

Promoting conceptual change in chemical equilibrium through metacognition development: students' achievement and metacognitive skills

A Mensah
25612778

Thesis submitted for the degree *Doctor Philosophiae* in
Natural Science Education at the Potchefstroom Campus of
the North-West University

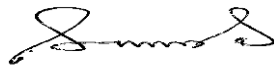
Promoter: Dr ON Morabe
Co-Promoter: Prof A Golightly

Final Copy October 2017

DECLARATION

I the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Mr A Mensah

A handwritten signature in black ink, appearing to read 'A Mensah', with a stylized flourish at the end.

Signature

7 June 2017

Date

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DEDICATION

This work is dedicated to the members of my family:

- My mother, Emma Tukpey, always supportive.
- My wife, Doris, for her unwavering support.
- My loving children: Abigail, Gregory and Emmanuel, who were understanding and supportive during this academic journey.

ABSTRACT

Poor student performance in the knowledge area of chemical equilibrium has been a challenge to most Physical Sciences students. The performance trend in this knowledge area has over the years been stagnant despite students' exposure to problem-solving practices. For that reason, the purpose of this study is to propose a framework that will promote achievement and metacognitive skills in chemical equilibrium among grade 12 Physical Sciences students.

The exploratory sequential mixed method research approach which involves an initial qualitative phase and a final quantitative phase was used. The qualitative phase explored students' learning difficulties on four chemical equilibrium problems using the think-aloud protocol. Four low achieving and three high achieving grade 12 Physical Sciences students were purposively sampled for the qualitative study. In the quantitative phase the hypotheses developed from the qualitative phase were tested through a pre-test/post-test quasi-experiment involving 35 students in the experimental group and 34 in the control group. The experimental group was taught through conceptual change instruction based on metacognition development method while the control group was taught through the traditional lecture method.

The chemical equilibrium achievement test (CEAT) and the chemical equilibrium metacognitive skills questionnaire (CEMS) were the instruments for data collection. The validity and reliability of these instruments were established in a pilot testing involving 207 grade 12 Physical Science students in the Mpumalanga province of South Africa prior to the main study.

Results from the qualitative phase revealed that metacognitive skills of low achieving students was unacceptable or low while high achieving students had relatively high levels of metacognitive awareness. The study also found that the factors influencing the use of cognitive strategies were: (1) mental model/declarative knowledge of chemical equilibrium (2) scientific reasoning (3) conditional knowledge (4) confidence judgement (5) metacognitive knowledge. Data for the quantitative phase of the study were analysed using ANCOVA statistics. Results revealed a significantly better performance of the experimental group in achievement in chemical equilibrium over the control group $F(1, 65) = 44,53$ $p < 0.0001$. The post-test mean score for the experimental group was 41.57% and for the control group it was 26.58%. Results also indicated a significant performance of experimental group over control group in metacognitive skills $F(1, 66) = 21.25$, $p < 0.0001$. The mean of post metacognitive skills for the experimental group was 3.13 and that of the control group was 2.69. The results of this study suggest that metacognitive development occurs

side by side with conceptual change. It is recommended that the development of metacognitive skills should form the bases of conceptual change instructional decisions.

Keywords

Constructivism, inquiry learning, approach to learning, chemical equilibrium, metacognition, conceptual change, students..

OPSOMMING

Swak leerderprestasie in die kennisarea van chemiese ewilibrum bied steeds 'n uitdaging aan die meeste Fisiese Wetenskap-leerders. Prestasie in hierdie area het oor baie jare onveranderd gebly ten spyte van die feit dat leerders aan probleemoplossingspraktyke blootgestel is. Dit het aanleiding gegee tot hierdie studie, wat poog om 'n raamwerk daar te stel wat prestasie en metakognitiewe vaardighede by graad 12 Fisiese Wetenskapleerders sal bevorder. Om hierdie doel te bereik is onderrig in konsepsuele verandering wat op metakognitiewe ontwikkeling gegrond is geïmplementeer.

Ondersoekende opeenvolgende gemengdemetode navorsing is gebruik, wat 'n inisiële kwalitatiewe en finale kwantitatiewe metode behels het. Die kwalitatiewe fase het leerders se leerprobleme met vier chemiese ewilibrumprobleme ondersoek deur die hardop-dinkmetode te gebruik. Vier swak-presterende en drie goed-presterende leerders in graad 12 Fisiese Wetenskap is as doelgerigte steekproef gebruik vir die kwalitatiewe studie. In die kwantitatiewe fase is die hipotese wat uit die kwalitatiewe fase ontwikkel het getoets deur 'n voortoets/natoets kwasi-eksperiment wat met 35 studente in die eksperimentele groep en 34 leerders in die kontrolegroep uitgevoer is.⁶⁹ Fisiese Wetenskapleerders uitgevoer is.

Die chemiese ewilibrum-prestasietoets (CEAT) en die chemiese metakognitiewe vaardigheidsvraelys (CEMS) was instrumente vir data-insameling. Die betroubaarheid en geldigheid van instrumente is voor die hoofstudie bepaal in 'n loodstoets wat 207 graad 12 Fisiese Wetenskapstudente in die Mpumalangaproovinsie van Suid-Afrika betrek het.

Resultate van die loodstoets het getoon dat die metakognitiewe bewustheid van swakpresterende studente onaanvaarbaar of laag was, terwyl goedpresterende student relatief hoë vlakke van metakognitiewe bewustheid getoon het. Die studie het ook gevind dat die volgende faktore die gebruik van kognitiewe strategieë beïnvloed het: (1) geestelike model/voorafkennis van chemiese ewilibrum; (2) wetenskaplike redenering; (3) voorwaardelike kennis; (4) oordeelsvertroue; (5) metakognitiewe kennis.

Data vir die kwantitatiewe fase is geanaliseer deur van ANCOVA-statistiek gebruik te maak. Resultate het aangedui dat die eksperimentele groep beduidