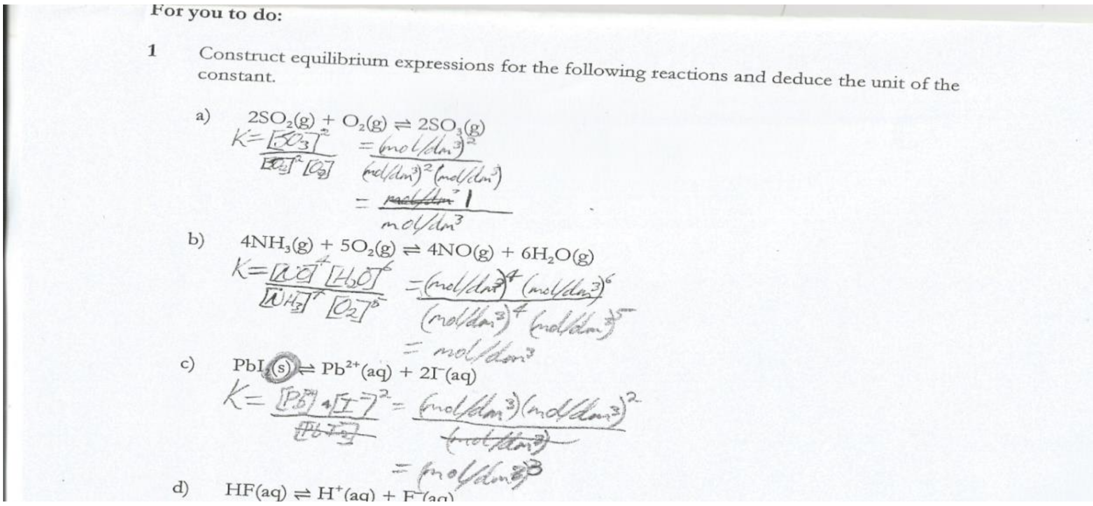
Fig 4.8: A snapshot showing an example of the effective use of the whiteboard by Mr Humour



Mr Humour also pointed out the significance of a large value of the equilibrium constant by suggesting that it meant "*the forward reaction is favoured and it has gone too far compared to the backward reaction. If K is large the reaction has gone so far, that the concentration of the denominator is so small"*.

Mr Humour utilised the question and answer method, whole class discussions, demonstration, group work and one-on-one consultation as teaching strategies. He used different examples to demonstrate how to calculate the equilibrium constant and deduce its units. Mr Humour asked the students to work out some examples from their booklet while he moved around assisting the learners as shown in Fig 4.9.

Fig 4.9: An example of questions answered by learners during the lesson.



For you to do:

1 Construct equilibrium expressions for the following reactions and deduce the unit of the constant.

a) $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

$K = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{(mol/dm^3)^2}{(mol/dm^3)^2(mol/dm^3)} = \frac{1}{mol/dm^3}$

b) $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$

$K = \frac{[NO]^4[H_2O]^6}{[NH_3]^4[O_2]^5} = \frac{(mol/dm^3)^4(mol/dm^3)^6}{(mol/dm^3)^4(mol/dm^3)^5} = mol/dm^3$

c) $PbI_2(s) \rightleftharpoons Pb^{2+}(aq) + 2I^-(aq)$

$K = \frac{[Pb^{2+}][I^-]^2}{\cancel{[PbI_2]}} = \frac{(mol/dm^3)(mol/dm^3)^2}{\cancel{(mol/dm^3)}} = (mol/dm^3)^3$

d) $HF(aq) \rightleftharpoons H^+(aq) + F^-(aq)$

He continually urged the learners to work together as he walked around attending to individual learners. The learners would work through a question and if there were common problems, he would explain the question on the chalkboard.

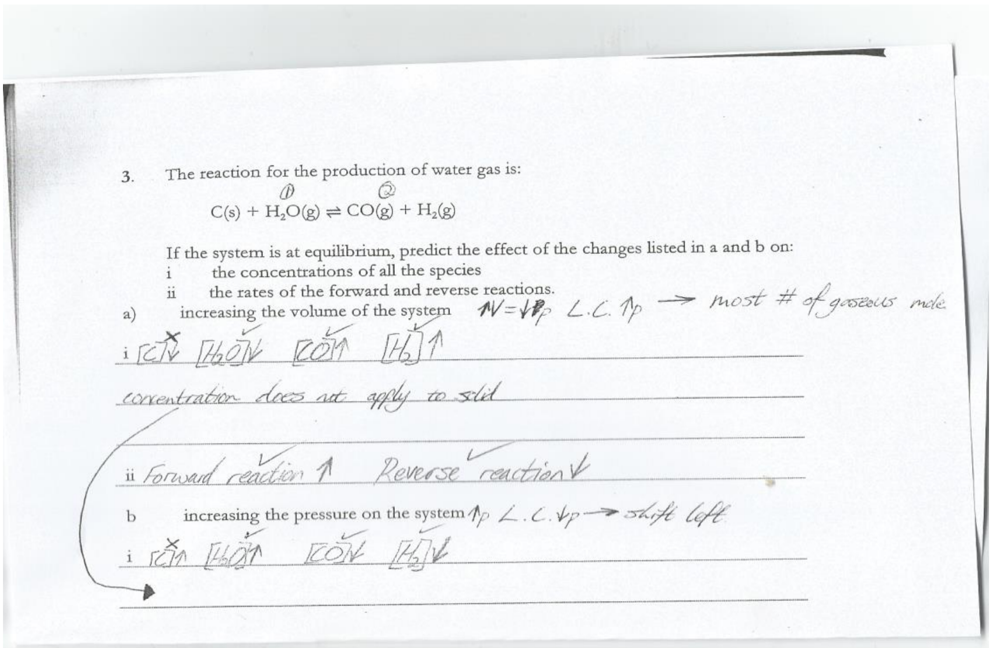
In this lesson, some learners found it difficult to understand the significance of the magnitude of the equilibrium constant. Mr Humour attempted to assist learners to comprehend by using another description. One learner kept asking what an equilibrium constant equal to one meant. It appeared the learner found the explanation to be unsatisfactory as presented by her body language.

Other learners failed to find the units of the equilibrium constant, as they were not proficient at using indices. Mr Humour attempted to go back to the laws of indices assisting some learners but not all. Similarly, the learners struggled with one question involving a solid in the chemical equation. Mr Humour helped the learners by articulating '*Oh, yes, there is something I forgot to mention, solids and liquids do not appear in the equilibrium expression'*.

Best practices and missed opportunities for lessons 1-3

As with Mrs Focus, Mr Humour gave accurate explanations of the equilibrium concepts. He mentioned one analogy after the other. For the duration of his lessons, he made effective use of the whiteboard. The exercises given to the learners contained a variety of examples covering all aspects of a particular idea. This exposed the learners to the different types of possible examination questions. Mr Humour made sure he revised the questions with the learners to correct any misconceptions as shown in Fig 4.9.

Fig 4.10: An example showing an exercise given during a lesson and how the learner corrected his answers after discussion with the teacher


3. The reaction for the production of water gas is:

$$C(s) + H_2O(g) \rightleftharpoons CO(g) + H_2(g)$$

If the system is at equilibrium, predict the effect of the changes listed in a and b on:

i the concentrations of all the species

ii the rates of the forward and reverse reactions.

a) increasing the volume of the system $\uparrow V = \downarrow p$ L.C. $\uparrow p$ → most # of gaseous mole

i [C]↓ [H₂O]↓ [CO]↑ [H₂]↑

conentration does not apply to solid

ii Forward reaction ↑ Reverse reaction ↓

b increasing the pressure on the system $\uparrow p$ L.C. $\downarrow p$ → shift left

i [C]↑ [H₂O]↑ [CO]↓ [H₂]↓

However, Mr Humour, like Mrs Focus, could have given the learners more opportunities to talk. There were instances when a point generated some debate but Mr Humour would quickly move on to answer the question stalling the conversations. Equally, there were some points; I thought he should have explained further. These include, limiting reagents and an equilibrium constant of one. In my opinion, learners were not as actively involved as they could have been. Integrating more of learners' prior knowledge, practical activities and varying teaching strategies, might have improved learner involvement.

4.5 Interviews

In this study, I carried out four interviews, two before the lesson observations and two after. The aim of the pre-interview was to answer my first research question, namely, what are the teachers' views and experiences of teaching the topic on chemical equilibrium? The post-interviews were used to solicit additional information, seek clarification as well as a data validation tool.

4.5.1 Pre-interview with Mrs Focus

The interview began with greetings and explanation of the purpose of the conversation. Mrs Focus was quite at ease and gave some useful insights of her views and experiences on the chemical equilibrium topic.

Mrs Focus experienced that the equilibrium topic was '*conceptually tricky*' to use her words. She added that '*teachers themselves do not understand chemical equilibrium*'. Mrs Focus also admitted that in her first years of teaching she herself found the topic very difficult and non-concrete to this end she commented:

> "*I don't know, I must say, I don't think I really understood it. I remember just getting by just getting through. Maybe because it was really abstract. The idea that a reaction can go either way"*.

She added that teachers themselves do not understand the topic.

Mrs Focus eventually mastered the topic by repeatedly revisiting the concepts. She said:

> "*Eh, I guess a lot of reading. A lot of questions from the children making me rethink my understanding. I also had a lot of very experienced peer teachers at that time. There was one teacher in particular; I must have sat in, on his lessons"*.

Furthermore, Mrs Focus explained that learners found predicting changes in volume particularly difficult by stating "*for some reason, volume is the hardest because they don't see the link in decreasing volume and increasing pressure"*.

According to Mrs Focus, repetition was the key to helping learners overcome the challenges they face during the mediation of learning the chemical equilibrium topic. She suggested that it is why her learners perform well on equilibrium questions in the examinations. She commented that:

> *"Um, I think that the repetition helps. That's why I think my children will do well in these questions and from marking I can see that they do well. But I think it's through repetition, repetition, repetition and you do see that it's start to click. You know the first week you teach it, there are not many kids you see, oh, I have got it. But then as you go over and over the thing, you see that this one picked it, this one picked it up and once they have picked it up, they fly. It just takes a while to get there".*

4.5.2 Stimulated recall interview (SRI) with Mrs Focus

At the start of the pre-interview, we watched some video clips of the lessons. Mrs Focus was intrigued to see how she taught and remarked, "*I am happy with how I delivered the lesson and my own information and my knowledge".* She was impressed with how well the learners had answered the equilibrium questions in their end of term examination. When I asked what could have contributed to this success and she replied, "*a low gradient, taking it step by step, the grounding of a concept before moving on to the next, teaching them the method of asking themselves questions, just drilling them on that".*

In addition, I enquired from Mrs Focus what she felt could be improved in her lessons. She indicated that no matter how well one teaches there is always room for improvement. Mrs Focus thought she should have included more demonstrations, practical activities and models. As a result, she felt she needed more support with finding resources such as videos and practical activities carried out by the learners.

4.5.3 Pre-interview Mr Humour

The interview with Mr Humour was very short as he seemed uncomfortable with the recorder. All the same, I managed to extract some of his views and experiences on mediating learning of the chemical equilibrium topic.

Mr Humour expressed that he personally enjoyed the topic and found the concepts to be very interesting. All the same, in his experience learners found working out the equilibrium constant difficult because they confused the concentrations at equilibrium. He added that those learners who did not understand the factors affecting the rates of reaction struggled with the topic. In other words, some learners have problems with the chemical equilibrium topic because they lack the prerequisite knowledge. To this end, Mr Humour revealed that some learners had problems with Le Chatelier's Principle by pointing out "*yes, some people take time to get the grips with Le Chatelier".*

Furthermore, Mr Humour explained that he assists his learners to make sense of the concepts by using various strategies, he stated *"so you really have to act it out on the board or draw diagrams"* and *"I have used even real life examples".* Comparable to Mrs Focus, Mr Humour cited repetition as one of the most important strategies he uses. He mentioned that, "*but again with repetition and other means of explanation 90% get there".*

In addition, Mr Humour stated that as a teacher he needed practical activities, demonstrations and video clips on chemical equilibrium. He felt that these could assist him during the mediation of learning.

4.5.4 Stimulated recall interview (SRI) with Mr Humour

We commenced the interview with looking at video-recordings of some lessons. Mr Humour was amused to see himself teaching.

Reflecting on the lessons, Mr Humour was pleased with the analogies he had used and stated "*my examples were quite correct; I would repeat the same examples".* He however felt that he should have spent more time on explaining Le Chatelier's Principle as he felt only a few learners understood the principle. He said:

> *"I think the students didn't get the statement of the principle because those who responded were either good English speakers or very good students and to improve their understanding 'I would first of all state Le Chatelier's principle about thrice or three times before I proceed, so that I would get more people to participate".*

The two interviews with Mr Humour were shorter than intended, as he seems distracted by the voice recorder. Once the recorder was switched off he started talking freely.

4.6 Phase 2

During this period, my research participants and I co-developed a module on the topic on chemical equilibrium. The teachers found the exercise to be of mutual benefit. Mrs Focus pointed out that "*it was an excellent idea"* and "*the right way to do it"*, to use her words. As a teacher, I found the exercise to be enriching and educative.

The two teachers were from the same school and had developed their own teaching module, they were using during mediation. They, however, felt that the teaching resource needed to be improved to enhance learners' understanding. Mrs Focus mentioned that more practical activities should be included in the module. Both teachers expressed the wish to have more links to You-tube clips included in the unit of work. They argued that if learners could carry out some practical work and visualise the chemical equilibrium phenomena it would help them to comprehend the abstract concepts more effectively. We looked for more of these resources and added them to the module. In the paragraphs below, I present the first lesson from the unit of work. The rest of the module is found as Appendix G.

4.6.1 Lesson 1: Reversibility of reactions

An outline of the lesson follows.

Introduction

Using specific examples, learners discuss in their groups what they think reversible reactions are and write these down.

Main part of the lesson

The learners present their information to the class and discuss their findings.

Consolidation

The learners summarise reversible reactions.

Assignment: The learners are to do research on the carrying of oxygen by haemoglobin and the $CO_2\,(g)_l$/ $CO_2\,(aq)$ equilibrium in fizzy drinks for the next lesson.

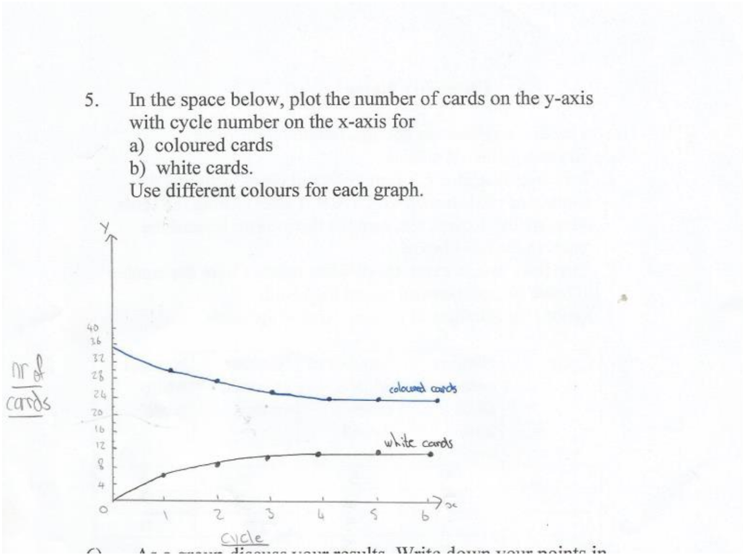
4.6.2 The equilibrium game

The module contains an equilibrium game (see Appendix G2). I piloted the game on my fellow MEd colleagues and some BEd Honours students from Rhodes University. They found the game to be particularly interesting and informative.

In a revision lesson, the learners played the equilibrium game involving turning cards and counting them. During the process, the learners were enthusiastic and actively involved. The game resulted in a substantial amount of learner-to-learner interactions and resulted in more. conversations than in the previous lessons.

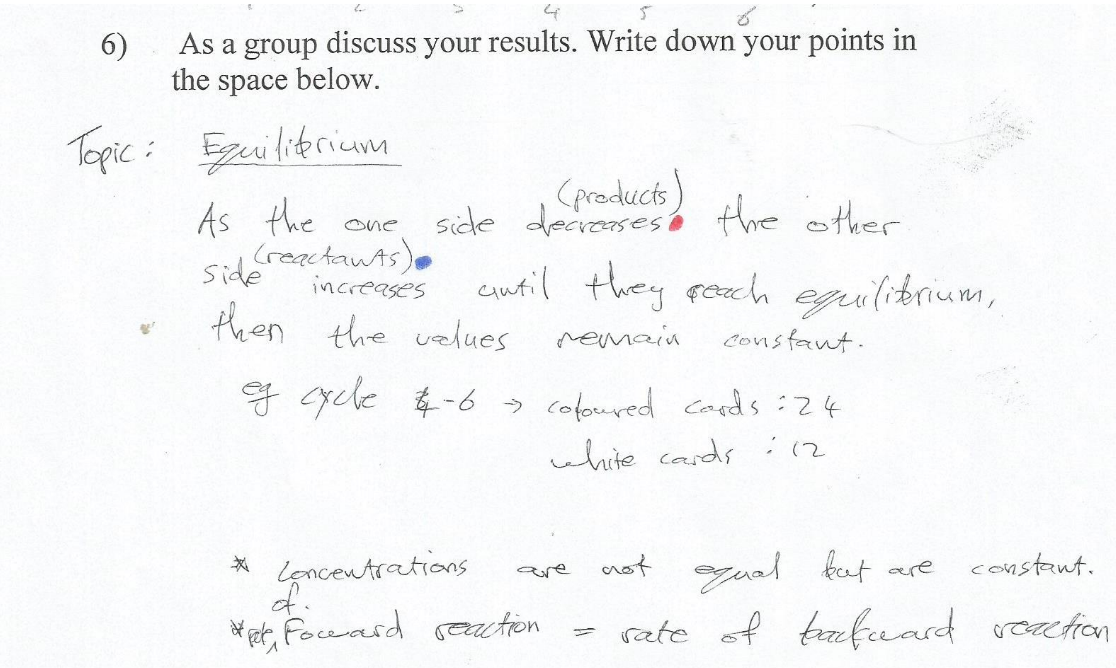
The learners drew graphs deduced from the data generated in the game. These graphs replicated equilibrium reactions as shown in Fig 4.11.

Fig 4.11 Shows an example of the graphs generated from the equilibrium game



In addition, learners drew some accurate conclusions about equilibrium from their results.

Fig 4.12 Shows an example of correct conclusions drawn from the game.



6) As a group discuss your results. Write down your points in the space below.

Topic: Equilibrium

As the one side (products) decreases the other side (reactants) increases until they reach equilibrium, then the values remain constant.

eg cycle 4-6 → coloured cards : 24
white cards : 12

* Concentrations are not equal but are constant.
* rate of Forward reaction = rate of backward reaction

Best practises and missed opportunities for Phase 2

The module contains a number of teaching strategies which are learner centred hence promote learner engagement and motivation. The inclusion of YouTube clips and practical activities ensures learner enjoyment during lessons on chemical equilibrium. The equilibrium game promotes group work, discovery learning and creates an opportunity for learners to co-construct knowledge. The learners were actively involved and took control of their learning.

In addition, when we collaborated with my research participants to create the teaching module, we learnt from each other. We shared our knowledge and experiences enabling us to develop professionally.

4.7 The selection of examples from each data set

My theoretical framework and research questions guided the selection of examples from each data set. Selected samples from document analysis, lessons and interviews were grouped into these categories:

- Analogies;
- Challenges and misconceptions;
- Prior knowledge;
- Strategies, tools and learner- teacher support materials (LTSMs).
- Teacher explanations;
- Teacher-learner interactions; and
- Teacher's views and experiences.

4.8 Concluding remarks

In the chapter, I presented the data I collected using documents, lesson observations pre-interviews and stimulated recall interviews. The documents, which I analysed, were the teachers' LTSM and the diagnostic test. The LTSM was of a very high standard and adequately covered the content for the topic on chemical equilibrium. However, it fell short in terms of practical activities and learner centred teaching strategies. The diagnostic test revealed that most of the learners had the necessary pre-knowledge needed to understand equilibrium concepts.

The data from the lesson observations reflected that the teachers had impressive subject knowledge. There were able to articulate the equilibrium concepts clearly and with great ease. Nonetheless, during the mediation process they encountered various challenges. They were able to overcome most of the difficulties by using strategies such as repetition and analogies.

Further, I presented the data gathered during the interviews. In the pre-interviews, the teachers shared their views and experiences. They both agreed that the topic on chemical equilibrium was difficult. The reflections of the teachers were captured in the stimulated recall interviews. The teachers were pleased with some aspects of their lessons but at the same time felt, there were areas where they could improve.

In the next chapter, I interpret and discuss my findings.

Chapter 5

Interpretation and discussion of findings

> *It is in the discussion that you tell the reader what you make of the findings. Were there any surprises? How do they compare with what is already known? What conclusions do you draw overall (Merriam, 2009, p. 248).*

5.1 Introduction

In this chapter, I interpret and discuss my research findings on how teachers mediate the learning of chemical equilibrium. The interpretations are based on data gathered from document analysis, interviews and lesson observations. I developed my analytical statements to answer my research questions. As mentioned by Merriam (2009) in the epigraph, in my discussion, I compare my findings to literature.

To recap, my research questions which directed my study are:

1) What are Grade 11 Physical Science teachers' views and experiences of the mediation of learning of chemical equilibrium?

2) How do Grade 11 Physical Science teachers provide a scaffold for learners to make sense of the concepts associated with chemical equilibrium?

3) What challenges do Grade 11 Physical Science teachers experience in teaching chemical equilibrium?

4) In what ways can Grade 11 Physical Science teachers be supported with the mediation of learning of the topic chemical equilibrium?

Considering these research questions, I constructed four analytical statements from my data for interpretation and discussion purposes. The analytical statements were inductively drawn using the themes which emerged from my data. These analytical statements aim at answering my research questions. They are outlined in Table 5.1 below:

Table 5.1 Analytical statements addressing my research questions

Data sources	Themes	Analytical statements	Research questions addressed
Document analysis, and observations	Tools in mediation of learning.	Mediational tools are central in provide a scaffold for learners to make sense of chemical equilibrium concepts.	1&2
Document analysis, semi structured interviews and observations.	PCK.	Teachers exhibit diverse aspects and distinct forms of PCK while mediating learning of chemical equilibrium concepts.	2
Document analysis, semi structured interviews and observations.	Challenges to mediating chemical equilibrium and possible solutions.	Teachers face and partially overcome challenges when mediating chemical equilibrium concepts.	1&3
Document analysis, semi structured interviews observations and interactions between researcher and the two teachers.	Chemical equilibrium module.	The development of a chemical equilibrium module can help to improve the way teachers mediate and provide a scaffold for learning.	4

5.2 Analytical Statement 1: Mediational tools are central in providing a scaffold for learners to make sense of chemical equilibrium concepts

In the literature review chapter, I gave an outline of Vygotsky's (1978) mediation of learning theory. Vygotsky (1978) emphasises that mediation of learning is achieved through the use of physical or psychological tools. Examples of psychological tools are language, symbols, formulae and graphs. Physical tools are for instance, pen and paper (ibid.).

As postulated by Vygotsky (1978), I found that tools were fundamental in the mediation of learning of chemical equilibrium. To this end, in this study the teachers utilised various meditational tools to provide a scaffold for learners. These included prior knowledge, language, practical activities and analogies.

5.2.1 Prior everyday knowledge

Several authors argue that it is crucial to integrate prior everyday knowledge during the mediation of learning (Roschelle, 1995; Stears et al., 2003; Kuhlane, 2011; Oloruntegbe & Ikpe, 2011; Rennie, 2011). Roschelle (1995) postulates that if teachers proceed from the point of view of prior knowledge then learners are able to construct new knowledge. This implies that meaningful learning takes place by incorporating learners' prior knowledge during teaching.

Oloruntegbe and Ikpe (2011) express similar opinions. They assert that the inclusion of learners' prior everyday knowledge enhances conceptual understanding. Judging from their actions, the teachers seemed aware of the importance of learners' everyday knowledge. Both teachers drew on learners' prior knowledge during their lessons, for example, Mr Humour started one of the lessons by asking the learners what they knew about reversible reactions. He continued his lesson from the answers given by the learners. As a result, the learners could easily follow what he was teaching as reflected by the answers they gave during the course of the lesson.

Furthermore, the teachers constantly referred back to what was taught in the previous lessons as a way of integrating prior knowledge. For instance, similar to Mr Humour, Mrs Focus began one of her lessons by saying '*in the last lesson we started talking about reversible reactions. Someone please tell me what a reversible reaction is?*' However, the teachers limited their use of prior knowledge almost exclusively to the beginning of the lessons. This practice diverges from Stears et al.'s (2003) view that prior knowledge should be assimilated into all the stages of a lesson.

Stears et al. (2003) and Kuhlane (2011) propose that learners enjoy linking their everyday contexts to school science. In agreement, Rennie (2011) recommends integrating school and everyday science to promote learner motivation. Yet, apart from the use of analogies, the teachers did not draw on learners' experiences from outside the classroom. They mostly focused on prior knowledge, which was acquired from previous lessons, in other words, school science.

As a result, they missed an opportunity to promote greater learner engagement by incorporating prior knowledge gained outside the classroom.

Taylor (1999), on the other hand, criticises the inclusion of everyday knowledge during teaching. He argues that it is unstructured and can confuse learners. He submits that the inclusion of prior knowledge can retard the gaining of knowledge. Tyson et al. (1999) express a similar opinion by proposing that prior knowledge can impede the comprehension of chemical equilibrium concepts. They posit that the knowledge of the collision theory leads learners to incorrectly predict that the addition of solid affects an equilibrium system.

I found this to be true in my lesson observations. As illustrated in section 4.3.4 some learners incorrectly applied the collision theory and made erroneous conclusions. When answering questions involving solids, learners would reason that increasing the amount of a solid reactant favoured the forward reaction. Other learners had difficulty in understanding why a catalyst had no effect on the position of equilibrium when it increases the rate of a reaction.

In essence, in my research I found instances where the inclusion of prior knowledge either promoted or retarded learning but the teachers did not seem aware of this. However, my findings showed that the benefits outweigh the drawbacks. Thus, according to my judgement, prior everyday knowledge is an integral tool in mediation of learning as proposed by authors such as Roschelle (1995), Stears et al. (2003) and Rennie (2011).

5.2.2 Language

According to Vygotsky (1978), language is the most important psychological tool in the mediation of learning because it allows for development on the social and intellectual plane (ibid.). Hodson and Hodson (1990) agree that language is essential to learning science as it allows teacher-learner interactions to take place. Interactions are critical in mediation of learning as discussed in detail in section 2.3.1 as such exchanges help learners to make sense of concepts. Thus, it emerged that the teachers made use of language as a meditational tool in a number of ways in this study.

Firstly, both teachers drew on language to explain chemical equilibrium ideas. The clarifications were clear, concise and scientifically sound. The vocabulary used was simple therefore easily accessible to learners. As an illustration, Mrs Focus described a reaction at chemical equilibrium as '*So when you look at the definition of equilibrium reaction it means the forward reaction is* *happening at the same time as the reverse reaction. But there is a trick to it. The rate of the forward reaction is equal to the rate of the backward reaction. One is not faster than the other'*.

In my view, the way the teachers expressed themselves contributed to the learners' ability to grasp problematic concepts such as reversibility. According to researchers such as Tyson et al. (1999) and Rollnick et al. (2008), learners find reversibility to be conceptually challenging. They have difficulties in imagining that reactions can proceed forwards or backwards. This was not the case with the learners observed in this study. For instance, a learner was asked to explain what a reversible reaction is, she correctly replied '*A reaction in which products are formed and the products react to form reactants'.* The learner went on to give a coherent explanation when probed further.

Furthermore, when explaining concepts both teachers used both words and symbols they wrote all the chemical equations including the states of matter on the whiteboard. As an illustration, Mrs Focus in one of the lessons explained, '*this is an example of a reversible reaction. The way for me to denote that is an arrow going from left to write and from right to left'.* Then she wrote on the whiteboard:

$$\underset{(blue)}{CuSO_4.5H_2O} \leftrightarrows \underset{(white)}{CuSO_4}$$

In the equilibrium pack the meaning of symbols was given a considerable amount of attention as reflected in the extract from the teachers notes below.

E1:

Frequently a double arrow is used as a way of indicating significant reversibility of a reaction. In the case of the reaction above this can be represented as follows:

$$2HI(g) \leftrightarrows H_2(g) + I_2(g)'$$

Marais and Jordaan (2000) posit that the mathematical language used in describing chemical equilibrium is often a source of difficulty. Learners are often required to interpret a number of icons and letters (ibid.). However, from examining the learners' written exercises and observations, most of them did not seem to have difficulty with comprehending the symbolic language used in the topic. Although there were some learners who still left out the states of matter when writing chemical equations, the teachers insisted these should be added whenever there were omissions. The teacher explained that the states of matter were important when working out the equilibrium constant and that solids and liquids would not be included in the calculation. Likewise, adding a solid reactant did not affect the position of equilibrium.

I would attribute the learners' competency in using symbolic language to the attention given to the meaning of symbols by both teachers. This in turn might have contributed to the impressive performance in the examination mentioned in the SRI by Mrs Focus. To this end, Chiu et al. (2000) suggest that there is a positive correlation between achievement in chemical equilibrium questions and proficiency in using chemical symbols.

Secondly, language was utilised during classroom interactions. Lemke (1990) posits that for learners to develop the 'language of science' they should be given ample time to talk in the classroom. In this way, learners are enculturated into science (Hodson & Hodson, 1998). This implies that there has to be a balance between teacher-talk and learner-talk. Nonetheless, I found that most teacher-learner interactions which I observed contradicted with Lemke's (1990, 2001) ideas. The teacher-learner interactions for both teachers were dominated by teacher-talk. Learner-talk was limited to short answer responses and the chorusing of answers. There were hardly any occurrences of extended learner talk. The level of verbal questions asked by teachers did not encourage learners to converse as suggested by Lemke (1990/ 2001). Instead, they required learners to simply respond to the questions or chorus out answers.

Probyn (2004) suggests that when the language of instruction is not the same as the home language of learners, teachers must employ strategies to assist learners in developing their language proficiency. She suggests approaches such as writing new words on the chalkboard, whole class discussions and practical work as ways to assist the learners. In my study the language of instruction was English, yet most of the learners were second language English speakers. As a result, I also found that in the lessons there was limited use of whole class discussions and practical work. At the same time, the learners experienced challenges which Mr Humour attributed to their lack of language proficiency.

In the same vein, Kocakulah et al. (2005) proposed that learning science in a foreign language limits comprehension of scientific concepts for high school learners. Similarly, Brock-Utne (2001) identifies language as a source of learning difficulties. Data gathered during the SRI with Mr Humour corresponds with these assertions. In reference to Le Chatelier's Principle, Mr Humour said *'I think the students didn't get the statement of the principle because those who responded were either good English speakers or very good students.'* He further explained that if the learners had clearly understood the wording of the principle they would have had fewer problems with predicting changes in conditions of equilibrium. This finding supports Probyn's (2004) assertion that effective mediation of learning will only take place when learners are given linguistic support.

Generally, however, the two teachers demonstrated skilled use of language as a meditational tool in their explanations. Although the teachers were a male and a female, I did not observe any gender issues in their lessons. Nevertheless, the teachers needed to pay closer attention to providing language support to learners and avoid dominating a lesson with teacher-learner interactions.

5.2.3 Practical activities

Millar (2004) postulates that by carrying out practical work, learners are able to understand abstract concepts as they are able to visualise phenomena. Consistent with this view, Mrs Focus carried out some demonstrations to mediate learning. One of the demonstrations involved the dehydration and rehydration of copper sulphate. These reactions were set to exemplify and explain the concept of reversibility. The Fe^{3+} / Fe^{2+} and NO_2 /N_2O_4 equilibria demonstrated the effect of changes in equilibrium conditions such as temperature and concentration. The learners were given an opportunity to see and explain the colour changes. This helped them to visualise are abstract concepts such as reversibility of reactions and the effect of changes in conditions of equilibrium.

In their study in Grahamstown, Maselwa and Ngcoza (2003) found that learners enjoy doing practical activities. However, these authors emphasise that the focus should be on development of key scientific concepts during practical activities rather than merely doing practical activities for the sake of doing them. My study revealed similar findings. I observed that learners appreciated the practical activities which were carried out in the form of teacher demonstrations. They exclaimed and made positive remarks throughout. The learners were more eager to ask and answer questions than in all other lessons.

Rudd (2007) suggests the use of Science Heuristic Writing (SHW) to improve performance in the topic on chemical equilibrium. In this method, learners are instructed through answering questions while carrying out practical activities. Mrs Focus utilised the SHW in her third lesson to show how temperature causes shifts in equilibrium. Evidence from the learners' workbooks showed that they answered questions relating to this section well.

Nevertheless, practical activities were limited to the teacher demonstrations carried out by Mrs Focus. Mrs Focus admitted in the SRI that the learners should have carried out the investigations themselves as there were enough chemicals at the school and the practical activity did not involve any dangerous reagents.

Furthermore, Mrs Focus and Mr Humour did include other types of practical activities such as investigations and exploratory tasks. Thus, there was a gap in terms of 'hands-on' practical activities. 'Hands-on' practical activities are highly motivating for learners as described by authors such as Hattingh et al. (2007) and Maselwa and Ngcoza (2003). Furthermore, Maselwa and Ngcoza (2003) suggest that learners view practical activities as valuable tools for conceptual development and comprehension of ideas. Learners feel that by experiencing science through practical work reduces learning by memorising (ibid).

On the other hand, the value of 'hands on' practical activities is disputed by Hodson (1990). Hodson (1990) who submit that learners do not always learn during practical activities and are occasionally not interested in them.

In my perspective, given the abstract nature of the chemical equilibrium ideas, practical activities are an indispensable tool in the mediation of learning. However, they should be well planned as revealed by the literature.

5.2.4 Analogies

Treagust (1993) describes analogies as comparisons made to help learners comprehend an idea. Bilgin and Geban (2006) support the application of analogies when mediating the concepts of equilibrium. They argue that learners grasp abstract ideas by comparing them with real life experiences (ibid.). Mr Humour made frequent use of analogies to scaffold learners when mediating learning. For example, he explained a reversible reaction in terms of water being pumped in and out of a pool as well as students enrolling and leaving a school. In this way learners were able to clearly understand the reversibility concept. To discuss why a decrease in volume increases pressure, Mrs Focus spoke of tennis and ping pong balls in an adjustable cube. The analogy assisted the learners to understand the relationship between volume and pressure.

Mr Humour was very pleased with his analogies and felt that they helped learners make sense of chemical equilibrium theories. When reflecting on his lessons, he commented that '*my examples were quite correct. I would repeat the same examples'*. This reflects that in coherence with

Bilgin and Geban (2006), he viewed analogies as an effective tool for mediating the topic on chemical equilibrium. Consequently, he would continue to use them in future lessons.

In contrast, Treagust (1993) argues that applying analogies in the classroom has numerous disadvantages. Learners may take comparisons too far resulting in misconceptions. The similarities and differences between real life experiences and scientific ideas may be difficult to identify.

In my study, I did not have the opportunity to explore the effectiveness of analogies. Still, in line with Treagust (1993), I regard Mrs Focus' comparison of an equilibrium system to a see-saw to be potentially problematic. It might lead learners to reason that at equilibrium the concentrations are equal which Cheung (2009) cites as a common misconception encountered in the topic. Overall, from my data I can posit that analogies are a useful tool in the mediation of ideas on chemical equilibrium.

5.3 Analytical Statement 2: Teachers exhibit diverse aspects and distinct features of PCK while mediating learning.

According to Schulman (1987), pedagogical content knowledge (PCK) refers to the ability of the teacher to transform subject matter into material, which can be grasped by learners. It is a multifaceted process involving preparation, lesson presentation, instruction and adaptation as explained in Section 2.3.3.

Kind (2009) described PCK as consisting of numerous intertwined aspects such as teaching strategies, knowledge of the curriculum, SMK and learner difficulties. I will discuss and interpret the various features of PCK exhibited by Mr Humour and Mrs Focus in the following paragraphs. Learner misconceptions and difficulties are discussed in a separate analytical statement.

5.3.1 Lesson preparation

The two teachers demonstrated that they had prepared for their lessons. They were in possession of a meticulously compiled hand out. The practical demonstrations were well planned and flowed smoothly. All the lessons were structured, thus reflecting a good level of organisation.

Czerniewicz, Murray and Probyn (2000) identify learning and teaching support materials (LTSMs) as organised materials which scaffold learning and support teachers during lesson mediation.

As both teachers were from the same school they compiled the equilibrium pack together and edited it over the years. By preparing the LTSM as a team, the teachers formed a ‘community of practice’ as proposed by Lave and Wenger (1991). These authors suggest that if members of a community, for example teachers in a school, work together they achieve more than they would as individuals. The teachers’ development of the chemical equilibrium pack agrees with Czerniewicz et al.’s (2000) proposal that teachers should prepare their own LTSMs in advance of lessons.

As mentioned in Section 4.4.2, I was impressed by the teaching resource. It contained explanations, procedures for teacher demonstrations and numerous student activities. The inclusion of learner activities proved that to a certain extent the LTSM was learner-centred as advocated by Czerniewicz et al. who recommend that LTSMs must be learner-centred giving the learners the opportunity for problem solving while the teacher acts as a facilitator.

According to most teachers, however, they do not have the time to develop their own LTSMs (Czerniewicz et al., 2000). Drawing from Mrs Focus’ and Mr Humour’s experience, it is time consuming for teachers to create their own teaching resources. Nevertheless, my findings reveal that it is worth the effort as the teaching module was adequately address the objectives of the topic.

The teachers discovered that the textbooks did not have all the required information, hence; they felt they had no option but to sacrifice their time to develop suitable LTSMs from various resources such as the internet to ensure that the objectives of the topic were met. I consider the development of the equilibrium pack as one of the major strengths observed in the teachers’ mediation of learning. The practice points to commitment and dedication from the teachers.

Mr Focus and Mrs Humour did not have formal lesson plans. Their preparation consisted of short and brief points on what they were going to cover in a lesson. Mrs Focus mentioned that in the coming year she intended to focus on teaching strategies she intended to use in her lessons. I reason that if the teachers had compiled detailed lesson plans they would have employed a wider range of instructional strategies.

5.3.2 Lesson presentation: Teaching strategies, LTSMs and SMK

In the ensuing paragraphs, I discuss the lesson presentations. The information is subdivided into teaching strategies, other LTSMs used and teachers' subject matter knowledge (SMK).

5.3.2.1 Teaching strategies

There were similarities and differences in the way Mr Humour and Mrs Focus presented their lessons. Both teachers made use of various teaching strategies and other LTSMs such as the whiteboard.

The lecture method dominated Mrs Focus' and Mr Humour's lessons. When analysing their lessons they were protracted episodes of teacher talk. Mrs Focus admitted to making *'extensive use of the lecture method in her lessons'*. When introducing new chemical equilibrium ideas, both teachers often resorted to lecturing. This was accompanied by writing on the board. While the teachers were lecturing, the students sat quietly and listened. This shows that the lecture method does not promote student involvement and motivation. Hence, it is regarded as a teacher-centred strategy. Bilgrin and Geban (2006) argue that lecturing learners does not promote their conceptual understanding of chemical equilibrium. They propose that teachers need to replace the lecture method with other teaching strategies such as practical activities (ibid.).

Additionally, both teachers utilised the question and answer strategy to provide a scaffold for learners. The questions were either oral or written. There were occasions when this method was very effective, especially when discussing concepts and building on existing knowledge as shown in the following conversation for Mrs Focus which took place during (give source).

E1:T1

'T: This is where the temperature is, so if I pull that out which I pull that out, which way would the equilibrium shift?
L: To the right.
T: Why?
L: Because when you remove heat, the system will try and bring back the heat and it would shift to the right.
T: That's well said, so that's one thing you can do, decrease the temperature. We will come back to that in a moment. Tell me any other thing I could do to make the equilibrium go to the right?'

As discussed in the earlier paragraphs the teachers should have asked verbal questions that required in-depth answers to facilitate language development.

During their lessons, both teachers asked learners to answer written questions. In chapter four, section 4.4.4, I showed some examples of the type of questions they asked. They ranged from simple questions to more demanding ones. The learners would answer the first questions in an exercise with the assistance of the teachers. Then they answered the rest of the questions on their own. The teacher would go back to the questions and make any necessary corrections to students' responses.

The way the teachers employed the question and answer strategy is in agreement with Vygotsky (1978) and other authors such as Goos (2004). Vygotsky (1978) created the theory of the zone of proximal development (ZPD) as discussed in Section 2.3.1. Goos (2004) refers to the ZPD as scaffolding and collaboration. She explained that scaffolding is the collaboration between the teacher and learner, which should be within the ZPD of the learner. The teacher structures an activity and the learner carries out the task under the teacher's guidance. In the process, the teacher gradually removes his/her support to allow the learner to carry out the action on his or her own (ibid).

In addition, these teachers would sometimes walk around the class and attend to individual questions. Such one-on-one interactions were a valuable teaching strategy as learners were individually attended to. I found the method to be especially beneficial to learners who seemed shy to ask questions or had fallen way behind the rest of the class.

Mrs Focus did not utilise many cooperative teaching strategies while in one of his lessons, Mr Humour encouraged learners to work in pairs. Mr Humour's practice is in line with the social constructivists' theory which advocates that learning occurs as result of social interactions (Moll, 2002) (see Section 2.3.2). McRobbie and Tobin (1997) add that the social constructivist approach to teaching improves involvement, autonomy and relevance of content. These enhance learners' understanding and motivation. Vygotsky (1978) insists that effective learning of science occurs through cooperative instruction approaches rather than through lecturing. According to Tudge (1990), peer collaboration can enhance conceptual development but does not always result in learning.

Several authors have advised that there are teaching strategies, which can help learners make sense of chemical equilibrium (Van Driel, 2002; Chiu et al., 2002; Quilez, 2006). I discussed these strategies in more detail in my literature review. Van Driel (2002) proposes that learners can study reversibility of reactions using the pink-blue cobalt complex system. Chiu et al. (2002) posit that the use of the cognitive approach method improves theoretical understanding. While

Quilez (2006) recommends the History and Philosophy of science strategy when mediating chemical equilibrium. The teachers in this study could have adopted some of these approaches to reduce their reliance on the lecture method.

5.3.2.2 Other LTSMs

Both teachers made extensive use of the whiteboard. Czerniewicz et al. (2000) identify the board as one of the LTSMs which can be used during teaching. Probyn (2004) agrees with using the whiteboard during teaching particularly as a strategy for language development. The teachers consistently wrote new terms on the board, which was an effective way of using the board. Still, they could have written the meanings as well in order to fully support the learners in terms of language needs. In addition, examples and chemical equations were displayed on the board for learners to see. I regard this as a good practice by the teachers as it helped the learners to follow the lessons and learn different symbols. The teachers supplemented what they wrote on the board with verbal explanations. As a result, learners were given an opportunity to learn through seeing and hearing.

In addition, Mrs Focus included YouTube clips in her teaching. Consequently, her lessons were more varied than those given by Mr Humour. One YouTube clip http://www.youtube.com/watch?v=d_NwW5kvVYk depicted what was happening at the submicroscopic level for a reaction at equilibrium. As a result, this approach enabled the learners to visualise abstract phenomena as proposed by Rollnick et al. (2008) and Van Driel (2002). Another YouTube clip showed a practical of the N_2O_2 and NO_2 equilibrium, which may be difficult to carry out in the laboratory. This proves that technology can assist teachers in teaching abstract chemical equilibrium theories that are difficult to demonstrate. Mrs Focus would occasionally pause the clips and explain what was happening. She supplemented the YouTube clips with her own explanations. Czerniewicz et al. (2000) support the idea of teachers modifying LTSMs to make them more suitable for their lessons.

5.2.3.3 Teachers' subject matter knowledge (SMK)

Schulman (1987) describes SMK as the principles, facts and concepts of a particular subject. SMK is a constituent of PCK which deals with knowledge of a particular discipline. Rollnick et al. (2008) found that in South Africa the teachers' limited subject matter knowledge (SMK) of chemical equilibrium concepts constrained mediation of the topic.

Contrary to Rollnick et al.'s (2008) observations, the two teachers demonstrated sound subject matter knowledge. They were able to articulate chemical equilibrium principles with relative ease. As exemplified in Chapter 4, I found all their explanations to be detailed and scientifically correct. The teachers appeared to be at ease with the topic content. They could shift from one example to another without faltering. This made transitions smooth and seemingly effortless. However, there were occasions when I felt the learners did not grasp the teachers' clarifications. I do not attribute this to inadequate SMK as in the case of Rollnick et al. (2008) but to other factors such as covering too much content in one lesson.

5.3.3 Adaptation

Shulman (1987) defines adaptation as the teachers' ability to modify lessons to cater for the needs of the learners. This takes into account the learners' contexts, interests, misconceptions, prior knowledge and learning styles (Shulman, 1987; Geddis et al., 1993). This implies that teachers must possess learner knowledge to make lessons more meaningful. Mr Humour and Mrs Focus seemed well acquainted with their learners. However, there were shortcomings in the way the two teachers catered for the needs of their learners.

My findings showed that there were several areas of strength in reference to learner knowledge. These reflected that the teachers had some awareness of how learners assimilated information. The fact that the teachers used a variety of teaching strategies such as demonstrations, question and answer, analogies and YouTube videos proves that they were addressing different learning styles. It attests to the fact that the teachers were aware of the need for learners to be taught in multiple ways in order to accommodate their preferences. The teachers drew analogies that were appropriate and matched learners' experiences. For instance, Mr Humour talked of a swimming pool, which a number of learners would have at home. Several authors such as Rennie (2011) underline the inclusion of learner everyday content. Occasionally, the teachers drew on learners' prior knowledge, which is a means of integrating learner contexts and interests discussed in Section 5.2.4. The way teachers sometimes moved around to assist learners as individuals helped those learners who prefer a one-on-one interaction with the teacher. Herein lies the importance mediation of learning as proposed by Vygotsky (1978) (see Section 2.3.1).

However, there were a number of areas, I perceive to be weaknesses in terms of adapting to learners' needs. The limited use of practical activities and cooperative teaching strategies such as peer tutoring, group work, whole class and small group discussions was a shortcoming on the part of the teachers. As already discussed, learners learn in these fundamental ways. There was no differentiation in the pace and activities given to learners to cater for the slower or faster ones. As a result, the same learners dominated most lessons, while there were a few learners who seemed to be ‘lost’. Although, there was an effort by Mrs Focus to try to draw these learners out by asking them questions, her attempts were not always successful.

In summary, although there were some similarities in certain aspects of the teachers’ PCK, each teacher had a distinctive style of teaching. At the same time, the PCK displayed varied in each lesson. Several characteristics of the teachers’ PCK were commendable, these include, preparing for their lessons, using various teaching strategies and adapting their teaching to the needs of their learners. Their SMK was extremely sound as well as their explanations. Nevertheless, the teachers could improve on their PCK by including more practical activities and group work in their teaching.

5.4 Analytical Statement 3:

Teachers face and partially overcome challenges when mediating chemical equilibrium concepts

Researchers such as Chiu, Chou and Liu (2002) and Rudd, Greenbowe and Hand (2007) agree that the chemical equilibrium topic is challenging and difficult for both teachers and learners. There are several factors, which are associated to the problems encountered when mediating this topic. In agreement with literature, my findings reveal that there were numerous challenges experienced by both teachers and learners during the mediation of chemical equilibrium.

Tyson et al. (1999) suggest that the concepts are difficult to comprehend because they are abstract in nature. Mrs Focus concurred that the topic is ‘conceptually *really tricky’* and ‘it is ‘*really abstract’*. In agreement with Tyson et al. (1999) and Rollnick et al. (2008), she cited the concept reversibility of reactions to be a problem for learners. In the pre-interview, Mrs Focus mentioned that learners found it difficult to understand ‘*the idea that a reaction can go either way*’. However, during my lesson observations, there were few difficulties with understanding reversibility of reactions. I postulate that Mrs Focus had modified her teaching in such a way as to eradicate the problem. In other words, the knowledge of learner difficulties helped her to mediate effectively. Shulman (1987) posits that to facilitate learning, teachers must understand learner difficulties.

Although the learners easily grasped reversibility as a separate concept, they struggled to distinguish equilibrium from reversibility. Tyson et al. (1999) explain that there is a subtle difference between some chemical equilibrium ideas. This leads learners to draw wrong conclusions. To overcome this challenge, Mrs Focus used an analogy of public speakers who were dynamic at assembly. She then explained the meaning of dynamic equilibrium.

In both Mr Humour's and Mrs Focus' lessons, I found that learners initially had difficulty with applying Le Chatelier's Principle (LCP) to predict the effect of changes in equilibrium conditions. Mrs Focus stated in both her interviews that learners found the effects of altering pressure to be particularly difficult.

Mr Humour attributed some of the learner difficulties to the wording of LCP. He thought it was complicated and only accessible to '*good English speakers'*. Similarly, Mrs Focus introduced the principle by saying 'Le *Chatelier put forward a proposal… so I am going to be very plain with it, I am not going to use it verbatim at the moment'.* Interestingly, Mr Humour also simplified the principle first before stating it fully. The teachers' actions converged with Quilez (2004) who motivates that the vocabulary used in the principle is vague and incomprehensible.

Additionally, there were instances when the learners made inaccurate predictions during lessons by applying the LCP. They would confuse which reaction would be favoured or which way the equilibrium would shift. This finding is consistent with authors such as Voska and Heikkinen (2000), Kousathana and Tsarpalis (2002) and Cheung (2009). These researchers advise that LCP may result in erroneous predictions when answering chemical equilibrium questions.

The teachers dealt with challenges associated LCP and the changes in conditions at equilibrium in various ways. Firstly, both teachers mentioned that repetition helped the learners understand. In the stimulated recall interview, Mrs Focus emphasised that when she started the topic few learners grasped the ideas but through repetition, other learners were able to understand. Secondly, the teachers made the learners carry out various written exercises to help them to clear up misconceptions. They revised the questions in class and the learners made the necessary corrections. Thirdly, both teachers utilised the question and answer method to deal with problems. The teachers would ask the students leading questions or probe until they realised their mistakes. The learners themselves would be encouraged to ask questions if they had any misunderstandings. The teachers responded to learners' enquiries as best as they could.

In addition, Mrs Focus relied on '*drilling*' the learners. This approach made the learners ask themselves questions on the procedure to follow. In other words, the learners were taught the pathway to follow when making predictions. For example, for changes in conditions of systems at equilibrium, the learners were encouraged to *'first determine what LCP would say'*, determine which reaction would be favoured and then predict the changes in concentration.

Mrs Focus felt that this systematic approach to answering questions was the reason why her learners performed well in examinations. Similarly, the Examiners' reports encourage teachers to use past examination questions as teaching resources to improve how students answer questions.

The equilibrium constant calculations proved to be problematic for learners. In the interviews, Mrs Focus and Mr Humour expressed opposing opinions concerning mathematical problems. Mrs Focus said '*calculations are not a problem'* while Mr Humour mentioned that ' *'let's say you try to do calculations, student's struggle with calculations'*. However, Mrs Focus conceded in the SRI that when working out the equilibrium constant, some learners would add up the concentrations of reactants instead of multiplying. Others would forget to include the coefficients in their equilibrium expression. Voska and Heikkinen (2000) acknowledge that learners experience problems with the mathematics involved in equilibrium. On the other hand, Tyson et al. (1999) insist that using mathematical formulations such as the equilibrium law eliminates incorrect predictions. My findings disagree with Tyson et al. (1999). Mathematical difficulties would limit learners' ability to use the equilibrium law.

The teachers tried to reduce mathematical errors by exposing the learners to numerous examples. These were worked out in class and as homework. Mr Humour drew on learners' prior knowledge of indices. When he started the section on deducing the units of the equilibrium constant, he did not mention indices. After realising that the learners were struggling, he went back to the laws of indices. Immediately, the learners began perform the calculations correctly. This shows that the teachers must integrate knowledge from other disciplines when mediating learning. At the same time, it affirms Roschelle's (1995) idea that learning will not be possible if teachers ignore learners' prior knowledge.

Furthermore, Mrs Focus had trouble with teaching chemical equilibrium concepts at the beginning of her career. She admitted to *'not fully understanding'* the topic. This is in agreement with studies by Cheung (2009) and Quilez (2004) who found that teachers in Hong Kong and Spain respectively, held numerous misconceptions related to chemical equilibrium. Coherently, Rollnick et al. (2008) mention that teachers struggle with teaching the topic because of limited SMK.

A number of factors enabled Mrs Focus to improve on her mediation. She observed more experienced teachers. On that matter, she said '*I remember frequently sitting in one teachers' lessons in particular*'. Mrs Focus read extensively around the topic developing her SMK. .As she gained more teaching experience, she found it easier to teach the topic. This finding agrees with Schulman (1987) who proposes that more experienced teachers possess more advanced PCK.

5.5 Analytical Statement 4:

The development of a chemical equilibrium module can help improve the way teachers scaffold learning

In the second phase of my study, I co-developed a chemical equilibrium module with my research participants. The aim was to develop a unit of work to support teachers with the mediation of chemical equilibrium concepts.

We compiled the module based on data generated during my study. The unit of work integrated the best practices observed in the teachers' lessons such as analogies as well as the specific areas which teachers indicated that they needed added support.

The teachers felt we needed to include as many practical activities as possible in the module. They reasoned that practical activities would improve participation of learners and enhance knowledge construction as proposed by Maselwa and Ngcoza (2003). To this end, we used the internet to look for suitable investigations to include. Unfortunately, most of the practical activities we came across were 'recipe type' practical work. This upholds Hodson's (1990) notion that most practical work is prescriptive and of no educational value. We found no other source of practical activities besides the internet.

In the module, we added more links to YouTube clips. Both teachers expressed a desire to have more visual aids. The practice concurs with Van Driel (2002) proposal that learners should view abstract chemical equilibrium phenomena to reduce misconceptions.

We retained the questions in the teachers' resource as we felt they were a good balance of factual recall and cognitively challenging problems. The aim was to use the questions to provide a scaffold for learners in their ZPD. Goos (2004) maintains that scaffolding should occur in the ZPD for learning to take place. The learners would move from the simple questions that they could do on their own to the more complex ones to be answered with the assistance of the teacher.

In the teaching module, I included the game on chemical equilibrium that I pilot-tested with the Masters and BEd (Hons) Science Elective students studying at Rhodes University. I shared the game with my research participants who gave it their learners to play in groups. The learners formulated their own conclusions from the results. The learners were keen to play the game and took control of all the proceedings. McRobbie and Tobin (1997) argue that learners must be actively involved during learning because it enhances conceptual understanding. They advocate for learner autonomy during lessons to promote learner motivation.

The learners worked in groups in line with Vygotsky's (1978) social constructivism. The theory advances that social interactions are crucial for learning. In adherence, Hodson and Hodson (1998) explain that cognitive development is a direct result of learners co-constructing knowledge. In this way, social constructivism reduces rote learning leading to better conceptual understanding.

The inclusion of the practical activities, whole class discussions and equilibrium game is in line with MEC (1993) learner centred education (LCE). The approach places the learner at the centre of education. Learner centred teaching methods such as discovery learning is preferred to traditional strategies.

The teachers felt that developing the module was beneficial to all of us as we were able to share our expertise. The teachers found the exercise so constructive that we went on to set some dates to develop modules for other topics. Mrs Focus acknowledged that

> "*It is an excellent idea, just using expertise from different people and everyone has personally has a slightly different understanding and putting it together makes for a really good process. It is the right way to do it".*

This experience is consistent with the ideas of Thompson, Gregg and Niska (2004) ideas who propose that when teachers solve a problem as a team, they benefit immensely and this, in turn, spills over to their learners. Thus, as teachers exchange information through collaborations, their performance is improved (ibid.). This is in agreement with Lave and Wenger (1991) who encouraged members of communities to work together for maximum achievement.

5.6 Concluding remarks

In this chapter, I discussed and interpreted my data gathered from document analysis, interviews and lesson observations. I constructed four analytical statements from my data presented in Chapter 4 as these answered my research questions.

In summary, I found that teachers and learners experience the topic of chemical equilibrium as a difficult one. The teachers drew on meditational tools and PCK to provide a scaffold for learners to make sense of chemical equilibrium concepts. They relied mainly on language, prior knowledge, lecture method, question and answer approaches and the equilibrium hand out. However, their use of practical activities and social constructivist teaching strategies were limited.

Furthermore, the teachers in this study encountered a number of challenges during the mediation of learning. These centred on language, making predictions for systems in equilibrium and calculation of the equilibrium concept. The teachers partially overcame some of the challenges by repetition and correction of misconceptions as they unfolded. To support teachers with this topic a module was co-developed with the two teachers.

In the next chapter, I present a summary of my findings and make recommendations for areas for future research as well critically reflect on my research journey. Finally, I present the conclusions drawn from my case study.

Chapter 6

Summary of findings, recommendations and conclusions

In this section, all loose ends should be gathered together. This is the place for looking backward, for distilling into a few paragraphs what has been achieved in each phase of the research activity (Leedy & Ormrod, 2014, p. 329).

6.1 Introduction

The main aim of this study was to understand how Grade 11 Physical Science teachers mediate learning of the topic chemical equilibrium. My experiences as a Physical Science teacher as well as a National Examiner marker motivated my study. I gained some useful insights on how teachers use meditational tools to provide a scaffold for learners, the teaching strategies they employ, challenges that arose and ways in which the teachers dealt with these challenges.

In this chapter, the findings of my research, limitations and the resulting recommendations are summarised as described by Leedy and Ormrod (2014) in the epigraph. The recommendations suggest ways to potentially improve how teachers mediate learning of the topic chemical equilibrium. At the end of the chapter, a critical refection of my research journey is outlined and this is followed by the conclusions drawn from the study.

6.2 Summary of my findings

The theoretical framework adopted for the study was mediation of learning infused with social constructivism and pedagogical content knowledge (PCK). Vygotsky (1978) posits that mediation of learning is a process in which an adult or more competent peer intervenes between the child and their environment to enable mental development. Vygotsky (1978), furthermore, proposes that mediation occurs through signs and tools. Moll (2002) explains that social constructivism is a sociocultural theory, which advocates that mediation of learning occurs as a result of social interaction with a more knowledgeable individual. This perspective highlights that knowledge is constructed socially within a community.

Shulman (1987) identifies PCK as one of the seven categories of knowledge a teacher has to possess in order to mediate learning. He explains that PCK describes the way in which teachers present and formulate subject content in order to make it understandable i. e. how concepts are presented during lessons to suit the abilities and interests of students. I carried out the investigation in two phases. During the first phase, information on how teachers mediate chemical equilibrium was gathered. The research methodology for the first phase was a qualitative case study underpinned by an interpretive paradigm. Creswell (2007) defines a case study as a comprehensive investigation of a confined system, such as individuals, centred on the extensive collection of data. The aim of a case study is to analyse phenomena from the perspective of the participants (Babbie & Mouton, 2006). An interpretive paradigm is characterised by its focus on the individual and their encounters (Terre Blanche, Durrheim & Painter, 2006). Document analysis, semi-structured interviews, lesson observations and stimulated recall interviews were my sources of data.

In the second phase, I developed a module on the topic in collaboration with the research participants and implemented part of it. This introduced an element of participatory action research (PAR) which is designed to produce knowledge by means of collaboration between the researcher and participants in order to improve educational practice (Bhana, 2006). Lave and Wenger (1991) propose that a community of practice is able to achieve more as people work together than when individuals work alone as they reason as a team. Through the occasions of PAR, I also validated data in the form of content knowledge for the unit of work.

Additionally, I ensured validity by comparing data from various sources, peer reviews and stimulated recall interviews. A combination of purposive and convenience sampling was utilised to select the research site and participants. Throughout the research process, I followed standard ethical protocols.

My research findings show that the teachers this study possessed adequate SMK to mediate the chemical equilibrium topic. They were instances when they displayed advanced PCK, for instance by using analogies in their teaching.

However, there was limited integration of learners' prior knowledge by teachers. Roschelle (1995) argues that learning can only take place if learners' prior knowledge is included during teaching.

The teachers made successful use of language through well-articulated explanations, however, they did not give the learners sufficient language support by allowing for extended learner-talk. Lemke (1990, 2001) suggests that learners' language proficiency develops as they converse during lessons. A few learners experienced problems associated with language because of this omission.

Furthermore, my study revealed that the only type of practical activities which were conducted were teacher demonstrations. Although this was a good practice, Maselwa and Ngcoza (2003) posit that learners must be involved in meaningful ‘hands on’, ‘minds on’ and ‘words on’ activities in order to develop conceptually. These authors claim that the ‘words-on’ approach plays a critical role in enhancing language during science lessons.

I found that the teachers consistently used appropriate analogies obtained from the learners’ everyday experiences. This is in line with Bilgrin and Geban (2006) who postulate that learners can understand chemical equilibrium through application of analogies.

The two teachers made extensive use of the lecture method, however, some authors including Chiu et al. (2002), Van Driel (2002) and Quilez (2006), argue that traditional teaching methods, such as lecturing, are ineffective when teaching chemical equilibrium concepts.

In agreement with Czerniewicz et al. 2000), the teachers utilised LTSMs such as ‘YouTube’ clips; whiteboard and the chemical equilibrium pack appropriately. Their good practice contributed to enhancing learners’ comprehension of chemical equilibrium theories.

There were challenges that learners faced. They found it difficult to distinguish between reversibility and dynamic equilibrium. Some learners had problems with calculating the equilibrium constants. Other learners struggled with the terminology of LCP and explaining the changes in conditions of equilibrium. These challenges are consistent with the findings by authors such as Quilez (2009) and Cheung (2009). One teacher admitted to initially grappling with teaching the topic but improving with practice.

My research findings revealed that the teachers managed to overcome some of the challenges by using analogies, multiple examples, repetition, practical demonstrations and video clips during mediation.

Finally, developing the module in partnership with my research participants was an enriching experience for all us. We were able to share our knowledge and experiences.

6.3 Recommendations

Several recommendations emerged from my research findings and discussion above. The objective of these recommendations is to alleviate some of the problems encountered when mediating chemical equilibrium concepts. I grouped these under curriculum, pedagogy, teamwork, strengthening of content knowledge, development of modules and the use of games and analogies.

- **Curriculum**

The Namibian Physical Science Higher syllabus needs to be transformed so that it follows a logical sequence. In the current syllabus, learners study the reversibility of reactions and immediately thereafter, the changes in conditions at equilibrium. Learners should be able to understand the idea of dynamic equilibrium before they can predict the effect of pressure, temperature and concentration. Hence, the concept of dynamic equilibrium must be inserted between reversibility and equilibrium shifts.

- **Pedagogy**

Teachers are encouraged to plan extensively for their lessons, particularly, in terms of the teaching strategies they intend to use. In addition, teachers should be encouraged to use a variety of teaching approaches that are learner-centred such as practical activities, group work and peer tutoring. This would reduce their reliance on traditional teaching methods such as the lecture method. In addition, workshops at local, regional and national level should be organised to train teachers on how to teach this difficult topic.

- **Strengthening of teachers' subject matter knowledge (SMK)**

According to Rollnick et al. (2008) teachers do not give adequate explanations of equilibrium principles because they lack the required content knowledge. Therefore, I recommend that a programme should be developed to strengthen teachers' SMK. This could be implemented in the form of workshops.

- **Teamwork**

I recommend that teachers should share their experiences of teaching chemical equilibrium in order to tap into each other's expertise. They can exchange ideas on how best to approach different aspects of the topic. Herein lies the importance of community of practice as proposed by Lave and Wenger (1991). In this way, teachers will broaden their perspective and improve their PCK. In the same way, I suggest that teachers must attend each other's lessons to understand how others teach the topic and learn from them.

- **Development of modules**

To support teachers with mediation, modules on chemical equilibrium, specifically, those with a focus on practical activities need to be developed. These modules can be formulated in collaboration with a number of teachers.

- **Use of games and analogies during teaching of chemical equilibrium**

My study findings reveal that the BEd Honours and Med students from Rhodes as well as learners found the equilibrium game to be educational and entertaining. Similarly, the teachers found analogies to be useful. Bilgrin and Geban (2006) support the use of analogies to enhance conceptual understanding in chemical equilibrium. I suggest that teachers should be trained in how to use analogies and games when mediating learning.

6.4 Limitations of study

Two teachers were involved in this study. Due to the small sample size the findings cannot be generalised, however, I gained useful insights into how the teachers mediated the topic on chemical equilibrium.

The research only focused on teachers' perceptions and experiences. The learners are a major constituent of the mediation process. Omitting them out from the research process excluded some potentially useful understandings, which could have added more depth to the study.

Due to time constraints, the teachers were unable to revise the interview and classroom observation transcripts. This limited the study in terms of validity. As a second option, I handed the transcripts to a critical friend, a Physical Science teacher, who was able to make the necessary corrections. This helped to reduce any errors made during the transcribing process. I managed to carry out the stimulated recall interviews, which further validated my data.

Another limitation is that that the teachers did not implement the unit of work that we co-developed to see if there were any improvements required.

6.5 Areas for future research

The following are potential areas for further research:

- The effectiveness of using analogies when teaching chemical equilibrium;
- The value of practical work when mediating chemical equilibrium;
- The usefulness of chemical equilibrium modules;
- The role of technology during the mediation of equilibrium concepts;
- Teaching strategies which can be used to mediate chemical equilibrium;
- Ways to deal with challenges which arise during the mediation of chemical equilibrium;
- The learners' perceptions and experiences of chemical equilibrium; and
- An analysis of how learners answer questions on chemical equilibrium.

6.6 Conclusion

The study illuminated the importance of meditational tools in scaffolding learners to make sense of the concepts of chemical equilibrium. The teachers exhibited some strengths as well as shortcomings when using these tools. In terms of language, although the teachers themselves were proficient, they did not give the learners enough opportunity to talk in order to develop their language skills.

Furthermore, the research highlighted the role played by teachers' PCK in determining how well the learners were able to make sense of the chemical equilibrium concepts. The teachers exhibited some aspects of advanced PCK with their use of appropriate analogies and varying their lesson presentations. However, they could improve on their PCK by employing more learner-centred teaching strategies.

The study concludes by suggesting that teachers should work collaboratively to develop modules that support them in mediating the topic of chemical equilibrium. These modules should focus on the various strategies teachers could use such as practical activities, learner cooperation, analogies and so forth in order to work within a community of practice and achieve the best possible result.

EPILOGUE: MY CRITICAL REFLECTIONS

My MEd course journey was full of discoveries and a considerable amount of learning. In my first year, my lecturers introduced me to analysing literature and academic writing. These tools proved to be invaluable during my research process. In that same year, I completed my research proposal, laying the groundwork for my study.

In the second year, the research process began in earnest. Guided by a team of committed and dedicated supervisors and supported by cooperative MEd colleagues, what could have been insurmountable turned out to be an exciting journey of new discoveries. As a teacher, I began to comprehend the value of prior knowledge, language and practical activities in the mediation of learning process. I started to appreciate the concept of pedagogical content knowledge (PCK) and the sociocultural approaches to learning. It dawned to me that a strong subject content knowledge precedes the development of PCK. As I reflected on the practice of other teachers, I perceived how I could improve on my own practice. The course opened my eyes to the world of research and the new ideas generated by the studies.

There were moments of frustration such as trying to find my way through what seemed like mountains of data and having to endure the ‘endless’ transcription process. Nevertheless, at the end of the day, it was a journey worth taking as I came out much more knowledgeable than I was before embarking on the process.

In retrospect, if I were to carry out the research again, I would make a number of changes. Firstly, I would make sure that I pilot my interview questions more thoroughly. This would eliminate the need to change them during the research process. I had to modify the pre-interview questions after my conversation with the first teacher because I realised they were not generating the required data. Secondly, I would make sure that my research participants were more comfortable with recording devices to prevent the situation were the teachers’ behaviour was completely altered by the presence of a voice recorder. Instead of first writing out my transcriptions by hand and then typing them, I would type as I transcribed. This would save me time during the transcription process. Lastly, during my second phase, I would have tried to implement parts of my unit of work. When I played the equilibrium game with my colleagues, I realised how enriching the game could have been for the learners.

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Appendices

Appendix A1- Permission letter to principal

01 April, 2014.

To: The Principal

Dear Mrs. [redacted]

Re: Request to conduct research at your College.

I am requesting for permission to conduct some research at your school from the 3 April to 8 April and 14 May to 21 May, 2014. My study will be on how two Grade 11 teachers mediate the Chemical Equilibrium topic.

Approximately, six lessons will be observed and video recorded. Furthermore, the data will be published in the form of a Rhodes University MEd half-thesis.

Pseudonyms will be used to ensure that the identity of the participants remains anonymous. In addition, all other standard ethical protocols will be observed.

Thank you for your support.

Yours sincerely,

Fungi Chani.

Student number: 613C6257

Reply slip.

I am granting Mrs F. M. Chani permission to conduct research at my school in my capacity as the principal.

Signature: Date

Appendix A2 Consent letter to teachers
Dear Research Participant

Re: Participation in chemical equilibrium research.

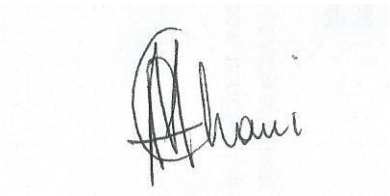
Thank you for agreeing to be a research participant in my study. As per our discussion, my research area is ‘How do Grade 11 teachers mediate chemical equilibrium?’

As indicated, I will observe and video record approximately three of your lessons on chemical equilibrium. At the same time, I will carry out some interviews which will be audio recorded.

The data will be published as a Rhodes University half-thesis. I will ensure that your identity remains anonymous.

Your support is deeply appreciated.

Yours sincerely,



Fungi Chani : Student number 613C6257

Reply slip

I agree to participate in the research on condition that I can withdraw at any time.

Name……………………………………

Signature………………………………… Date……………………………………..

Appendix B: Diagnostic test Total 18 Marks

1 Study the reaction below and answer the questions which follow

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

a) Complete the table below to show the names and states of molecules.

	Name	State
$H_2(g)$		
$O_2(g)$		
$H_2O(l)$		

[6]

b) Identify the reactants and products in this reaction. Explain your answer. [2]

2 Explain what happens to the pressure of a gas (in a closed container) when its volume is decreased at a constant temperature. [2]

Explain what happens to the concentration of the gas when the volume is increased.

[2]

3 Describe the effect of a catalyst on the rate of a reaction. [2]

4 What do you understand by the term ‘reversible reaction’? [2]

5 Nitrogen reacts with hydrogen to form ammonia. Write a balanced chemical equation for the reaction. [2]

Appendix C1: Pre-interview schedule (modified version completed after the first interview)

1) What are your views and experiences of teaching chemical equilibrium?

2) How do you teach the topic, what strategies do you use?

3) How do you ensure that the learners are actively involved?

4) What challenges have you faced when teaching the topic?

5) How do you deal with these challenges?

Appendix C2:SRI Interview schedule

1) What do you feel went right with your lesson.

2) What do you feel you could improve on?

3) What were the challenges you faced during your lessons.

4) How did you deal with these challenges?

Appendix D1: Interviews (T1, Mrs Focus)
Transcribed pre-interview, I = interviewer, T = teacher

I: Good morning. Thank you so much for agreeing to have an interview with me. I am just going to be asking you a few questions on your experiences as a teacher specifically on the equilibrium topic. So my first question is how do you introduce this topic?

T: I usually introduce this as a balance thing, sometimes I play like a little bit of a silly game, where I give the students, eh, pieces of paper and I slit them in two and I get them to roll up the paper in a small ball and then throw them at each other. And they must pick them up and throw them back as quickly as possible. And sometimes I give the one side of the classroom all the paper and I let them go and when I can see that they are kind of evenly distributed and I get them to count the pieces of paper, so I am trying to introduce if you know one side is throwing as hard as the other, it will end as a balance, essentially that's one way. Then I also use the concept of a see-saw. I don't know if it's called a see-saw here.

I: Yes, it is.

T: Yes, just that concept of a seesaw if you want to keep it balanced them add more people to one side, what must happen to compensate, so I talk a lot about compensating and balancing things out and how you can get it back in balance.

I: Do you ask them about what they already know?

T: Yes, but usually, so I would ask them, I would show them the symbol and we will talk about. Before we studied equilibrium we would have covered reversible reactions, so then would have talked about what a reversible reaction is, but I do not think with equilibrium the kids come in with hardly anything, if they understand reversible, that's probably all they understand about this concept.

I: That's quite interesting. What do you use in the classroom, do you use the chalkboard. do you use?

T: No, I have got notes, so I use notes. I have got for equilibrium two YouTube clips that I show them, the notes are quite comprehensive. I try and get them to watch me writing on the board rather than copy things down, because I feel that their attention is split if I do it that way. I tell them please watch and then I will give you time, so that they can focus at one thing at time.

I: The clips, what are they on?

T: I have clips of N_2O_4 and $2NO_2$ equilibrium, so the yellow gas going to colourless, brown and colourless, sometimes show them the potassium iodide equilibrium, I think I also have that. And also I do try and show the NO_2 with the gas cylinder, then I put in ice and in hot water.

I: At which point do you this? As you are going on?

T: I do the demonstration as prediction exercise. I show the, let's predict which way the equilibrium, in which direction. I don't use it as an introduction.

I: As part of, that sounds great.

I: How do you make the learners more actively involved?

T: In just a normal lesson, I really try to spread out the questions, say I am teaching, I look at indicators, so I would say, let's say the name. I guess I use their facial expressions a lot, you clearly see. I do try to do lots of examples on the board and ask them what to do. I do a fair bit of lecturing.

I: What other teaching strategies do you use, you have mentioned, yea, the.. .

T: Yea, the demonstration that's what I try to use more in Chemistry because it is so conceptual. For example, when looking up the shape of molecules. The problem with Chem is that it is so conceptual, the more hands on they can do. And it's so funny, also with chemical equilibrium the students find it difficult, then repetition helps. With equilibrium, we almost make up a song, if this happens then that will happen, trying to get them.

I: And, and eh, how do you make sure they understand? You have talked about, eh, asking questions. Do you have other ways of making sure they have understood?

T: I think they have to teach it, if they tell me. You pick out misunderstandings more from homework, em, then they are actually put on the spot, if you like. If someone does not clearly understand you can read it.

I: So you ask them to explain in class?

T: I will get them to explain to others. Recently I have been giving them homework of what we are doing and also putting a stoichiometry question, trying to see those who do not understand it, so repetition.

I: And, and from your experience what problems have you seen? What exactly is the problem with the chemical equilibrium? Is it the calculations? Is it..?

T: It's the concepts. Conceptually it's really tricky, I think they can't know the starting point, so they cannot conceptualise what directions. The calcs are not a problem.

I: They cannot comprehend the concepts?

T: I don't know, I must a say, I don't think I really understood it. I remember just getting by, just getting through. Maybe because it was really abstract. The idea that a reaction can go either way: I think the way my kids will get by is not by rote learning but by learning the skills to know, if this happens then.. Increasing the temperature, I use the Le Chatelier's. Le Chatelier's would say decrease the temperature. Ok which side the shift but which way it will move and then they will write that. Um, I think that the repetition helps. That's why I think my children will do well in these questions and form marking I can see that they do well. But I think it's through repetition, repetition, repetition and you do see that it's start to click. You know the first week you teach it, there is not many kids you see, 'oh, I have got it. But then as you go over and over the thing, you see that this one picked it, this one picked it up and once they have picked it up, they fly. It just takes a while to get there.

I: So it's more of them knowing the procedures, you teach them the procedures?

T: I teach them what they have to think about to get there. What questions they need to ask themselves.

I: So which part is really problematic. Is it the predicting of the effect of the change?

T: I think it's the explanation. I think the prediction is okay. I think it's actually, I think if you ask, if you increase the concentration, I think that they can answer that well. But then I think the pressure and volume questions are the ones, I think they are higher order and the prediction is tricky.

I: How can we improve this, how can we help the children?

T: When we answer the question, I use like a short hand way of showing them. So for example the question the question is, increase the pressure, I do an arrow up, therefore Le Chatelier's says, decrease the pressure. So I do with pressure, then I go to volume after pressure. So once they understand pressure, then I will do the abbreviation for volume. So decreasing volume equals increasing pressure. So I think it is a conceptually hard thing. As soon as they see volume, they want to start talking about a gas or something but I get them to realise that decreasing volume equals increase in pressure. And they I write there Le Chatelier's says decreasing pressure. For some reason volume is the hardest because they don't see the link in decreasing volume and increasing pressure. One get that concept then you think they are fine.

Transcribed stimulated recall interview with T1, Mrs Focus

I: Good morning. What do you feel went right with your lessons?

T: I am happy with how I delivered my own information, my knowledge. I feel the students have a good knowledge, because they were clearly able to answer questions. Calculations went well. I feel the lesson achieved their goal.

I: What do you feel you could improve on?

T: I could have put in some more demonstrations and some models. If there could be more modelling, visual stimulation and more questions. Practical demonstrations worked well, maybe to use them as practical demonstrations.

I: What were the challenges you faced?

T: Just trying to finish what you want to say and then a question comes in between do you stop or finish, equilibrium brings a lot of questions. There was a misconception on the decrease in volume and the effect on pressure. I ended up drawing boxes on the board. The students confused the word equilibrium expression and constant adding instead of multiplying and forgetting to use the co-efficient. Obviously I didn't emphasise that enough.

I : How did you deal with these challenges?

T: A low gradient asking it step by step. The grounding of a concept before moving to the next one and teaching them the method of asking themselves questions. For example the sort of songs in their head, so they always have the question, what's the change, what does LC suggest? What shift do I expect and what are the ramifications of that shift, just drilling them on that, enables them to answer questions well.

I: What support would you need to teach the topic?

T: I would like more you-tube clips, practical activities. Just finding the resources is time consuming.

Appendix D2: Transcribed interviews (T2, Mr Humour)

Transcribed Pre-interview

I: Good morning. Thank you so much for agreeing to the interview, I appreciate your help. I am going to ask you questions on the Chemical Equilibrium topic. My first question will be what are your views and experiences with the teaching of Chemical Equilibrium topic.

T: Thank you Mrs Chani. It is an interesting topic for me although I find some children who struggle with it, maybe it would be based on their lack of understanding of rates of reaction or factors that affect reactions. But most of the time, the more able student is able to cope with this topic.

I: Thank you so much, so when you see that they are struggling, how do you help them to make sense of the topic?

T: Thank you, eh, I have used even real life examples, like at theoretical level, like them, at one time I used the enrolment of students at the College. And let's say you could enrol a student at the same time as one student goes away, that appealed to them as a good example of an equilibrium system.

I: That is a nice example and what other problems do you experience, for example when we talk of predictions, do you experience any problems?

T: Yes, let us say you try to do calculations, students struggle with calculations. Let's say final concentrations even if you give them one concentration, they fail to apply the equations properly or the calculations properly. They struggle with the mathematical side of the calculation.

I: That's interesting, what about the descriptions?

T: The descriptions, yes also, when you are saying, let's say you are describing the equilibrium shifts to the left and to the right,, they struggle with that, so you really have to act it out on the board or draw diagrams . In some cases it is easier to say the colour change to darker or changes to lighter, to show the progress of the reaction and the position of the equilibrium constant. So unless you say that very clearly and repetitively they won't understand it.

I: That's interesting, you talked of challenges, do you have any other challenges that you face when teaching this topic?

T: Yes, I do not have enough reactions that I can use to demonstrate to the students.

I: Do you have any demonstrations that you do?

T: Yes there is one of the nitrogen oxide.

I: And you would wish for more?

T: Yes, I wish for more examples that I can demonstrate, then I can say the colour is changing or fading, whatever changes are.

I: Ok, very interesting. Strategies, you talked about demonstrations do you also have other strategies you use like technology, group work and allow for discussions.

T: Yes, I think I lack on group work. For technology, yes there is information available on the internet. Like there is a demonstration by young students on equilibrium.

I: Do you show them?

T: Last time, I had a lesson; I forgot to show them, I will do my best next time.

I: But you would like to show them?

T: Yes, it was informative, it was clear.

I: And practicals, do they do any practical work?

T: No, equilibrium constant, no, we only have rates of reactions.

I: So I want to go back to predicting changes such as pressure and volume, do you use Le Chatelier's principle.

T: Yes

I: Do you find it effective to predict changes in Equilibrium.

T: Yes, Le Chatelier's is very effective for that. For those who understand the principle on its own, they can predict what happens in which direction the equilibrium shifts and the amounts at equilibrium. They can predict that easily, if they grasp Le Chatelier's principle.

I: Do you have students who do not?

T: Yes, some people take time to get the grips with Le Chateliers, but again with repetition and other means of explanation 90% get there.

I: How do you find the involvement of the students when you are teaching this or how do you ensure that they are actively involved?

T: I throw the questions at them, so that they are forced to answer. I say, what do you think happens and why?

I: Alright, that's a good way of getting the students views and understanding. I am done, thank you.

Transcribed Stimulated recall interview with T2, Mr Humour

I: Good morning. Thank you so much for agreeing to the interviews, you are a very involved person and your time is limited. Ok, let's start. What do you think about your lessons, what would you do again, what would you do differently?

T: My examples were quite correct. I would repeat the same examples. But I would first of all state Le Chatelier's principle about thrice or three times before I proceed, so that I would get more people to participate. The problem is that I got few hands and a few participants and I suspect they did not quite get the principle.

I: So you are saying if you stated the principle again, you would have more students to participate.

T: Yes, I think the students didn't get the statement of the principle because those who responded were either good English speakers or very good students.

I: So what other challenges were you facing?

T: Just the fact it was new to them, sometimes they needed something to be done over, it has to be reinforced.

I: You think Le Chatelier's was the challenging part.

T: Most probably, yes, at the start it was a bit of a challenge but as the lessons progressed, it a lot easier for them to catch up.

I: Why do you think Le Chatelier's is a bit difficult for the students to grasp?

T: It shouldn't be, but since it was first mentioned it was still a bit new and students were coming to grips with it.

I: So it's a new concept which they have they have not come across before?

T; Yes, it's completely new, although we tried to give examples of students coming in and going out, it was still a new concept.

I: Do you think also the wording of the principle might contribute?

T: Yes, it might, that's why at the start the first few students who understood it are those with a good grasp of English.

I: Any suggestions you can make on how to make these learners to understand?

T: If I had a u-tube presentation of Le Chatelier's, or let's say I could have a U-tube clip of a bus and of children coming and children going out before we start asking questions.

I: In summary what would you say, how would you improve your lessons?

T: I think I definitely need I.T, I need to make sure that they understand before I proceed and doing a practical would have helped.

I: What would you do the same?

T: I would definitely do the same, backed by I.T. I would do the same questions; I thought they were quite relevant.

I: So you believe, they must do as many questions as possible.

T: Yes

I: And these questions should they answer them orally or should they write them down.

T: First of all, I think they should answer the questions orally to clear doubts in the minds of others and if there is time in the lesson they can answer them on paper or in the ensuing lessons.

Appendix E1: Transcribed Lesson observation (T1, Mrs Focus)
Lesson 1

T: In some reactions reactants can make products and also products can reverse to make reactants. There are five molecules of water bound to the copper sulfate to form blue. If I want to remove the water what would I do?

L: Heat the….

T: I just wanted to show you, I had started doing the process just to save some time, but you can see there is a blue section in the middle and white around because I hadn't finished making it. I will only finish heat in it in a moment. If you have white copper sulphate, just by adding three spurts of water to blue (Demonstrates). This is an example of a reversible reaction. The way for me to denote that is an arrow going from left to write and from right to left.

$CuSO_4.5H_2O \rightarrow CuSO_4$

(blue) (white)

So forward reaction to go this way, I had heat, now if you have a reaction written as

$NaCl_{(s)} \leftrightarrows NaCl_{(aq)}$

It means it is an equilibrium. What is an equilibrium?

L: Balanced.

T: Balanced, good. It is an equilibrium reaction. What about the reaction is balanced?

L: It is the amount.

T: It is not usually the amount (smiles). I am going to tell you an example of that in a moment. What would it be if not the amount? There is not necessarily the same amount of product as it is the reactant.

L: What happens is the products are continuously forming reactants, as soon as it forms they break down, they from products. They happen at the same time.

T: That's almost perfect. She says they are happening at the same time. So when you look at the definition of equilibrium reaction it means the forward reaction is happening at the same time as the reverse reaction. But there is a trick to it. The rate of the forward reaction is equal to the rate of the backward reaction. One is not faster than the other. Once the balance is reached, so it is allowing this balance, once the balance is reached, it maintains the balance. So there is an equation I wanted to give you, it is something also, just a physical process. If had a beaker, water and some sodium chloride. I keep adding teaspoons of the NaCl what's going to happen?

LLL: It is going to dissolve.

T: I keep adding and adding until it reaches a saturation point. Ok, what does that actually mean?

LLL: No more can dissolve.

T;: Ok, no more can dissolve. So what will I actually see in the beaker?

LLL: Some salt.

T: A white solid salt. I will then see a layer of sodium chloride (draws). Will there be still sodium chloride in the water. What will be floating around sodium ions, chloride ions and water molecules here, ok. What type of compound is it?

L: Ionic.

T: Visually at an atomic scale what would you see?

L: A 3D lattice.

T: A 3D lattice of sodium ions and chloride ions. There you are sitting with a saturated solution. Do you think, this is what I am trying to ask you? Do you think that the sodium ions and the chloride ions are stuck at the bottom and will stay at the bottom?

LL: No

T: Why not?

L: Won't the sodium and chloride ions fuse and come together.

T: Ok. Visualise what happens to the ions in a liquid.

L: They slide.

T: Do they do more than slide. They have more kinetic energy remember.

LL: They move.

T: Is there a chance that they will meet together, they come into contact and connect. So if they drop out of solution, remember we already know that it's a saturated solution, at the same time, what will happen?

L: mumble

T: Good, another one will break up. So this how we express it. A saturated solution. This is not a chemical change, no new products is formed. This is an example of a physical change happening at equilibrium. When one of them breaks up to form an an ion, at the same rate two come together to form that. Now if you think of what I have already told you, we have a beaker of water and teaspoons of salt only. This is what happens

$$NaCl \leftrightarrow Na^{+} + Cl^{-} .$$

I am not going to show the water. Then it gets to a point when it's saturated, then this reaction will start to take place. So first of all the forward reaction is in control and then it gets to a point where the reverse reaction starts to come into play. It will finally get to the point which we call equilibrium. The rate of the forward reaction is equal to the rate of the backward reaction. Does anyone have any questions about the concept?

(Silence)

T: Ok, I am going to show you a short clip on what is happening in the beaker. Remember we have just talked about water, it is a polar molecule which one is the negative and which one is the positive. This is why something dissolves. A little bit off topic. The water molecule is polar that is why it can overcome the ionic bond. Remember a precipitate falls out of solution. In this case, the ions are connecting at the same time as the sodium and chloride ions are forming. To make sure you have this concept, this is what type of reaction?

L: Reversible.

T: This type is also reversible. It can go from left to right and right to left, but this is at?

L: Equilibrium.

T: I just want to show you one more.

` $N_2O_4 \leftrightarrow NO_2$

L: But it is not balanced.

T: Yes, I am getting there in a moment (balances the equation).

N_2O_4 and $2NO_2$ which are colourless and brown

This is looking at two gases. The timing is good. This gas is brown and the other is colourless. If I had these in equilibrium, what would the mixture be?

LL: Brown.

T: It would be brown. Does everyone agree. If more of the dinitrogen tetraoxide is made then it will be a lighter brown. I just want to show you another clip. Look at this reaction, what do you think when it was put in hot water. (Shows clip to learners)

L: More NO_2 was made.

T: When it was heated more NO_2 and when it was cooled what did you notice?

L: colourless

(Continues with clip)

T: I just want to show you a little bit about this reaction. What you need to understand about equilibrium is if it is seating here, the rate of the reaction is equal to the rate of the backward reaction. By doing something to the reaction the lady says we can favour, we can push the equilibrium if you like, further or push the reaction and make it go forward. If we make it go forward the rate of the forward reaction and at the same time the rate of the backward reaction will decrease. Vice versa, if we push the backward, if we push that the rate will increase, we will talk about how we can do that later, but the rate of the forward reaction will decrease. Ok let's have a look at our notes. I have tried to just cover some terminology, with the terminology, let's look at page 38. Please go to page 38. Ok, I am not going to read through, I just want you to keep this in mind this whole concept of reversible reactions. So reversible is exactly what it says. It can go one way or another. The example we have here says vapour is in equilibrium, now what I showed is a saturated solution. Now just imagine water is in a sealed container and I want you to think of what processes that may happen. If it gets heated little by little what will happen.

LL: mmmmm

T: Some of the liquid will become gas, the container is sealed and can it escape? Then you have water in this gaseous phase, they will be molecules, who knows? Let me take you back. How did you get from liquid to gas?

LL: mmmmm

T: They gain some energy. If they gained enough energy they will become what, what will happen? Now there are gases darting around in the closed container. What will happen as they are moving around. What will happen as they lose energy?

LLL: Chorus (not audible)

T: If they lose enough energy what will then happen? What is the process called?

LLL: Condensation.

T: Condensation, there is another example of a physical change that can happen at equilibrium. If the rate of evaporation is equal to the rate of condensation, then that will be another example of a physical change reaction happening, ok. I must show the liquid going to gas. I tried to include that in a diagram. Then I asked you some questions. If the temperature of the system, the system is at equilibrium, what happens if I Increase the temperature by 10^0C.

L: More will evaporate.

T: Ok, more will evaporate. Ok, let's talk in terms of forward and reverse reactions. Look at the reaction, let's look at the reaction. If more evaporate, which reaction will be favoured?

LL: Forward.

T: Forward reaction, let's just make sure, forward is going from left to right. If more liquid is becoming a gas, the forward reaction is favoured. Why would the forward reaction be favoured, if I increase the temperature by 10^0C? What am I actually doing by increasing by adding temperature?

LL: mmm

T: I am adding energy therefore more particles will evaporate. So therefore more of the particles are more likely to evaporate. More of the particles will have enough energy to escape. What's holding the water molecules together.

L: Covalent bonds.

T: Yes but what's holding the molecules together is a covalent bond. But the reason why water is a liquid is because there are?

LLL: Intermolecular forces.

T: There are intermolecular forces between particles. So they even need energy to break those intermolecular forces that they jump from being a liquid to being a gas. If you go over the page you will see that an increase in temperature by 10^0C., we favour the forward reaction. After sometime the system will settle into a new equilibrium. At this new temperature, if you maintain the temperature it will reach a point when the rate of the forward reaction is equal to the rate of the reverse reaction. ok, so a new equilibrium is established, is established, ok. Now we need to some work. Have a look at the picture I have got on page 39. There is a example which shows that sodium is in contact with a saturated solution. There is an example of a simple sketch. I want you to try and answer the questions. I think we have covered most of it. Answer questions 1 and 2 and in five minutes I will check.

T: The solution is sodium in sodium chloride solution. Write an equation to represent this. How would we write the equation?

L: Sodium chloride and then the reversible sign. The sodium ions, aqueous and chloride ions, aqueous and the sodium chloride.

T: What state is sodium chloride? On the left, what was the state?

L: Solid.

T: So essentially we will write something like this

$NaCl\ (s) \leftrightarrow\ Na^{+}(aq) + Cl^{-}\ (aq)$, the states because it is a physical change are very important.

L: Sometimes we don't dissociate the ions?

T: At this stage, yes, you could write NaCl*(aq)*, it fine, the aq shows that the sodium chloride is dissolved in water. What are not showing here that's present?

LLL: Water.

T: Yes, you could write as $NaCl_{(aq)}$ and water, it will be fine but it's not necessary to show this.

L: Is chlorine a diatomic?

T: Chlorine as an element is diatomic but we are talking in a compound, ok. The second question describes the rate of dissolving and crystallisation for this equilibrium system.

L: I said the rate of crystallisation and dissolving would be the same.

T: Good. They are equal and as simple as that question sounds, that's really home the point. The rate of the forward reaction is equal to the rate of the reverse reaction when at equilibrium. Now they are a number of a couple of questions that I want you to try and apply the knowledge. Just be careful because it says macroscopic changes. What does macroscopic mean?

LL: What you can see?

T: What you can see with your eye.

L: What happens to the diatomic chlorine?

T: Since that has been asked twice, let's go and see how it is formed. It's really a misunderstood concept.

L: How do you answer this question?

T: Ok Grade 11, let's quickly answer the questions. Hang on. You must listen please. Can you read the questions? Can someone read?

L: A, describe the macroscopic properties.

T: The first thing we are doing in chemistry is to write an equation. It's not a reaction but we can. Just read the last question.

L: Describe the macroscopic changes.

T: So it's macroscopic, what are you going to see? What is the process called. In this the forward reaction is evaporation and the reverse reaction is condensation. This is equilibrium, so the rate of that is equal to that. So now we have changed, so they start to cool. So what happens when we cool?

LLL: Condensation.

T: The rate of condensation is increased or you can say the rate of the forward reaction is favoured. It's another way of saying that, ok. What would happen to the forward reaction, we talked about the temperature increasing, what would happen to the rate of evaporation?

L: Decrease.

T: Ok, so we had a nice balance and the conditions of equilibrium where changed, so the balance is tipped. So that's what happens when the conditions of equilibrium are changed. For the next lesson we will discuss this. Please do the rest of the questions by next week Wednesday. Quiet please, I am almost done. Because these concepts are new, you need to go through them at home.

Lesson 2

T: Get organised settle down and then make sure you have your notes. We are on page 40. A, please keep quiet. In the last lesson we started talking about reversible reactions. Someone please tell me what a reversible reaction is?

L: A reaction in which products are formed and the products react to form reactants.

T: Good, that's a perfect answer. So, the reactants form products and the products form reactants. I also showed you the demonstration, we had this hydrated copper sulphate and if we heat that up we end up with copper sulphate and five water. This one is blue and that one is white. So, it went from blue to white by heating and the water came off. So you guys how do you get from white to blue, can someone tell me?

L: You added water.

T: Yes when I heated it, it became white and when I added some drops of water, it becomes blue. Shall we do some quick revision? Then I talked about, remember what I said about a saturated solution. We said that if a solution is saturated it has dissolved the maximum amount of solid. Then you have solid at the bottom and some ions standing around the solution above. We said that if it was saturated then even though it had a solid at the bottom and some stage it will dissolve at the same time s odium ion and chloride would meet together and precipitate out. Then we said the rate of dissolving was the same as the rate of dissolution. Ok. Then we introduced the term equilibrium. Can anyone remember what equilibrium is? How is that a little bit different from a reversible reaction?

L: Isn't at equilibrium that rate of the forward reaction is equal to the rate of the backward reaction.

T: Perfect that's a perfect definition. She would get two full marks for that. She has used the magic word, ''rate''. The rate of the forward reaction and the rate of the backward reaction. so they are equal. A, can I answer your question?

L: It's fine.

T: Gone, ok, let's talk about that equilibrium. The rate of the forward reaction is equal to the reverse reaction. The other day I didn't mention that the equilibrium occurs in a closed system. What would a closed system be?

L: In a container.

T: Good if we are especially dealing with gases, if the container is sealed that would be closed conditions. If I have this system of sodium chloride dissolving into sodium ions and chloride ions, and if I did not have a lid on this container, do you think there would be sodium ions and chloride ions escaping?

L: No.

T: What could happen if I didn't have a lid on the system?

LL: Evaporation

T: Yes, you could get a little bit of evaporation, but essentially this system is closed. It is not likely that something will enter or leave it, so that is called a closed system. Let me quickly check these before I go to new work for today. Sorry did I check page 39, ok, did I check question 1. Ok did I check?

L: No

T: Ok let me quickly go over that. If there is a closed system containing ethanol liquid and ethanol vapour. Let's write the equation for that. I f tell you that the formula of ethanol is C_2H_5OH and I need you to write an equation for that. In equilibrium with the ethanol vapour what symbol would I use? This one $\rightleftharpoons$?

L: That one (the double arrow)

T: Yes, in equilibrium with ethanol vapour what does that mean?

L: Gas

T: Yes we would write ethanol vapour in equilibrium with ethanol liquid. What's happening here and what's happening there? What is the process called?

LLL: Evaporation.

T: And this one?

LLL: Condensation.

T: Now tell me what is happening to the rates of condensation and evaporation.

L: The rate of the liquid turning into gas is equal to the rate of the gas turning into liquid.

T: Yes, that's the situation we have at the moment. Then the next question says a closed system containing ethanol vapour and ethanol liquid is cooled at 20 degrees Celsius to 10 degrees Celsius. We have now the system is at equilibrium but we have just made a change. What change have we made?

L: Temperature.

T: Yes essentially what have we removed from the system.

L: Heat.

T: Heat. Ok, we have removed heat. So what have we done to the particles?

L: Slow down.

T: What have we removed from the particle?

L: Kinetic energy.

T: What's going on here, which process will take place? Can you see that if you remove energy, the gaseous particles will have less energy, but this process is likely to be favoured? Which means the backward reaction is favoured, i.e the condensation will occur. There will still be a little bit of evaporation but you can say that it favours the reverse reaction. Ok, we did that by changing the conditions that's what we are going to talk about in a moment. Question 2 looks at this process here. The solubility of sodium chloride is 36g per 100ml. Can someone explain to me, what does it mean the solubility at 36^0C is 36grams per 100ml?

L: 36grams is dissolved in 100ml.

T: Good, exactly right. If you had 100ml of water in a beaker, 36g of sodium chloride will dissolve in it, and at what temperature, at 36^0C.

L: No, isn't it at 40^oC.

T: At 40^0C if I increase the temperature it says 50^0C, 37g will dissolve. So by increasing the temperature more will dissolve. The question is, if I put 40g of salt into 100g of water what will happen. You tell me?

L: If you heat it?

T: I am asking a question how much of it will dissolve. What will happen if I add 40g at 40^0C.

L: eh, eh.

T: Ok, if I have 40g and 36g is supposed to dissolve, what happens to the other 4g. Where is other 4 g.

L: At the bottom.

T: Yeah, 40g is just sitting at the bottom. If I increase the temperature to 50^0C. Ok, yep. It's now heated to 50^0C, what will happen to the initial 40g sitting in the beaker.

LLL: It will dissolve.

T: Good, we will actually see that 37g will dissolve and 3g will be sitting at the bottom. The reason why I am asking you this is sometimes we have a system at equilibrium and we can change something which means a change in the system. This is what I am going to teach you in a moment. Ok, the last question is just practice.

L: What will happen to the water, will it evaporate.

T: At 50, remember evaporation occurs at any temperature, but it's not going to boil and promote rapid evaporation.

L: Ok, ma'am won't the amount affect equilibrium.

T: Once we keep the temperature constant, then it is only temperature that will affect the amount. If obviously we added some water, then more of it will dissolve. Ok, let's do the question to introduce the work for today. J, you need to read for us.

L: When nitrogen and hydrogen react under conditions of high temperature and pressure, ammonia forms.

T: Let's stop there. We are going back to writing a balanced equation. What's the formula for nitrogen?

LLL: N_2

T: And what is its state?

LLL: Gas

T: What's the formula for hydrogen?

LLL: N_2

T: And the state?

LLL; Gas

T: So what does it say?

L: It forms ammonia.

T: So read on.

L: A sample of ammonia produces hydrogen and nitrogen. What does that tell you?

L: The reaction is reversible.

T: Ok go on.

.L; Write a balanced equation to represent this reversible reaction.

T: Ok the equation is $N_{2\,(g)} + H_2\,(g) \rightleftharpoons NH_3\,(g)$. What's wrong with the equation?

LLL: It is not balanced.

T: So you balance it and it is $N_{2(g)} + 3H_2\ (g) \rightleftharpoons 2NH_3\ (g)$, so we have 6 hydrogen, 6 hydrogen, 2 nitrogen, 2 nitrogen, good that's balanced. If you have been asked to write an equation for a system at equilibrium, you will be penalised if you do not use the equilibrium symbol. Because that's what they are trying to see.

L: Sorry, what exactly is the difference between a reversible reaction and a reaction at equilibrium.

T: Both can go both ways, ok. Both can go from left to right and right to left, ok. In equilibrium they can occur at the same time. They occur at the same rate. This reaction to go from $CuSO_4.5H_2O$ to $CuSO_4 + 5H_2O$ can go in one way. I can't be heating it and adding water so that they can occur at the same rate.

L: But isn't it in a reversible reaction the reactants will form and the products will form. The products will break down to form the products.

T: It's more to do with, I know what you are asking. For this reaction, I cannot form water at the same time. But in equilibrium the reactions are happening at the same time that's the key.

L: So the arrows have to be different.

T: Yes to be absolutely correct, the symbol is for reversible and this one is for equilibrium, but this symbol is correct for both. So it's a little bit controversial at the moment. But our recommendation is to use the one for equilibrium.

L: For the last question in number 3. Is there anything to indicate that this reaction is in equilibrium?

T: No, it tells you that the reactants form products and the products form reactants.

L: But it's not saying it's happening at the same rate at the same time.

T: You are absolutely correct; it's not saying they are happening at the same rate at the same time.

L: Ma'am they are at equilibrium because it says nitrogen and hydrogen produce ammonia. And ammonia produces nitrogen and hydrogen.

T: I don't think that's enough indication to show that they are in equilibrium. I want to use this reaction to show equilibrium. If you read in your syllabus, it says dynamic equilibrium, ok. Let's talk about dynamic, if you have a public speaker our drama club this morning, you would say they were dynamic speakers. How would you describe them?

L: Moving.

L: Changing

T: Yes, if someone is dynamic, they are not the same all the time, they are changing, they are moving. So we say they are dynamic, it means to change. Now I want you to get one more concept. This is a reaction that occurs at equilibrium and it is also an exothermic reaction. When nitrogen reacts with hydrogen it gives you ammonia and heat. If I read it from left to right. If I read it from right to left ammonia requires heat to turn into hydrogen and nitrogen. If I was reading it this way, what kind of reaction?

LLL: Exothermic.

T: Right the forward reaction is exothermic and the reverse reaction is endothermic. Let's talk about equilibrium the rate of forming the products is equal. You can imagine that you have a balance. Imagine we have a see-saw and I am on this side and there are two small children on the other side but we have reached a point where we are balanced. How do I get the balance off the see-saw?

L: Take something off.

T: Take something off or add something on. It is the same concept as equilibrium. These are all gases, some put them in a sealed container. The way I would describe it is, I would add something to the container. Let's talk about that number one, is concentration, let's talk about ok, concentration. You don't have to write something down; we have quite a lot of it actually written down. If I could add more nitrogen, in other words I would increase the concentration of nitrogen. What do you think would happen then?

L: More ammonia.

T: Ok, J says more ammonia would be formed.

L: So that it could take out the nitrogen.

T: Ok, so you are almost saying it's striving to reach equilibrium again. Le Chatelier, sounds very French isn't it? Le Chatelier put forward a proposal, that a system that a system in equilibrium, the system is always at equilibrium, so I am going to be very plain with it, I am not going to use verbatim at the moment. If you would make a change to a system at equilibrium, it will try to compensate for that change. What it is actually saying is that if I change the concentration of this, ok. The system will move to compensate or balance the change. In this case if I increase the concentration of nitrogen, I am going to use square brackets for concentration, is everyone ok with it.

LLL: Yes.

T: The Le Chatelier's principle says the system will respond as to decrease the concentration of nitrogen. Which reaction, this one or that one will decrease the concentration of nitrogen.

LLL: The backward.

T: Le Chatelier says decrease the concentration of nitrogen. I am going to do the abbreviation $\uparrow [N_2], \downarrow [N_2]$ If you look at the reaction, the only reaction that will decrease the nitrogen is the forward reaction. So the forward reaction will be favoured. So we can say the equilibrium will shift to the right to compensate for the change. This can happen on either side. Let's say we pump in ammonia into the system, that is in equilibrium in a sealed container. It's closed, ok, I have pumped ammonia into the system, and I have now unbalanced the system. In what direction will it move to regain the balance?

LLL: It will move backwards because that the reaction which uses up ammonia. Let's try another one, I am going to make it tricky this time. What about if I decrease the concentration of hydrogen what would the system do? Obviously it doesn't have a personality, what would the system want to do?

LLL: Increase the concentration of hydrogen.

T: How do I increase the concentration of hydrogen? By favouring the backward reaction because that's the reaction which produces hydrogen. Any questions?

L: If I increase the concentration of nitrogen obviously at some point the hydrogen will get finished, what happens?

T: That's an excellent question. The reason why I used this reaction is that it is industrially important reaction. We are going to look at it again. Ammonia can be sued for things like fertilisers. This reaction has to be profitable. J said what happened when you increase nitrogen, isn't hydrogen will be used up. So when you make ammonia which way do you want the reaction to go?

LLL: Forward.

T: You haven't carried out. Obviously if you own a factory, you do not want the reaction to reach equilibrium. You want to push the reaction here, what would you do?

L: Add both of them.

T: Add both them. Ok, let's look at the moles. How many moles of nitrogen are on the left?

LLL: One

T: Ok, how many moles of hydrogen?

L: Three

T: So is there any use in adding a mole of nitrogen and a mole of hydrogen?

LLL: No.

T: So when we look at this reaction we say we want to add them in their stoichiometric ratio. If we add them in their stoichiometric ratio that would increase the amount of ammonia produced. Ok, let's do number 2, the second thing we want to look at is temperature. The reason why we have written it this way is that we want you to think of left to right and right to left. Ok. From right to left, I add heat. If I add heat to the system, if I increase the temperature of the system, what would the effect of the increase the temperature. If you get hot what are you trying to do?

LLL: Cool down.

T: So you try and compensate for the change. So you increase the temperature.. Le Chatelier tells us that the system will try to decrease the temperature. Let's look at it, if I increase the temperature Le Chatelier says the system wants to decrease the temperature. Which way will this reaction go?

L: Backward

T: Why backward?

L: Because it will use up the energy.

T: Excellent. If I add heat the backward reaction is favoured. So let's try to use the correct terminology. I would say an increase in temperature, Le Chatelier says decrease the temperature, the system will favour the backward reaction. The system shifts to the left. What does that one mean? If it shifts to the left, is it still in equilibrium, what is going on, is it still in equilibrium?

L: No

T: If it favouring this one, what is happening to the rate of the forward reaction.

LLL: Increasing.

T: So if the backward reaction is being favoured, may be for a moment in time there is nothing happening with this forward reaction, ok. So what I am going to say is it favours the reverse reaction and nothing going on with the forward reaction will occur. But at some moment in time, equilibrium will be re-established. It will go back to the rate of the forward reaction and the backward reaction occurring at the same rate at the same time, ok, but the equilibrium will not be the same. I think I am just going to let you practice a few questions before I talk of volume and pressure. Let's quickly look on page 47 please. I just want you to practise question 1 on the table. Ok, you can just quickly do it, so let's look at what I have said and I want you to look at the reaction, so that we can consolidate the information. The first reaction we have is sulfur dioxide plus oxygen in equilibrium with sulfur trioxide. Please tell me what happens when there is an increase in the concentration of sulphur trioxide. It's going to increase the …

LLL: The forward reaction.

T: Please tell me why, why? Yea, if we increase the concentration of sulphur dioxide in the first reaction. Everyone is saying it's going to shift to the right, why?

L: It's the only way we ac use up the sulphur dioxide.

T: Excellent, it's the only way we can use up the sulphur dioxide. The change is in the concentration of sulphur dioxide. Shifting that way will use it up and cause the system to try and re-establish equilibrium. Ok, let's look at the next one. What about if we decrease the concentration of carbon dioxide in the second one? Essentially, I am pulling out the carbon dioxide out of the solution. A, what will happen?

L: The forward reaction will occur.

T: Why?

L: Because there is need to reduce the carbon-dioxide in the system.

T: Excellent work. If I increase the concentration of chloride ions what will happen?

L: If I add more chloride the forward reaction will occur.

T: The forward reaction will make even more chloride ions to compensate for the change.

L: No

T: Is that the correct answer?

L: No.

T: So if you want to make sure that everyone you understand this, as you move backward you use up the excess chloride ions. Let's skip to the next one on the table. So we have sulphur dioxide plus oxygen in equilibrium with sulphur trioxide again. Moving left to right, is this an exothermic or endothermic reaction?

LLL: Exo

T: Ok, so S, what happens if I increase the temperature of that reaction?

L: The forward reaction is favoured, no, the backward reaction is favoured.

T: Ok, again think about it, when you have got, when you increase the temperature, the system will increase the temperature, the system will compensate for the addition of energy. If we add more heat to the system, we will favour the backward reaction. So let's go on to the next one. Y, tell me, nitrogen oxide plus oxygen gas plus 180 kilojoules gives you two nitrogen monoxide gas. Endo or exo?

L: Endothermic.

T: Endo, ok, let's have a look at this one. If I decrease, the temperature what's going to happen when I am going to the left or right? In this case I am taking the heat out. What will be the opposite of that, how do we change that, how do we compensate for the change.

L: Move forward.

T: Ok, I am going to do that with the heat. Ok, let's have a look at that, if I remove heat from the system. So essentially, Le Chatelier would say you want to compensate for that change. If I decrease the temperature what will I do to fix that if you like. What is the opposite?

L: Increase temperature.

T: Ok, I want to increase the temperature, so I move this way, left to right. I will have made more heat? Look here.

L: No

T: So which way must it shift? So it must shift this way because that is the way that increases the temperature in the system. Ok, the last one on the page from left to right, is it endo or exo?

L: Endo

T: Endo, if I am read it left to right, good if I decrease the temperature

L: Backward reaction.

T: It will favour the reverse reaction because that is the reaction which will put more heat into the system. Can I just do volume quickly? Before I get to volume, I want to talk about pressure because if we do pressure, it is easier to understand. We have already started on this reaction. If we read this equation how many moles are on the left?

LLL: Four.

T: And on the right?

LLL: Two.

T: So the moles of the reactants are 2 and the products are 4. I read form left to right. Let's talk about a closed container. All of these are gases. So it's a closed container. If I have lots of moles in that container. For example if I have four moles and then if I first have 2 moles in the container, which one will exert more pressure?

L: Four.

T: Yes, everyone agree, make sure you understand that. Think about ten ping pong balls in a container. They will exert a certain amount of pressure. What is pressure?

L: Force over area.

T: So it's the force the ping pong balls are exerting in a given area of the container. I have ten of them. Now I take out 5, what will happen to the pressure?

LL: Decrease.

T: Yes, less amount of ping pong balls, less pressure. Make sure you have that concept, less moles less pressure. Now let's look at how this relates to equilibrium. Next thing, I have this container and I increase pressure of the container. If I increase the pressure of the container, Le Chateleir's says the system will shift to compensate the change. So I will shift to do what to the pressure of the container. If I increase the pressure obviously the system will compensate to decrease the pressure. How does this system increase pressure?

L: Increase the production of hydrogen and nitrogen and it will be balanced.

T: Correct, please make sure. This is a little bit trickier, if I want to decrease the pressure, I want the least amount of moles in the system as possible because that will decrease the pressure., I want the least amount of moles in the system as possible because that will decrease pressure. So the decrease in pressure, we will shift to the side with the least gaseous moles. So it will shift to the right. Let me just explain why I say gaseous moles. If we have a reaction of solid calcium carbonate in equilibrium with solid calcium oxide and carbon dioxide gas. Usually, what will that look like in a container? We have two solids and a gas. Where are the solids? Where will the solids be?

L: At the bottom.

T: So what is the one thing that is exerting pressure on the container?

L: Gas

T: The gas, ok. So that's why we only look as at gaseous moles. Because a gas is the one that exerts pressure on the container. So when I am using that terminology, I am using it carefully. So in this one, if I increase the pressure, I want to shift to the side which decreases the pressure. Does everyone agree? I want to repeat, how many gaseous moles on this side?

L: None.

T: There is no gaseous moles. How many on this side?

L: One.

T: Ok, so which way will decrease the pressure. In this reaction, we will deal with the gas because it is the one which exerts the pressure. Ok, I am going to leave it at that. Right, I am not going to give you an assignment for the holiday, but please don't turn off. Go home and make a summary.

Lesson 3

T: Hopefully, you have the theory; you know the concept of shifting left and shifting right. So what I am going to show you is two demos and you guys are going to work out what is happening with equilibrium. So, this one is the iron and iron cyanide complex. Now we have talked about the word complex.

LLL: No

T: Ok, the we are going to touch a little bit on that so that you can have a look at it, so that you can gain understanding. So you have two ions of iron, for example iron three ions. I am just going to show you that this solution has iron three ions, it's yellow-orange. Would you agree so that is iron three ions in solution. The other one has the thiocyanate ions in solution. Remember complex ions are charged. You can see that the one is colourless, not clear, because there is also clear but not colourless. What we are going to do is to mix them and we will make a complex of iron thiocyanate. Complex is quite a group of atoms. The ion has a charge and you put the square brackets. So essentially we have a cation surrounded by anions grouped together. So essentially, since we have that electrostatic force of attraction, but it's complex, because if you look at it it's more complex than normal. So we will do more of that we will look at, eh, when we look at the next section. So, I just wanted you to understand the word. So I am going to mix them, basically they are about the same concentrations. I am just going to put about the same values. So I put one of those and one of those. So colourless and orange and the reaction starts to take place.

LLL: Wow

T: What colour is formed?

L: Red.

T: Yes, you are not going to miss that. (Laughs). So, the system will establish equilibrium. So I am going to add hydroxide ions. Can you see anywhere in the reaction?

L: Where are they?

T: No, no, I mean in the reaction. Fe^{3+} and SCN^{-} to form a complex. Do you see any hydroxide ions?

L: No

T: So what we are trying to do is, you are trying to guess which way the reaction would go if you add hydroxide ions. Notice the colour of it. Now I am starting to add the hydroxide ions. Now what colour is it turning?

L: Brick- red.

T: It was red, now it has gone more, have a look up here, it was red and now it has become less red, so which way do you think equilibrium has shifted.

L: Left/ Right

T: Ok, by adding the hydroxide, the equilibrium has shifted is it to the left or to the right?

L: Left.

T: Ok or the backward reaction has been favoured. Did you see that, ok, let me explain why, ok. The reason I used that is sometimes, if I start adding no Fe^{3+} that's quite logical, then what do you notice?

L: It turns more red.

T: Yes, and this is what we expected. The equilibrium shifts to the right when I add hydroxide ions. When I added the hydroxide ions, what I have actually done is to pull the Fe^{3+} out of solution. So what I am actually doing by adding hydroxide ions is decreasing the concentration of iron ions in solution. Make sure you understand this, the hydroxide irons, are forming iron(III) hydroxide. So what it does is the hydroxide pull the iron ions out of solution. If I decreased the concentration of iron ions which way should would it shift?

L: Backward.

T: Forward or backward. Backward isn't it? Because we wanted to counteract the change. That's why it went yellow. Does everyone get it? Just make sure you can answer the questions. It says describe what happens when the hydroxide ions are added. It's not asking you about the chemistry, just what you see. The solution went? What are you going to write?

L: Do you mean the initial one?

T: The initial one, with the sodium hydroxide, what colour was the solution?

L: Red.

T: And it went, it faded or became orange? I just want to make it clear that when you are writing a description of the changes, it's better to say, it was red and went more orange, than to say it went more orange because it does not really describe what went on. And then it says explain the above observation using Le Chatelier's. I am just going to put in my words but you can turn and write them in your own. The change was (III) ions, the equilibrium shifts to the right, will you put that in your words.

L: So the hydroxide is not a catalyst.

T: No, it is not, we are putting in the hydroxide to decrease, pull out the iron (III) ions.

L: So we are saying it decreases the concentration of Fe^{3+}.

T: Yes, we are almost saying it's coming in to form a compound. It's almost as coming in and collecting them out, it's pulling out the iron (III) ions out of solution, so they become bound and are no longer available to react anymore). Just to make sure it's clear, adding sodium hydroxide will decrease the concentration of iron (III) ions, Le Chatelier's says the system will shift to the right to increase the concentration of iron (III) ions. Now let me show you another reaction let me put a white background so that you can see. What I am doing here is, what colour is the gas?

L: Blue.

T: And look at the gas, it's orange colour. The reason why it's blue is to make this gas. I had to put some copper and nitric acid to make the nitrogen dioxide gas. I tried to get equal concentrations. So what happened here was an equilibrium was established between the brown NO_2 and colourless N_2O_4, so there is a mixture of gases. So hopefully, it's similar concentrations, then the yellow-brown colour is similar. Now what I want to is to put one in warm water and one in ice. So, what I am doing here is adding heat and what I am doing here is taking away heat. It says describe the colour of the gases at room temperature. What was it? Light brown, you can say yellow- brown. the same conclusion. Think about it, who wants to tell me, who wants to try?

L: I think endothermic.

T: Ok, you want me to put the heat on the left hand side. It's ok to do a trial and error as well.

L: Laughs.

T: If I put endothermic, let's see if the practical would match that. If I added heat which way should it shift and I added heat, what colour would it go? So this would become colourless.

L: Oh no, no, no, it's exothermic then.

T: Ok, if it's exothermic, I added then, if I added heat, then it would be brown, is that what happened?

L: Yes.

T: Then we would say that this is an exothermic reaction. And if I remove heat it would shift to compensate for the change and become colourless. But why does it not become colourless, you can see that it's getting very clear but not colourless, why not?

L: There will always be a certain concentration of NO_2 at equilibrium.

T: Good, remember it is trying to re-establish equilibrium at the new temperature, so there will always be a little bit of NO_2. We need to do the appraisal process so please make sure that, that is completed.

Lesson 4

T: This is the production of ammonia as I said to you or maybe to the other class, this is one of the most important industrial reactions because ammonia can be used for like fertiliser, pharmaceuticals and ammunition. So you can see that if you come and produce ammonia, you want and produce as much ammonia as possible, in the shortest time possible. Do you agree?

L: Yes.

T: So there are ways, because this is an equilibrium reaction, there are ways in which we can manipulate this reaction, so that we can ensure that the forward reaction occurs. So there are ways to ensure that the forward reaction occurs. Tell me one thing I could do which could make the equilibrium shift to the right.

L: You could increase the temperature.

T: Hang on, do you know whether it's an exothermic or endothermic reaction?

L: Exothermic.

T: Ok, let's put that in, J is saying it is an exothermic reaction and he is right. So what would you do you want to do to make sure that the equilibrium shifts to the right.

L: Decrease the temperature.

T: Ok, let's make sure that everyone agrees to that. So if I decrease the temperature, what I am really doing? This is where the temperature is. So if I pull that out which I pull that out, which way would the equilibrium shift?

L: To the right.

T: Why?

L: Because when you remove heat, the system will try and bring back the heat and it would shift to the right.

T: That's well said, so that's one thing you can do, decrease the temperature. We will come back to that in a moment. Tell me any other thing I could do to make the equilibrium go to the right?

L: Increase the concentration of nitrogen.

T: Good, I am going to say increase the concentration of nitrogen, square brackets. Would that be enough, what else would you like to do at the same time?

L: You would also want to increase the concentration of hydrogen.

T: Yaa, you would want to increase the concentration of hydrogen as well. Let’s look at this stoichiometric ratios of this. How many moles of hydrogen? How many moles of hydrogen?

LL: One.

T: How many moles of nitrogen?

LL: Three.

T: So in what ratio would I like to supply that?

L: One to three.

T: So a one to three ratio. When I increase the concentration of these, yes the equilibrium will shift to the right and we want to make more ammonia, but we would want to look at sort of the ratio. We will waste if we put 3 moles of this to 3 moles of this because two moles will remain unreacted. Let’s look at ammonia, why would you like to take it out, when you make it?

L: So that we can use it.

T: Definitely. (Smiles)

L: But also it would create an imbalance in the equilibrium, so more ammonia will be formed.

T: So if we leave the ammonia to collect and collect, what will happen?

L: Then it will start to decompose and produce hydrogen and nitrogen.

T: Good, so if we allow the ammonia concentration to build up to high. It will shift the equilibrium back. So when we make something if we keep taking it out, it will ensure that the forward reaction is still favoured. Let’s talk about pressure, are we going to carry this out in a high pressure or low pressure situation? Let’ s have someone else. Yes M? Tell me how many moles of gas on the left hand side?

L : 4 on the left hand side.

T: Ok, let’s work this out, step by step. If you decrease the pressure, what does Le Chatelier’ s principle say?

L: Increase the pressure.

T: So which way would it shift?

L: To the left.

T: Is that what we wanted?

L: No.

T: Let’s work with the other one. If I increase pressure Le Chatelier’s says it would shift to decrease the pressure. So it would shift to the side with less pressure.

L: Yes.

T: Yes, it’s the side with two moles. If you increase the pressure to decrease the pressure, the system will shift to the right. So you would like to carry out this reaction in a high pressure system

L: Ma’am but doesn’t heat always increase the pressure.

T: It can yes.

L: But doesn’t that cancel each other out, because the one with 3 moles is cold and the one with 2 moles is cold.

T: Yes, let’s leave out temperature for now because there is something else which is involved. We will come back to temperature in a moment. We are just talking about shifting the equilibrium but obviously a reaction has a lot of other things. I just want to talk about volume because this is a new one. I just want to use that as an example. Remember the last time; I drew a little cube, think of a reaction as ping pong balls or tennis balls darting against the cube. Remember, it’s a magic cube and I can make it smaller. What happens to the pressure?

LLL: Increase.

T: Let’s just make sure that this is clear. A decrease in volume means an increase in pressure and obviously vice versa. Let’s talk about the increase in volume, what does it mean?

L: Decrease in pressure.

T: So if I decrease pressure, what does Le Chatelier say?

L: Increase pressure.

T: Therefore I will shift which way?

LLL: Mumbling.

T: So how are you going to write it in the exam?

L: Favour the reverse reaction.

T: Favour the reverse reaction. Is one what or which other ways, someone else. It will shift to the left; we are favouring the reverse reaction isn’t it? G, what would you say?

L: The system, I don’t know.

T: What about this, the number of gaseous moles. Will you say anything about that? So the last part of it will be. Le Chatelier’s says it will increase the pressure, therefore it will shift left because this is the side with less gaseous moles.

L: Isn’t it more?

T: Sorry, did I say less, it’s more. If you want to increase the pressure, you need the side with more gaseous moles because you want more collisions with the side of the container, I just want, I know that does not apply to this reaction because you do not want it to shift left, but I just wanted to apply the volume, that was the only new section from what we did the other day. So if we want to apply pressure, the only new step is to relate volume to pressure. I haven't forgotten you, but I just want to talk about the last one. I just want to talk about the role of a catalyst. Let's roll back to a couple of weeks. Why do we use a catalyst?

L: To speed up a chemical reaction.

T: Yes, to speed up, so I can use the word 'rate', to increase the rate of a reaction. Everyone understand that we use a catalyst speed up the rate of a reaction. we haven't done activation energy.

L: Is a catalyst only used to speed up a reaction, is it not used to decrease a reaction as well.

T: You can get things that decrease, we usually call those inhibitors. Obviously it's not usual to want to decrease the rate of a reaction, but we call that inhibitors. So everyone has an idea that a catalyst increases the rate of a reaction. What if the catalyst is at equilibrium? Someone else, tell me a good definition for equilibrium again. If something is at equilibrium, what does it mean?

L: The rate of the forward reaction is equal to the rate of the backward reaction.

T: Ok, the rate of the forward reaction is equal to the rate of the backward. So we have an increase in the rate of reaction for a catalyst and we have the rate of the forward reaction is equal to the rate of the backward reaction. So how can we put these two together? What does a catalyst do to a reaction at equilibrium?

L: It will increase the rate of one reaction and not the other.

T: Can it do that?

L; It doesn't do that?

T: So what effect does a catalyst have?

L: Nothing.

T: Nothing, if the reaction is already in equilibrium, it will increase the rate of the forward and backward reaction equivalently. So the catalyst does not have any effect on the position of equilibrium. A catalyst can help the reaction to reach equilibrium much quicker, remember if we just stick some nitrogen and hydrogen, first of all, which of these reactions is going to go ahead.

LLL: The forward.

T: The forward reaction at the initial stage, it will look like this : $N_2 + 3H_2 \rightarrow 2NH_3$. It will only be when the concentration has increased that that this reaction will start to take place and when it reaches a certain stage when they are the same, and the reaction has reached equilibrium and it will be $N_2 + 3H_2$ at equilibrium with $2NH_3$. So a catalyst will speed up the reaction such that equilibrium is reached faster, and once it is in equilibrium it will have no effect. That's, often the question, what effect does a catalyst have on an equilibrium reaction. You just say, if it is at equilibrium, it will have no effect, because it will increase the rate of both reactions. Let's go back to temperature and then we will do some practice questions. Let's pretend you own this company for the production of ammonia. We understand all the things to do with `equilibrium. We understand how to push the reaction forward. We said we wanted a low temperature, a high concentration of nitrogen and hydrogen preferably at a ratio of one is three. We want the reaction to be carried out at a high pressure. Let's talk about that. So we could make this and take it out or you could liquefy it and pump it out. Let's talk about, we could remove ammonia. Do you want the reaction to happen at fats rate? Because we are going to make more money if the reaction is fast. Now let's tie it up to the fact of the rate of reaction. We have a bit of a problem here, we want a low temperature because it will push the reaction forward, but what will happen to the rate of reaction at low temperature.

LLL: Slow.

T: It's really slow. These molecules will not have enough energy and might not have enough activation energy. We want high pressure for a good yield. So I am going to call it yield of ammonia. Do we need a high pressure for a good rate of reaction?

LL: Yes.

T: If we have high pressure, what's likely to occur to collisions, hopefully in the right orientation and with enough activation energy? So there is no compromise needed because high pressure is needed both for a good yield and a good rate of reaction. Let's look at temperature; we have to have a compromise. We want a low pressure, oh sorry, a low temperature for a good yield but a high temperature for a good rate. That's why I put an asterisk next to it. So for this reaction, I can't remember very accurately, they do it around 500^0C, we might not think that's a moderate temperature. Do you think 500^0C is moderate?

LLL: Mumbling

T: Ok, in terms of industry 500^0C is considered to be a moderate temperature because sometimes like in the blast furnace we are talking of thousands of degrees. Around 500^0C is a compromise, I think I am saying the right number. It's a compromise a decent rate and a decent yield. Does anyone have any questions?

L: When you say a catalyst affects the rate of both reactions, what about a specific catalyst?

T: I just want to make clear that a catalyst does not have an effect on the position of equilibrium. Once you have equilibrium and you introduce a catalyst, the equilibrium is not going to shift. So let's say this one has a catalyst, it does have a catalyst of iron oxide, so it actually uses a catalyst so that it can be carried out at a moderate temperature. So there is a specific catalyst for this reaction. I just want you to understand that the position of equilibrium is not affected once it is at equilibrium. Nearly all industrial reactions will use a catalyst to lower the activation energy.

L: So there is no catalyst which works on only the forward reaction or reverse reaction.

T: Do you know Mrs Chani , a catalyst which would work on only on the forward or reverse reaction?

I: They are happening in the same container, so it would be difficult to separate the two. They are in a closed system.

T: Yeah, that's the thing about equilibrium, it happens in a closed system, so if they are not in the same container they would not be in equilibrium.

L: So if the catalyst increases the rate of the forward reaction with the catalyst wouldn't the backward reaction be able to occur faster?

T: In fact that's what they actually do, they stick this in with the reactants so that the forward reaction happens faster, then the backward reaction kicks in and they are at equilibrium, but at that point one they are at equilibrium the catalyst.

L: So the catalyst would only help to get to equilibrium faster?

T: Yes that's exactly right.

L: So ma'am they would use a catalyst, for instance if they decrease the temperature of a reaction like this, where it actually slows down the rate. Will that catalyst help it to react faster?

T: Mmmm, that's exactly right. The catalyst allows for the compromise if you like. The moderate temperature alone might not work for making this, but the rate will be slow. So they put in the catalyst which allows the reactants to react without such high activation energy. The catalyst is part of the temperature compromise. Ok, I just wanted to explain, when you look at your notes you might see graphs They may have something like time and they may have concentration of nitrogen. The big square brackets mean concentration or just concentration of reactants. Let's try and do this practically, let's say we have a concentration of hydrogen and concentration of nitrogen. So I will constantly graph that. This is a reaction at equilibrium. The reaction will be constant. Can everyone see that, because there is no change? If I am making some I am also decomposing some. So the concentrations are constant but they are not the same. So when you see the first parts of this graph, it means they are in equilibrium. When you stick in hydrogen instantaneously, then is going to drop, I mean it is going to increase. Then what's going to happen? Who else wants to talk today? Tell me, so what's going to happen, which way is the equilibrium going to shift?

L: Right.

T: To the right, so what are we going to see is a vertical line, so remember this is sort of time. So what is going to happen to the concentration of hydrogen, remember it's shifting to the right?

L: It will drop.

T: So it will start to drop. So what will happen to the concentration of nitrogen.

LLL: Decrease/ increase.

T: Some are saying increase others decrease. It's shifting right, so the nitrogen is being used up. So let's say we have my ammonia there, what will happen to my concentration of ammonia now.

LLL: Increase.

T: So it would increase. I am writing these as curves because the increase and decrease is gradual. For the hydrogen, it's vertical because I just stuck it in, so it increases instantaneously. After sometime, it will re-establish equilibrium and the rate of the forward reaction will now be equal to the backward reaction. What will happen to the concentration of the species at the time?

L: They will be the same.

T: Do you mean they will be the same as they were in the beginning?

L: They will be constant.

T: That's a nice word, they will be constant. So when you re-establish equilibrium here and here, this is at equilibrium, this is the effect of the change and this at equilibrium again. But this equilibrium is not the same as the first one because we have changed the system. But you can see that equilibrium is re-established again. I just wanted to use this because I use it in our notes. I think it's a little beyond our syllabus but isn't just to explain the changes. You do not have to know these graphs.

L: Ma'am if you add a catalyst to this reaction, will the curves be smaller as the reaction is faster.

T: I don't think that there would be a change if there was a catalyst. Because the catalyst would have to work here before the position of equilibrium is reached. After that, they will be affecting both reactions, the same way. Would they be steeper? I am actually not sure.

L: I think it would actually be shorter.

T: Because it provides a larger surface area? I think the only way we would be certain is to graph a reaction with a catalyst and one without a catalyst, perhaps. Can you turn to your notes, I want you guys to turn to your notes. I must say equilibrium is one of those topics that is not well explained in the exam. When we mark these questions, kids really get confused. So I really, want you to have practice answering these questions. If I say to you here is an example of a reaction at equilibrium, explain what would happen if the temperature of the system is increased and we sat that's two or three marks. You really practice how to do that. so that's what I want you to start doing. I have been giving you examples as we go along. Don't use this, ↓,↑ issue this notation but you need to put it in words. If it says increase in temperature, then you would say Le Chatelier's says you would decrease the temperature, therefore the system would shift. Then I just want you to practice those questions I will be reading your answer as you go. What page are you on J?

L: Page 47.

T: Even if you have done them, just check that what you have written is correct, because we have done a couple of equilibrium lessons. Then we will go to the more detailed questions.

T: Sorry, I didn't make this clear. Let me take a reaction, I am just going to say A and B to give you C and D. So if we are looking at pressure, what kind of moles are you looking at.

L: Gaseous.

T: If they are all gases, you really need to check sometimes there are solids. If there are all gases, then there are two moles of the gas on the left and two moles on the right, changing the pressure will have no effect. If the moles are balanced then there is no advantage of going the other way. So in that case, you would write no effect. A change in pressure will not affect that reaction. Today we are going to do some questions. I would like you to do page 47 and page 48 and if you do not finish today. I want you then to do them at home. I want you to practice them and then I will check them and then we practice again, because we are going to be perfect at them in the end. If you want to say the concentration of ammonia, you need the square brackets. If you increase the concentration of oxygen here what would you say?

L: There would be no change.

T: If you increase the concentration of oxygen here what would you say?

L: It would shift to the left.

T: Look at this, if you increase the concentration of oxygen. So as soon as you increase oxygen it has to be used. So, what I do is, I increase then, it means it has to decrease, then it's decrease and decrease, so the equilibrium shifts to the right. Now let's leave the table for a second, I just want to explain question 2 so that you will understand when you get home how to get it. Can everyone look at the reaction please? It says you have a reaction of ammonia and oxygen and you produce nitrous oxide and water at equilibrium; predict the changes listed in A and B. So really, when you answer this question, you need to answer about the concentration and you need to answer about the rate. But before you can talk about the concentration, you need to talk about the rate. But before you can talk about which way it's going to shift, so when it says A. adding more oxygen to the system Everyone look and tell me which way it's going to shift. When I add more oxygen?

LLL: Right.

T: It's definitely going to shift to the right, everyone is in agreement? Next to that point a little arrow shows right. So where it says adding more oxygen to the system, just put an arrow for yourself so that you already know it's shifting to the right. What's going to the concentration of ammonia, if it shifts right? What's going to happen to the concentration of ammonia?

L: Decreases.

T: Decreases what's going to happen to the concentration of the products, they?

L: Increase.

T: They increase. Now let's be really tricky, what happens to the concentration of O_2. I just added O_2. It will initially instantaneously increase and then?

LLL: Decrease.

T: That is a real understanding of what's going on. If you realise that initially it increases then I when I wrote the answer, I wrote $[O_2]$ initially ↑, then ↓, then I just wrote $[NH_3]$↓ and then I wrote for the other two [NO] and $[H_2O]$↑, they increase. So you look at each of the species and what actually happens to each one of them.

L: Couldn't you just say that the oxygen decreases. I mean they are already telling you that the oxygen decreases. I mean they are already telling you that they added oxygen.

T: You can, but I, I, especially because of these types of graphs, it's a good understanding. I guess they told you that they add oxygen so the increase in oxygen is in the question already.

L: Yes.

T: But just that understanding that when you add it, you can just say it will increase followed by a decrease.

L: Ok.

T: So the second part of the question says you need to talk about the rate of the forward and reverse. So, we have drawn the arrow which says this way. So the forward reaction will be favoured. So the rate of the forward reaction will increase and the rate of the backward reaction will?

LLL: Decrease.

T: Until

LLL: Until equilibrium.

T: Until equilibrium is re-established. So the change is an increase in the rate of the forward reaction and a decrease in the rate of the backward reaction, until is re-established. So I want you to do page 47, 48 and ideally 49. I want you to try that for the next two and half pages. 49, has one last one. You can actually have lots of time; I don't see you until next Wednesday. Guys you know what I am saying, you can do 47, 48 and 49 please.

E2 Transcribed Lesson observations (T2, Mr Humour)

Lesson 1

T: Today's lesson is reversible reactions (writes on the board). Ok, reversible reactions, reversible reactions. Anybody who recalls a reversible reaction from Grade 9? J?

L: A reaction in which reactants can form a product and products can react to form reactants.

T: Yes, give me an example.

L: Ammonia which is formed from nitrogen and hydrogen.

T: Oh, ok. What about you A? Just call out what we did in Grade 9. (No answer from student).Here is an example (Writes on the board). Nitrogen plus hydrogen. What is the arrow I put here? This one, $\rightleftharpoons$, this one $\rightleftharpoons$.?

LLL: Yes $\rightleftharpoons$

T: Is this a gaseous reaction?

L: Yes

T: How do I balance it?

LLL: Put a 3 in front of H and 2 in front of N.

T: Wow, yes put a 3 here and a 2 here. Now here is a type of reaction, depending on the conditions that are prevailing it can go this way or that way. Now let's talk about what is that way and this way. Let's agree that the top arrow is showing what, the forward reaction. As these are reactants, meaning these are our product. Reactants on the left and products on the right. Let's call the reverse the backward reaction. So this is, let's take this as the forward reaction and going back, let's call it what?

LLL: Backward reaction.

T: (Writes). Wow, simple stuff. So it depends on the conditions that will be having, that are prevailing that can affect this. But let me give some physical examples. Have you ever seen a fountain which sprays water up. Yaa?

LLL: Yes.

T: Does the water get finished?

LLL; Yes/ No

T: The water is pumped, is circulated, again it is pumped, and it's circulated and keeps being pumped and comes back and pumped out. Swimming pool, what about the swimming pool. The level stays the same although you see there is gap there by the top of the swimming pool where the water is going away but there is a pump which pumps back the water. Is that true?

LLL: Yes

T: So I am saying technically, the water stays the same although there is water coming in and water going out. So we say when we have such a system, we say the rate of the forward reaction is equal to the backward reaction. We can borrow from Physics some terms. In Physics when we are doing moments. We say the system is in equilibrium. Isn't it?

LLL: Yes.

T: That kind of equilibrium is called static, this means it is not changing. Static, unchanging. For these in chemistry, remember we said water is going out and pumped in, going out and pumped in. For these in chemistry, we say what type of equilibrium, someone can guess.

LLL Dynamic equilibrium.

T: Which means things are constantly changing. Let's use your example of ammonia. In this reversible reaction we get to a point, we can reach a point when the rate at which nitrogen and hydrogen are reacting is equal to the rate at which ammonia is decomposing to form reactants (Shows on the board). So we are going to talk about, actually the equilibrium later. But what we are saying is this, we can have a reaction like this where the forward reaction is equal to that. When we start with the reaction the nitrogen and the hydrogen react, when they react, they react going forward to produce NH_3. The speed of the rate of forward reaction slows down and we start forming products. So we are saying in this reversible reaction, it is possible depending on what will change here which I will show you shortly. But here is a typical example. Here is another example, if you have hydrogen reacting with iodine, you can also have a reversible reaction, giving you hydrogen iodide. Is this a gaseous reaction? Say yes.

LLL: Yes.

T: Let's balance this with a 2.Once again top equation, forward reaction. (Writes H_2 (g)+ $I_{2(}g$ $\rightleftharpoons$ $2HI_{(}g)$ There comes a time when the rate of the forward reaction is equal to the rate of the backward reaction. If you are observing with our eyes, suppose we have different colours, here and there, you will see that the colour changes but if you apply some effect. The colour will change, it will become more of this or that and we will be affecting the equilibrium system. Are we together? So in our notes that was page 38. Ok, that was page 38. We come to a point where the rate of the forward reaction is equal to the rate of the backward reaction. That was the introduction. Let me give you another example, suppose here at school everytime you were getting ready to leave and go to another school, there was another student coming in. we would sent another student to immediately come in. suppose this was your last day at school. No offense. If today is the last day, some new student from let's say D, would come the day you leave. The number of students remains constant. Although, somebody came in and somebody goes out. Notice, two students came in and two students went out, notice the teacher just says 25 students. Although the dose is 2 students in and 2 students went out. Are we together? It's the same as this, that's what we call a reversible reaction. is that alright? Is that ok? Is that alright? Alright, alright? Right, let's move on. I am on page 42 of your notes, I am on page 42 of your notes. Lets go into detail about this concept of equilibrium. Equilibrium, so we said equilibrium in Physics is static because the number, this moment on the left causing anti-clockwise rotation is 30Nm let's say, and this one in the opposite direction is 30Nm in the opposite direction. That's static, static equilibrium. In chemistry, we said equilibrium is dynamic, two students went in and two students went out. Water went in, water went out, it is recirculated. Hydrogen and iodine are reacting but they are coming back. This thing comes to a point where it settles down and we have what we called equilibrium.

T: Yes, Sir.

L1: Does it occur when products are decomposing naturally. Could water be a reversible reaction when it decomposes?

T: We can have water in an equilibrium system like this H_2O*(l)* H_2O*(g)* in a closed container. CO_2 also behaves that way in a closed container CO_2*(l)* CO_2*(g)*, so the rate at which the liquid changes to vapour is the rate at which the vapour changes to liquid in a closed container. Question?

L2: Sir, I am not sure if that's what J meant. I thought he meant if you have water and break it down into hydrogen and oxygen and can you set it back.

T: No, no, the reaction between the oxygen and hydrogen is one directional equation. Hydrogen and oxygen you get water. I thought you meant a change of state, a change of state in a closed container then you can have an equilibrium. That like here, if it's in a sealed container. Right, ready, I am on Le Chatelier's principle. I think I am moving very fast, am I not.

LL: No

T: Here is a certain principle how do I say it? French students? Let's see. Le Chatelier's principle). Let's paraphrase it before we state it correctly. We said that the rate at which the students leave the class, let's say two per month, let's say must be kept constant with the rate come back or are enrolled. Let's say we would do it every day as in say you are leaving on the 24th and the on the 24th, two students are coming back here. So that what this principle says, if that thing can be maintained. They even say whatever disturbs our balance here, the whole system actually adjusts itself to balance it out. Let's say it again. Le Chatlier's Principle says whatever disturbs this balance or this equilibrium, then the system on its will adjust itself to balance out. To go back to a new equilibrium position. Let's talk about your body, have you ever, eh eh eh, swallowed something that's not good for your body? What does you're your body do? You feel sick isn't it?

LLL: Yes.

T: That's you reacting. That's your body trying to counter the wrong thing that you have put in up there. So your body starts sweating or you start having a running tummy or you start other things, having fevers and so on. It's our natural LCP that says I was at equilibrium, you have disturbed me, by changing something, by changing, by changing, by changing something, you mention it, then it says I would like to reverse everything you have done to get back to equilibrium. Now, let's look at factors, let's start with factors which will affect equilibrium, let's mention them in passing. Factors affecting equilibrium. They are 1,2,3. One, its temperature. If you adjusted the temperature for a system in equilibrium, the system will be disturbed and then slowly it will readjust itself. Let's get back and say that slowly. If we have a system that is in equilibrium right and we disturb the equilibrium by some temperature change, the shift itself and get back to another balance or equilibrium. Let's try another one. Pressure, if we adjusted pressure of this reaction, let's see, these are gaseous reactions, this is one is a gas. If we adjust Pressure, adjust pressure,…. the system will adjust to counteract the change in pressure and then the last one. The other, number 3, if we change the concentration of the reactants, the system will again, change the reactants of any one of these, the system will adjust itself to counter that. So here is what Le Chatelier's principle says, someone read for us page 42. Let me read it for you. If a chemical system at equilibrium is subjected to a change in conditions, the system will readjust itself in such a way to partially counteract the change. So we are saying for a system, here is our system, it is in equilibrium. Then you introduce a change. What does the system do? The system is now out of equilibrium, the system will readjust itself to counteract the change you have made.

L: The temperature, does it stay higher or lower when you have equilibrium?

T: Let's say my reaction was at 50^{o}C, I raise it up to 70^{o}C, I have disturbed the equilibrium.What will happen is the system at 70^{o}C adjust itself such that the amount of these substances will change. So this is just a temperature increase or decrease, this is just a pressure increase or decrease, and this is concentration. Concentration will mean if you add hydrogen, the system must react to counter the excess hydrogen which is on the reactants side. Question?

L: So sir, this adjustment, it will never, it will never affect, what has been changed, if you put in more hydrogen, the adjustment will take out the hydrogen.

T: No we won't remove it from the system, but if added more hydrogen (writes a big H, then there is laughter). You know what will happen we will consume Hydrogen that way. This top reaction favours the reaction between hydrogen and iodine. What if I just pumped in hydrogen iodide for some strange reason, you know what will happen, we will consume this way, it is this way to produce more of what. So we do not take out we adjust with what is there, hahaha.

L; But sir, with the equation you gave us, that if you pump in more hydrogen then the forward reaction will increase, but wouldn't more iodine be required as well, because for that as well the amount of iodine must increase.

T: Ok, alright, so for example iodide, if I increase the amount of hydrogen (writes big H_2 writes 20 under H and 5 under I)and there is laughter. Which reaction favours the consumption of H, which reaction?

L: Forward

T: Remember we are at equilibrium we didn't take out all the iodine and finish it form HI, let's say at the start of the reaction, if we increase A, then B will decrease at the end. If increase the amount of reactants (but points to AB), how do we reduce this to cause equilibrium? That is my question. How do we reduce this, we reduce by going backwards, which will increase A and B.

LLL: Laughs

L: I still wanted to know about the HI, won't the theory be able to make like 5 moles of HI. Won't iodine be a limiting factor almost?

L: Because there will still be 15 moles of hydrogen left.

T: Our theory just accept, let's take an ideal situation where the ideal situation where there is enough iodine. These numbers are not exact I just picked them arbitrarily from the sky. But later in the next lesson, we will actually do the calculation. We will actually see the numbers changing, going up and down as you change either temperature or concentration. Sharp.

L: Sir, will we be tested on this?

LLL: Laughter.

LLL: Reaction.

T: What does exothermic mean?

LLL: Give off heat energy.

L: Won't the backward reaction be endothermic.

T: To counter the increase in temperature. Check that one, is that ok.

L: Yes.

T: We were balanced at 60 and but now we have changed the temperature. We can change to 90^o, let's say we have put a fire, how does the reaction change the temperature? Try the next one. What if we were to reduce the temperature for the same reaction? Le Chateleir's says let's counter the decrease in temperature. How? Which reaction absorbs energy and which one gives out energy, we absorb energy, our energy is decreased. When the energy is increased what does the system do. The forward reaction which produces heat too,write on top of your arrows which reaction is endo and which is exo.

T: Questions anybody, questions?

L: Yes, sir, if we swop the endo and exo will the backward reaction be favoured.

T: So we want to put the forward reaction as exo, let's do that. Example 3, let's increase the temperature for an exothermic reaction. Le Chatelier's says if we increase the temperature the system will favour the reaction which takes in energy, which one is that?

L: Forward reaction.

T: Forward reaction

T: So we have countered the change for an exothermic reaction. Makes sense.

(No reply)

T: Makes sense, let's try again.

L: Sir, will the temperature always be different, the one for the forward and the backward reaction.

T: No, no no, we are using an enclosed container, like this (draws a box). Isn't it? So we are at a certain temperature, let's say 60^0, then we increase it to 90^0 right now this reaction, forward is exothermic. We are not saying the endothermic is at this temperature and the exothermic is at this temperature.

Lesson 2

T: Last week we discussed the effect of temperature and today we will discuss the effect of concentration. Let's have a typical equilibrium, last week we had nitrogen and hydrogen to give ammonia. This is the equation we had last time, eh. Let's talk about concentration and the changes in concentration. The changes in of concentration is in the form when we either increase the concentration of any one of the substances, whether the reactants or the products, right. So we must figure out what will happen, which reaction will be favoured whether the backward or the forward, is that ok?

LLL; Yes

T: Suppose in an equilibrium system then we increase the amount of nitrogen, what do you think will happen according to LCP. The principle states that if the system is in equilibrium, you affect it in any way, it will readjust itself to get to a point of a new equilibrium. Right, so that's what we say, let's talk in terms of concentration, what do you think will happen here? If you increase the amount of concentration of nitrogen gas. What do you think will happen? Describe in full.

L1: We will increase the concentration of hydrogen.

T: How do we do that, how will that affect, describe in full.

L1: More nitrogen will be used.

T: You are saying more nitrogen will be used meaning we will consume this hydrogen, ok, what do you want to say V?

L: I just want to say more ammonia will be produced.

T: What will happen to the hydrogen?

L: When there is an increase, there will be more hydrogen to react with the nitrogen.

T: Yes

L: There will be more of hydrogen and they react so more ammonia will be produced.

T: Yes, J, what do you say?

L: More ammonia will be produced, because the backward reaction will be favoured to make more ammonia.

T: You are contradicting yourself. You said more ammonia will be produced, that will be the forward reaction.

L: Yes, it's the forward reaction, if more ammonia is produced then the breakdown of ammonia is favoured.

L: He means that if more ammonia is produced then the breakdown of ammonia will be more, more hydrogen and nitrogen.

T: And more nitrogen on this side. So the reaction, this one, the forward reaction will be favoured, because LCP says we are trying to counteract this excess nitrogen. So we are trying to counteract the effect of the increase in nitrogen. So if I increase the concentration of any one of the reactants, the reaction which consumes them will be favoured. Is that clear? Is that clear? Let's try the other way round, what if we decrease the concentration of either nitrogen or hydrogen, which reaction will be favoured and why? Yes.

L: The backward reaction because more nitrogen and hydrogen will be required.

T: So the backward reaction, how will this happen.

L: ammonia will form nitrogen and hydrogen.

T: So will decompose to form more of the reactants. Is that correct? Is that correct?

L: Yes.

T: Let's try another one, what if we increase the concentration of the product. What if we increase the concentration of ammonia.

L: More nitrogen and hydrogen will be released. So the backward reaction.

T: How will it happen?

L: It will form nitrogen and hydrogen from ammonia.

T: So ammonia will decompose and more of the reactants will form. Is that correct? Is that correct?

LLL: Yes.

T: Let's try the other way round. What if we increase the concentration of the product, what if we increase the concentration of the product ammonia? What will happen?

L: Ammonia will decrease.

T: So the backward reaction will be favoured. What if we decreased the concentration, it is our factory isn't it? What if we take out ammonia, yes, yes, what will happen? I cannot hear. Any takers? What if we decreased the concentration of ammonia?

L: The forward reaction will be favoured to produce more ammonia.

T: So that's the effect of adjusting the concentration for a system at equilibrium. Let's try the next one. What if there are pressure changes, let's stick to the same equation here. Look at the production of ammonia we have an increase in pressure and a decrease in pressure. I change the pressure for the entire reaction environment. These two are reacting and producing this in a closed container or closed vessel and then we increase the pressure. What do we mean by increasing the pressure? It's reducing the volume of a reaction isn't it? This is gas, this is a gas, somebody with a bright idea, what if we increase the pressure or decrease this volume, same effect? What will happen? Anybody?

L: The particles will form the product which take up less space.

T: Takes up more space? Which one takes up more space?

L: The particles when they are combined will take up less space.

T: What do you think, J. Isn't it the opposite, which one takes up more space.

L: Isn't it less space when they form ammonia.

L: More nitrogen and hydrogen and nitrogen will be released so the backward reaction.

T: How will it happen?

L: It will form nitrogen and hydrogen from ammonia.

T So ammonia will decompose and more of the reactants will form. Is that correct?

LLL: Yes.

T: You got it right the first time. Let's look at this equation ($N_2 + H_2 \rightarrow NH_3$). Can you quickly balance this equation for me, it's here 3 and there 2. So we are saying at equilibrium nitrogen and hydrogen react to give us ammonia. It involves one mole of this to produce how two moles. So the reactants have more gaseous moles and this side we have less. So on this side we have three plus one mole which is four moles and on this side two. so as these guys have said, if we reduce the volume you are creating less space for the reaction, so the reaction or reaction that produces fewer moles is favoured. So which on is that? Forward? True?

LLL: Yes

T; Let's try again. What if I decrease the pressure? A decrease in pressure means an increase in what, in volume. I have increased the volume and decreased the pressure. Which reaction is favoured, obviously?

LLL: The backward reaction, correct. So we are saying the reaction to be favoured is the one which produces more moles or a greater space or volume. So more of this form 2 to 4 simplified. Question? Question? So that is how you explain pressure changes in equilibrium reactions.

L: Sir, what if the pressure is increased will the backward reaction be favoured?

T: When pressure is increased, the forward reaction is favoured. When it is decreased the backward reaction makes sense. Then the last point with a star, what if we were to introduce a good catalyst, what if we were to introduce a good catalyst? Let's say this reaction can have a catalyst, if we choose a common catalyst, iron fillings, finely powdered and then introduce the catalyst. Which reaction will be favoured, forward or backward?

LLL: Forward?

T: Why do you say forward? Please make sure you support your answer? J why do you say the forward?

L: The catalyst will speed up the rate of reaction causing the forward reaction.

T: Say it again, loud and clear.

L: The catalyst will speed up the rate of reaction, so the forward reaction is favoured. Ah, it can be both.

T: So what are you saying? What is the overall effect of the catalyst on the reaction?

L: The catalyst will speed up both the forward and backward reaction.

T: So what is the overall effect?

L: Isn't it, it doesn't favour any any reaction?

T: It does according to him. But my question is what happens to this shift; do we shift that way or this way?

L: The total rate of reaction is higher on both sides but there is no shift.

T: So the rate of reaction is higher on both sides?

L: But there is no shift. It still remains a reversible reaction.

T: So you are saying no effect in terms of position of equilibrium. The addition of a catalyst does not affect the position of equilibrium. So we all not have more or less of ammonia but what will happen is that we will get to equilibrium much faster than before, we will get too equilibrium faster. Every time we have the forward reaction it will be equalled by the backward reaction, so it will get there much quicker. So it will not affect the value. Yes, sir?

L: So catalysts speed up the rate of reaction?

T: Yes catalysts speed up the rate of reaction. Let's say for instance the chemistry of enzymes, it makes a reaction go faster. So this will make the reaction get to equilibrium faster but it didn't affect whether it's more of reactants or more of products. Any questions?

L: So we are doing this worksheet.

T: We are doing it now. Any questions? Ok let's do questions on page 47, so I will be asking for answers and explanations. Complete the table look at the changes there and let's hear what will happen. Question one let's hear what will happen if you change the concentration of sulphur dioxide? What will happen?

L: More SO_3 will be formed.

T: Correct, reaction number two, $CaCO_3$ decomposes to form CaO and CO_2, what will be favoured if you increase CO_2. Forward reaction is that correct.

L: Yes.

T: Next reaction, with sodium ions and chloride ions, if you increase Cl^-.

L: Backward reaction.

T: Is that correct.

LLL: Yes

T: Reaction 3, silver chloride decomposes to silver and chloride ions. If you increase the concentration of chloride ions, which reaction is favoured.

LLL: Backward.

T: That's correct, if you increase nitrogen and hydrogen producing NH_3, if you decrease the volume, what will happen?

LLL: Forward/ backward reaction.

T: Forward reaction, it has less. Next one, if you have nitrogen dioxide heated with oxygen to form 2NO, what is the effect if you decrease the volume?

L: No effect.

T: Forward reaction?

LLL: No effect/ forward reaction.

T: Some are saying no effect. Let's look at it. How many moles are there on the reactants side, ? Two and how many on the products side, two. Answer? So there is no effect. Put an apostrophe there. Next one, sulphur dioxide plus oxygen, you get two sulphur trioxide, again this is an increase in volume, what happens?

L: Backward reaction.

T: Is that correct? Backward reaction? Nitrogen again and oxygen but this time they specify plus 99KJ on the products side. Tell me what kind of reaction is this?

LLL: Exothermic.

T: Exothermic? So it's because the energy given out is on the products side, so it's an exothermic reaction. right, ready to go. So what happens if you increase the temperature?

LLL: Forward/ backward.

T: Forward reaction? Backward reaction? (looks very surprised). Who is sure of the answer, S what's your answer?

L: Backward reaction.

T: Backward reaction. If you increase the temperature, the temperature favours the, what, the endothermic reaction. So now we have an increase in temperature what are we favouring?

LLL: Endothermic.

T: Which one is what?

L: Backward reaction.

T: So the next one says, nitrogen and oxygen, this time around we say plus 182 kilojoules, producing 2NO, what type of reaction?

LLL: Endothermic.

T: Now if you increase the temperature who is favoured?

LLL: Endothermic.

T: So which one is the endothermic reaction?

LLL: Backward/ forward.

L: No, it's the forward.

T: So the backward reaction is endothermic and the backward reaction is exothermic. IF you decrease the temperature the backward reaction is favoured. Next one silver chloride decomposing to silver and chloride ions but they say plus 60KJ. If you increase the temperature, which reaction is favoured?

LLL: Backward.

T: The backward reaction is exothermic. Any problems with this? You are ok? Are you ok? Are you ok with the previous question of nitrogen. Why is there no effect when volume is changed?

L: Why is there no effect?

T: Look at the number of moles on the reactants and the products side. How many moles on the products.

L: Which one is it?

T: The one of the nitrogen.

L: Two

T: On the reactants side?

L: Two.

T: So whether I increase the volume there will be no change, because there is no side with fewer moles.

L: Why is the endothermic reaction increasing when you increase the temperature?

T: In a reaction ($A + B \leftrightarrow C$) let's start with the endothermic. Let's start with the endothermic, if you increase the temperature, you increase the amount of energy you are giving this vessel too much energy, according to Le Chatelier's the system has to counteract this energy. We have to counteract this by the endothermic, so we must decrease this energy by going through the endothermic. So do you think you can answer the questions on your own?

LLL: No.

T: You can answer number seven onwards on your own. Can I talk about the equilibrium constant?

LLL: No.

T: What? Why not?

LLL: It's too much.

T: Is this confusing? It takes a lot of thinking. Let's use another equation and let's settle this once and for all in our mind. Let's say we have A decomposing to B and it's exothermic. Let's solve this so that we can solve it once and for all. So going this way, so the forward reaction is exo and the backward reaction is endothermic. Just by looking at this reaction, the decomposition of A is favoured just by the energy given out. Right, so whatever change I will apply is governed by what I will write here. Look, I increase temperature, I am saying I will end up with excess energy so to counteract excess energy I must be consuming this energy by this way, the endothermic way. Do you accept that? If we increase the temperature, we have an increase in energy and we consume it by means of an endothermic reaction. Two, if you decrease temperature and which reaction decreases this? The forward. That's my conclusion for temperature, concentration, pressure and catalyst. Any? No questions, yes sir

L: When they say they have changed the concentration, what are the effects?

T: Yes let's try question 2 if the reaction of ammonia and SO_2 gives us NO and $6H_2O$ is at equilibrium predict the effect of the changes in the concentration of each species. Then they tell us the change is addition of O_2. Ok, please give me the answer, do it in groups or in pairs, I will give you three minutes.

(After some time)

T: What happens to the ammonia, nitrogen oxide and oxygen in terms of their concentrations? Tell us what happens to each of the species involved?

L: Sir, I think concentration of the products will increase.

T: So you have an increase in nitrogen monoxide, dioxide and water is that true?

LLL: Yes.

T: What happens on the left hand side?

L: The oxygen was increased.

T: So what happens to the NO_2?

L: It will stay the same.

T: It will stay the same!

L: It will decrease.

T: Yes, it will decrease because we are saying, if we favour the forward reaction, we must consume NH_3. So it will go down.

L: Sir, which reaction will be favoured and what happens to the concentration?

T: Right, so we are saying the concentrations of ammonia will decrease and of NO and H_2O will go up.

L: Why does ammonia decrease?

T: Because it is reacting with excess oxygen.

L: What happens to the oxygen?

T: The oxygen although we produced a spike when we added it, it will also come down at the end. It will come down, but it cannot be lower than the previous one.

L: Oh, oh.

T: Let's say we were at 4 moles then increase to 6 moles, when we came down, we will get let's say to five which is higher than four.

L: We can say…

T: Yes, are you listening?

T: Let's look at the next one. Describe what happens to the rates of the forward and backward reactions? Which reaction is favoured?

LLL: Forward.

T: So let's say that in terms of the rate of reaction. Say the rate of the forward reaction is faster or more than the rate of the reverse reaction. Next, part B, part B is saying reducing the concentration of NO. So where is NO?

L: Right.

T: So let's hear the answer, what happens to the concentrations of the individual species?

L; Oxygen and ammonia will increase.

T: So ammonia and oxygen will increase what about water?

L: Water will increase.

T: So water will increase, are you sure it will increase?

L: Yes.

T: Ok, talk to me. When we increase the concentration of NO, what happens, which reaction is favoured? Yes, M?

L: Backward.

T: Backward, so you are consuming water also.

L: No.

T: (Looks surprised). Alright let's start again. What reaction will be favoured?

LLL: Forward right, so what happens the water, if we favouring the forward reaction? What happens to the water?

L: It will increase.

T: It will increase, right.

L: Sir, what does it mean when you say a reaction is favoured?

T: We are saying the rate of reaction is more. For example, for this one, if I say the forward reaction is favoured, then I am saying the rate of the forward reaction will be greater that the backward reaction.

L: So basically when you increase these things, you take it out of equilibrium.

Lesson 3

T: The equilibrium constant is on page 51 to somewhere up there (Writing on the board). Scientist or chemists have discovered that if we have a reaction like this aA + bB ↔ cC + dD. They discovered that the ratio of the concentrations of the products, there is a relationship between the ratio of the concentrations on this side and this side and they can be stated in an expression which gives you the equilibrium constant, wait for it. So on this side are the reactants and on this side the products. So there is an expression which we are going to introduce now, which gives you the equilibrium constant. So the equilibrium constant is tis expression, symbol capital letter K, where you take the products or the products as your numerator raised to the power of, for now allow me to do:

$$K= \frac{[\text{products}]^x}{[\text{reactants}]^y}$$

So we are talking about the concentration of products and the reactants compared to each other. In this case the complete statement, the complete statement for the equilibrium expression will be written as this, we take the concentration of these reactants, so these small numbers, let's say you are balancing the equation of the number of moles in equilibrium. This expression in full will look like these, the concentration of the product C raised to the power of the coefficient c, X by the concentration of substance D raised to the number of moles and so on. This is called our equilibrium expression. Can you see, it's a comparison, it's a comparison of the concentration of the products raised to their powers and the reactants raised to their number of moles. This helps us in a number of ways. Suppose I get a large number of K and I can compare the products to our reactants. What do you think it means in a reaction. Let's say I have K equal to 2.5×10^{39}, what do you think is happening to the reaction (No answer). Ok, let's make it for real so that you can answer. If I have a large number of K, in mathematics it means the numerator is much bigger that the denominator. In terms of concentration, what does it mean?

LL: More concentration of products than reactants.

T: More concentration of these than these. In terms of progress of reaction, what does it mean?

L: The forward reaction is favoured.

T: The forward reaction is favoured and it has gone too far compared to the backward reaction. If K is large the reaction has gone so far, that the concentration of the denominator is so small, mathematics, making the ratio or the relationship between these such that our equilibrium is far this side than this way. Did you get that?

L: No

T: Let me repeat it in other words. What if K was very very smaller that one, something like that, $2.5X\ 10^{-39}$, let's exaggerate. What is happening?

L: It means there is very little concentration of the products. Yes so we are saying, not much of the reaction has occurred. We have more of the reactants than the products. Are we together? I have just used the general terms. Let's try and figure this one out. Let's say, let's do this one. There must be a unit for the equilibrium constant. Who knows how to get it? Who can make a good suggestion on how to get it? Unit? If I were to tell you that the squared brackets mean the concentration of the species. C and square brackets, concentration of D. Squared brackets mean concentration. So these are mol per cubic decimetre to the power. Let's give a real- life example. Suppose hydrogen reacts with iodine gas this way and give us, the equilibrium balanced
$H_{2(}g) + I_2(g)\ 2HI(g)$

Ready the K expression or the equilibrium expression would be HI to the power of 2 divided by the power and to the power.

Writes $\frac{[HI]^2}{[H_2][I_2]}$

On the right hand side what are the units. If the units are moles per cubic decimetre, then on this side the units will be moles per cubic decimetre squared. So for this reaction what are the units?

L: One.

T: There are no units.

L: Laughs

T: But for this reaction only because the units cancel out. So we have done the equilibrium constant, number one and two, this is how we work out the units ok, let's say that again, a large value of K means there is more reactants than products. Now the value of K is always given at a certain temperature. So when you quote this value then you say, therefore the value of the equilibrium constant of this reaction is this, at such and such a temperature because you know the effect of the temperature on the equilibrium constant. Can we go to page 52. We have a few questions. Page 52, can we do question 1, do you want me to do it with you.

LLL: Yes

T: p52 question 1a, if thats our reaction

If that's our reaction, the products and the reactants, the K will be will be product singular to the reactants sulphur dioxide, concentration of to the power of 2, then oxygen to the power of one. So concentrations raised to their powers over the concentrations of the reactants raised to their powers, like this:

$$K = \frac{[SO_3]^2}{[SO_2][O_2]}$$

Check that, let's go do numbers 2 and 3 and 4b, c, d. that's all we can do at the moment, then I will give you the concentrations and then you work out K.

L: Oh

T: Let's start with the equilibrium expression.

L: Do we need to write the states.

T: Oh, yes, there is something I forgot to mention, solids and liquids do not appear in the equilibrium expression. So we have (writes)
$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$

Then $K = \frac{[SO_3]^2}{[SO_2][O_2]}$

Which means concentration of SO_3 squared divided by concentration of SO_2 squared multiplied by concentration of O_2. Now if you put the concentration as moles per cubic decimetre, then we have

$$\frac{[moldm^{-3}]^2}{[moldm^{-3}]^2[moldm^{-3}]}$$

Then you cancel out.

L: Sir can you please do number c.

L: Sir how does that become $(moldm^{-3})^{-1}$

T: Mathematics, one divided by x is the same as x to the power of negative one.

L: Oh, ok.

L: But how did you get the first step?

T: Here?

L: Yes.
T: This is moles per cubic decimetre squared and this is moles per cubic decimetre only. So these cancel out.

L: So what does that mean?

T: The bracket just means the concentration of sulphur trioxide and from the equation we have a two. So this is concentration is in moles per cubic decimetre and you also put that two. So we have concentration squared and then you cancel out later.

L: Oh

L: Sir, can you please do number one c

T: Write this in full mol per cubic decimetre. For 1c, let's see for the numerator what's your total power, 6 plus 4, 10. And for the denominator, 5 plus 4 which is 9, so the 10 minus 9, you get 1 so its moles per cubic decimetre.

L: Oh, oh, oh,

T: So we are using the rules of indices.

L: So you can add them first.

L: Yes, you can add them and then cancel out. But there I didn't add, I just cancelled out.

T: We seem to have a problem with 1b, which is solid lead iodide, what is the equilibrium constant.

LLL: Nothing.

T: Are you sure not one?

LLL: No

L: So sir, how do you treat solutions?

T: Where is that question 1c. How do you treat a solid?

L: You do not include it.

T: But do you put a one?

L: No

T: D, let's do the aqueous one, same method. What the equation?

$$K = \frac{[H^+][F^-]}{[HF]}$$

L: Isn't aqueous a solution?

T: Yes, then you can work out the concentration.

Phase 2

Appendix G1: Lesson plans

Lesson 1: Reversibility of reactions

Introduction

Using specific examples, learners discuss in their groups what they think reversible reactions are and write these down.

Main part of the lesson

The learners present their information to the class and discuss their findings.

Consolidation

The learners summarise reversible reactions.

Assignment: The learners are to do research on the carrying of oxygen by haemoglobin.

Lesson 2 and 3: Reversibility of reactions

Introduction

Recap of the previous lesson and discussion of carrying of haemoglobin and oxygen. Then the teacher explains the practical activity to the learners.

Main part

The learners carry out the practical activity in groups (appendix G3). It involves the reversible reaction between hydrous copper (11) sulphate and its hydrated form in groups. Learners answer questions related to the practical activity.

Consolidation

Revision of questions.

Lesson 4: Reversibility of reactions

Introduction

Revision of reversibility of reactions drawing on learners' prior knowledge.

Main part

Answer practise questions in groups followed by discussions.

Consolidation

Corrections

Lesson 5 & 6: Chemical equilibrium

Introduction

Introduction of concept of equilibrium using analogies in appendix G4.

Main part

Learners play the equilibrium game (appendix G2).

Consolidation

Discussion and explanation of findings

Lesson 7: Chemical equilibrium

Introduction

Recap of chemical equilibrium concepts

Main part

Practical activity on $CO_{2\ (g)}$/ $CO_{\ (aq)}$ equilibrium (appendix G3)

Consolidation

Discussion of results

Lessons 8: Changes in conditions at equilibrium

Introduction

Revision of chemical equilibrium concepts.

Main Part

Discussion of LCP and changes in concentration, temperature and pressure using you-tube clips (appendix G6)

Consolidation

Summary of lesson and revision questions as homework (appendix G5).

Lesson 9: Changes in conditions at equilibrium: Effect of concentration

Introduction: Effect of concentration.

Question and answer session on previous lessons. Introduction of effect of concentration on a reaction at equilibrium using a You-tube clip (appendix G6).

Main part

Teacher demonstration of cobalt (II) complexes equilibria (appendix G3)

Consolidation

Learners complete worksheet

Lesson 10: Effect of concentration

Introduction

Discussion on effect of concentration on reactions at equilibrium.

Main part

Learners answer questions in groups (appendix G5)

Consolidation

Discussion of answers

Lesson 11: Effect of temperature

Recap of concepts. Introduction of effect of temperature using a You-tube clip of N_2O_4 and $2NO_2$ equilibrium (appendix G3).

Main part

Learners discuss N_2O_4 and $2NO_2$ equilibrium and answer questions (appendix G3).

Consolidation

Discussion of answers

Lesson 12: Effect of pressure

Introduction

Revision of previous concepts.

Introduction of effect of pressure drawing on prior knowledge.

Main part

Teacher demonstration of fizzy drink followed by discussion

Consolidation

Discussion of concepts and summary

Lesson 13: Effect of volume

Introduction

The teacher draws on prior knowledge of the relationship between volume and pressure.

Main part

Teacher shows You-tube of the effect of volume on reactions at equilibrium (appendix G6)

Consolidation

Practice questions for homework (appendix G5)

Appendix G2: Chemical Equilibrium game.

Chemistry Game

Use 36 cards – coloured on one side, white on the other

Place all cards coloured side up.

1. Turn over **one** in every **four** coloured cards, counting the number of cards turned over. (**N.B** If after turning the cards, there are three cards left, turn the third card). Record the result in the table below.
2. Turn back **one** in every **three** white cards. Count the number of cards turned over and record the result.
3. Record the numbers of coloured and white cards.

Cycle	Number of coloured cards turned over (step1)	Number of white cards turned over (step2)	Number coloured Cards (step3)	Number of white cards (step3)
1				
2				
3				
4				
5				
6				

4. Repeat the cycle i.e. numbers 1, 2 and 3 until cycle six.
   Record your observation.

5. In the space below, plot the number of cards on the y-axis with cycle number on the x-axis for
   a) coloured cards
   b) white cards.
   Use different colours for each graph.

6) As a group discuss your results. Write down your points in the space below.

Appendix G3: Practical activities
Chemical equilibrium teacher demonstration adopted from

http://www.nuffieldfoundation.org/practical-chemistry/equilibrium-between-two-coloured-cobalt-species-aqueous-solution

Practical on cobalt complexes equilibria.

The two different coloured Co(II) complex ions, $[Co(H_2O)_6]^{2+}$ and $[CoCl_4]^{2-}$, exist together in equilibrium in solution in the presence of chloride ions:

$[Co(H_2O)_6]^{2+}$(aq)(**pink**) + $4Cl^-$(aq) ⇌ $[CoCl_4]^{2-}$(aq)(**blue**) + $6H_2O$(l)

This **equilibrium** can be disturbed by changing the chloride ion **concentration** or by changing the **temperature**. The colour changes accompanying the changes in equilibrium position are as predicted by **Le Chatelier's principle**.

Lesson organisation

The distinctive colours of the two cobalt(II) species in solution produce an attractive visual demonstration of a reversible reaction and the effect of concentration and temperature on the position of equilibrium.

The demonstration can be used to introduce reversible reactions and chemical equilibrium or to illustrate Le Chatelier's principle once these concepts have been established. If students are unfamiliar with the formulae of complex ions this may confuse the issue. For the purposes of this discussion the equilibrium could adequately be represented by:

Pink cobalt species + chloride ions ⇌ Blue cobalt species + water molecules

A white background will help to show the colour changes to best effect. For big groups the reactions should be scaled up, using larger containers such as measuring cylinders or beakers, to improve visibility.

The demonstration could also be adapted for use as a class experiment with suitable groups.

Time taken should be about 10 min.

Chemicals

The quantities of chemicals given are for one demonstration:

Cobalt(II) chloride-6-water (TOXIC, DANGEROUS FOR THE ENVIRONMENT), 4.0 g

Concentrated hydrochloric acid (CORROSIVE), 100 cm^3

Crushed ice, about 200 cm^3**.**

Apparatus

Eye protection for the demonstrator

Boiling tubes, 6

Rack for boiling tubes, 1 or 2 (depending on capacity)

Measuring cylinder (100 cm^3)

Beakers (250 cm^3), 3

Dropping pipettes, 2

Access to a top-pan balance

Health & Safety and Technical notes

Cobalt(II) chloride-6-water, $CoCl_2.6H_2O(s)$, (TOXIC, DANGEROUS FOR THE ENVIRONMENT). As cobalt(II) chloride is a skin sensitiser, take care to avoid skin contact and wash hands well after use.

Concentrated hydrochloric acid, HCl(aq), (CORROSIVE)

Procedure

Before the demonstration

a Boil a beaker of water and prepare a beaker of crushed ice and water.

b Dissolve about 4 g of cobalt(II) chloride-6-water in 40 cm^3 of water in a beaker. A reddish-pink, approximately 0.4 M solution will be formed, which should be labelled as TOXIC.

The demonstration

c Make the pink cobalt chloride solution up to 100 cm^3 with 60 cm^3 concentrated hydrochloric acid from a measuring cylinder. A violet-coloured solution should be formed. Adding a more hydrochloric acid will produce a blue solution containing mainly $[CoCl_4]^{2-}$, while adding water will restore the pink colour.

d If necessary, add more hydrochloric acid or water by trial and error to produce an ‘in-between’ violet-coloured solution containing a mixture of the two cobalt ions. Place about 2 cm depth of it in each of the six boiling tubes in two groups of three in suitable racks.

1 Effect of concentration

e Keeping one tube as a control, use dropping pipettes to add water to the second tube and concentrated hydrochloric acid to the third until the colours change to pink and blue respectively. Swirl to mix well as the liquids are added. If desired, show that these changes are reversible by adding concentrated HCl to the second test-tube and water to the third.

2 Effect of temperature

Starting with three tubes of violet-coloured solution, keep one tube as a control, and place another tube in the hot water (over 90 °C). It will turn blue. Put the third tube in the ice/water mixture. It will turn pink. If desired, show that the changes are reversible by swapping over the two test-tubes.

Teaching notes

The change in colour from blue to pink of the cobalt complexes here has been the basis of cobalt chloride indicator papers for the detection of the presence of water. It is also used in self-indicating silica gel desiccant granules.

The reaction $[Co(H_2O)_6]^{2+}(aq) + 4Cl^{-}(aq) \rightarrow [CoCl_4]^{2-}(aq) + 6H_2O(l)$ is endothermic. Therefore, in accordance with Le Chatelier's principle, when the temperature is raised, the position of the equilibrium will move to the right, forming more of the blue complex ion at the expense of the pink species.

Adding concentrated hydrochloric added raises the chloride ion concentration, causing the equilibrium to move to the right, in accordance with Le Chatelier. Adding water lowers the chloride ion concentration, moving the equilibrium in the opposite direction

As an extension it is possible to show that it is the Cl^{-} ions in the hydrochloric acid that shift the equilibrium by adding a spatula of sodium chloride instead to the pink solution. This produces a bluer colour, but this may take some time because the salt is slow to dissolve.

Practical involving carbon dioxide equilibria adopted from http://www.nuffieldfoundation.org/practical-chemistry/equilibria-involving-carbon-dioxide-aqueous-solution

Practical activity involving carbon dioxide in aqueous solution

Demonstration and Class practical

Soda water is placed in a syringe and the plunger pulled out to reduce the **pressure** above it. Bubbles of **carbon dioxide** are seen forming ('out-gassing') as its **solubility** decreases. Methyl red indicator added to the soda water turns from red to yellow, showing that the solution has become less acidic as the **equilibria** in solution adjust.

Lesson organisation

This short experiment can be carried out as a demonstration or as a class practical, with students working in pairs. They should be familiar with the phenomenon of out-gassing when carbonated drinks are opened.

Students may not be familiar with methyl red indicator. If so, demonstrate its colours in acidic and alkaline solutions beforehand. It is red below pH 4.2 and yellow above pH 6.3.

Time needed is 5 – 10 min.

Chemicals

Soda water or carbonated mineral water,
a few cm^3

Methyl red indicator solution, a few drops

Apparatus

Eye protection

For one demonstration or each pair of students:

Plastic syringe (50 cm^3), (modified as in **Note 1**)

Syringe cap (optional)

Nail (5 cm)

Beaker (100 cm^3)

Health & Safety and Technical notes

Read our standard health & safety guidance

Soda water or carbonated mineral water - A fresh, unopened bottle is best. Flavoured fizzy drinks, such as lemonade or cola, are not suitable here because they contain added acids, such as citric acid.

Methyl red indicator solution - see CLEAPSS *Hazcard* and CLEAPSS *Recipe Book*.

1 A smaller syringe will do but the changes are less easily visible. Modify the syringe as follows: pull out the plunger so that the volume of air in the syringe is 50 cm^3 (see diagram). Warm the nail in a Bunsen flame and push it through the stem of the plunger as shown in the diagram. When the nail is in place, the plunger can be 'locked' at the 50 cm^3 mark.

Procedure

a Pour 10 – 20 cm^3 of soda water into the beaker and add a few drops of methyl red indicatorto give a red solution.

b Remove the nail from the syringe and insert the plunger completely. Draw about 5 cm^3 of the soda water and indicator solution into the syringe. Place a syringe cap over the end of the syringe (or use a finger), pull the plunger out to the 50 cm^3 mark and lock it with the nail. Bubbles of carbon dioxide will be seen out-gassing from the water and the indicator will begin to turn orange. Shake the syringe to speed up the out-gassing.

c Hold the syringe vertically with the nozzle pointing upwards, remove the syringe cap and the nail, and push in the plunger to expel the gas but not the solution. Seal the syringe again and repeat the out-gassing cycle in **b**. More bubbles will be seen and the indicator will turn further towards a yellow colour. Several more such cycles can be repeated until the indicator becomes completely yellow.

Teaching notes

A white background helps. Place the syringe next to the original red solution to emphasise the colour change.

An additional demonstration that shows the effect of temperature on the solubility of a gas, and the associated indicator colour changes, involves boiling some soda water containing a little methyl red indicator in a boiling tube. This will expel the carbon dioxide, which is less soluble at high temperatures, and shows the colour change of the indicator from red to yellow.

Soda water contains carbon dioxide that has been dissolved in it under pressure. The equilibria involved in this experiment are:

1 $CO_2(g) \rightleftharpoons CO_2(aq)$

2 $CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$ (**carbonic acid**)

3 $H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$ (**hydrogencarbonate ions**)

4 $HCO_3^-(aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq)$ (**carbonate ions**)

(For simplicity, teachers may prefer not to discuss this last equilibrium).

The solution of carbon dioxide is thus acidic because of the increase in concentration of $H^+(aq)$ ions resulting from these reactions. Reducing the pressure causes CO_2 to come out of solution, ie equilibrium (**1**) moves to the left. The result is that the other three equilibria also move to the left, removing $H^+(aq)$ ions from the solution and making the solution less acidic.

Practical activity for reversibily of copper (II) sulphate adopted from http://www.nuffieldfoundation.org/practical-chemistry/reversible-reaction-involving-hydrated-copperii-sulfate-and%C2%A0its-anhydrous-form

A reversible reaction involving hydrated copper(II) sulfate and its anhydrous form Class practical

Students remove the water of crystallization from **hydrated copper(II) sulfate** by **heating**. Condensing the vapour produced in a second test-tube collects the water. The white anhydrous copper(II) sulfate is then rehydrated and the blue colour returns.

Lesson organisation

This experiment can be carried out in pairs by students. It should take no more than 30 - 40 minutes.

Chemicals

Copper (II) sulfate(VI)-5-water (powdered), (HARMFUL, DANGEROUS FOR THE ENVIRONMENT), about 5 g

Refer to Health & Safety and Technical notes section below for additional information.

Apparatus

Each group will require:

Eye protection

Test-tubes, 2

Delivery tube (right-angled)

Beaker, 250 cm^3

Bunsen burner

Clamp and stand

Health & Safety and Technical notes

e

Wear eye protection.

Copper(II) sulfate(VI)-5-water, $CuSO_4.5H_2O(s)$, (HARMFUL, DANGEROUS FOR THE ENVIRONMENT)

Procedure

a. Set up the apparatus as shown, placing about 5 g of powdered hydrated copper(II) sulfate in the test-tube. Make sure that the tube is clamped near the bung as shown.

b. Heat the blue copper(II) sulfate until it has turned white. Move the flame along the length of the test-tube from time-to-time (avoiding the clamp) to prevent water condensing on the cooler regions and then running down on to the hot solid, possibly cracking the test-tube.

c. Act quickly to prevent suck-back if the level of water collecting in the test-tube reaches the end of the delivery tube. Lift the clamp stand so that the delivery tube does not reach into the water in the test-tube.

d. Allow the anhydrous copper(II) sulfate to cool back to room temperature.

e. Holding the test-tube containing anhydrous copper(II) sulfate in one hand, pour the collected water very slowly on to the white powder. What observations can you make?

f. Record any observations made during the heating process and when the water was poured back onto the anhydrous copper(II) sulfate.

Teaching notes

Ensure that the students have clamped the test-tube at the end nearest the bung before they start the experiment, otherwise they will be heating the clamp as well as the test-tube.

Warn about and watch for ‘suck-back’. Demonstrate how to lift the entire clamp stand and apparatus.

The reaction involved is:

$CuSO_4.5H_2O$(s)(pale blue solid) ⇌ $CuSO_4$(s)("dirty" white solid) + $5H_2O$(l)

Students should observe the colour change from pale blue to white and the change back to blue when water is added. The colour change on adding water to anhydrous copper(II) sulfate has been used as a test for the presence of water in a liquid.

The more observant should notice that the addition of water to anhydrous copper(II) sulfate is exothermic, as the tube becomes noticeably hot if the water is added very slowly. They should therefore conclude that the same quantity of energy is absorbed when the endothermic thermal decomposition takes place..

More able and older students might be asked to calculate the enthalpy change occurring during this process. They will need to find out from a Data Book the standard enthalpies of formation for anhydrous and hydrated copper(II) sulfate, as well as that for water.

Appendix G4: Analogies used in chemical equilibrium

- A child playing on a moveable stairway going down, jumps an equal number of steps up and remains in the same position. This shows a reversible reaction and equilibrium.
- Links to analogies
  http://pubs.rsc.org/en/content/articlelanding/RP/2009/b901455c#!divAbstract
  http://www.academia.edu/2446646/Analogies_in_the_teaching_of_chemical_equilibrium_a_synthesis_analysis_of_the_literature

Appendix G5: Chemical equilibrium exercises and key concepts
Reversibility revision questions

1. A closed system containing liquid ethanol in equilibrium with ethanol vapour at 20°C is cooled to 10°C. Describe the changes which occur to the following.

a) The macroscopic properties of the system (the observable properties of the system such as the mass of ethanol present as the liquid).

b) The rates of the processes involved.

2. The solubility of NaCl per 100g of water is 36.0g at 20°C and 37.0g at 50°C. 40g of NaCl is added to 100g of water at 20°C and the system is allowed to come to equilibrium. If the system was heated to 50°C, describe the changes that would occur.

3. When nitrogen and hydrogen are heated under conditions of high temperature and pressure, ammonia is formed. However, a sample of ammonia when heated produces nitrogen and hydrogen. Write an appropriate equation to represent this reversible system**1.**

Exercises on changes in concentration, pressure and temperatures

1 Complete the following table

System	Change	Direction of favoured reaction (→ or ←)
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$	increase $[SO_2]$	
$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$	decrease $[CO_2]$	
$AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$	increase $[Cl^-]$	
$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$	decrease volume	
$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$	decrease volume	
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$	increase volume	

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) + 99$ kJ	increase temperature	
$N_2(g) + O_2(g) + 180$ kJ $\rightleftharpoons 2NO(g)$	decrease temperature	
$AgCl(s) + 66$ kJ $\rightleftharpoons Ag^+(aq) + Cl^-(aq)$	decrease temperature	

2 If the reaction

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$$

is at equilibrium, predict the effect of the changes listed in a and b on:

i the concentrations of each species

ii the rates of the forward and reverse reactions.

a) adding more O_2 to the system

b) reducing the concentration of NO

3. The reaction for the production of water gas is:

$$C(s) + H_2O(g) \rightleftharpoons CO(g) + H_2(g)$$

If the system is at equilibrium, predict the effect of the changes listed in a and b on:

i the concentrations of all the species

ii the rates of the forward and reverse reactions.

a) Increasing the volume of the system

b) Increasing the pressure on the system

4 If the system

$$2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g) + 564\ kJ$$

is at equilibrium, predict the effect of the changes listed in a and b on:

i the concentrations of all the species

ii the rates of the forward and reverse reactions.

a) increasing the temperature

b) reducing the temperature

5. Consider the reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) + 99\ kJ$$

What would be the effect of adding a catalyst:

a before the system reached equilibrium

b after the system reached equilibrium

Explanations of key concepts

Reversible Reactions

Previously we have viewed reactions as proceeding from reactants to products. In many reactions, however, there is a significant reaction in the opposite direction in which the product molecules react to regenerate the reactants. Because of this, the terms ‘forward reaction’ and ‘reverse reaction’ are frequently used.

For example, if the reaction:

$$2HI(g) \rightarrow H_2(g) + I_2(g)$$

is described as the forward reaction, the reaction:

$$H_2(g) + I_2(g) \rightarrow 2HI(g)$$

Will be the reverse reaction. Frequently a double arrow is used as a way of indicating significant reversibility of a reaction. In the case of the reaction above this can be represented as follows:

$$2HI(g) \leftrightarrows H_2(g) + I_2(g)$$

When the reactants are placed in a closed container under appropriate reaction conditions, products begin to form by means of the forward reaction. As the concentrations of reactants decrease the rate of the forward reaction also decreases. This occurs because collisions between reactant molecules become less frequent. As soon as products begin to form the reverse reaction becomes possible. The reverse reaction rate, which was initially zero, will gradually increase as the concentrations of products increase. Eventually, the rates of the forward reaction and reverse reactions become equal and the system is said to have reached chemical equilibrium. When a system of two reversible reactions is at chemical equilibrium, no further observable changes are noted, unless the equilibrium is disturbed.

Equilibrium

- An equilibrium system is a closed system in which both the forward and reverse reactions occur simultaneously with equal rate and no macroscopic change to the system.
- An equilibrium system can involve a chemical or physical reaction

Le Chatelier’s principle

“ If a chemical system at equilibrium is subjected to a change in conditions, the system will adjust to re-establish equilibrium in such a way as to partially counteract the imposed change.”

<u>The factors that can affect the equilibrium in a reverse reaction include:</u>

1. <u>Changing the concentration of one or more of the species involved</u>

If the concentration of one of the reactants or products in an equilibrium system is changed and the temperature kept constant, Le Chatelier's principle predicts that the system will re-establish equilibrium in a way that partially counteracts the change. This means that increasing the concentration of one of the substances involved will cause the system to favour the direction that will decrease the concentration of that substance. Conversely, decreasing the concentration of a substance will favour the direction of reaction that leads to an increase in the concentration of that substance.

Note that in equilibrium systems that involve liquid or solid species, changing the quantity of the solid or liquid present has no effect on the position of equilibrium. This is because the concentrations of the solids and liquids present remain unchanged.

2. <u>Changing the temperature</u>

The effect of changing the temperature of equilibrium systems (when pressure or concentration are kept constant) can be predicted from a knowledge of the heats of reaction. If the temperature of a system is lowered, the exothermic reaction is favoured. If the temperature is increased, the endothermic reaction is favoured.

3. <u>Changing the total pressure acting upon a reaction that involves gases or changing the volume of gaseous species are present</u>

If the external pressure on a gaseous system is altered, it will change the volume of the system. An increase in pressure will lead to a decrease in the volume of the system, with a resulting increase in the concentrations of all the components. Conversely, decreasing the external pressure leads to an increase in the volume of the system and a resulting decrease in the concentrations of the components.

Where an equilibrium system contains equal numbers of gaseous molecules on both sides of the equation, changing the volume does not affect equilibrium. If the reaction

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

were at equilibrium and the volume of the system was decreased, this would lead to an immediate increase in the concentration of all the substances, but there would be no subsequent change in the relative amounts of each.

Appendix G6: You-tube links

- Introduction on chemical equilibrium:www.youtube.com/watch?v=yFqYrBxbURY

- Chemical equilibrium you-tube link:
  http://www.youtube.com/watch?v=d_NwW5kvVYk on NO_2/ N_2O_2 equilibria showing effect of change in temperature.

- *You-tube clip on the effect of temperature on equilibrium:*
  www.**youtube**.com/watch?v=0XQVXFL4uoo

- *You-tube clip of effect of pressure on chemical equilibrium:*
- www.youtube.com/watch?v=PxJbp1SzGjY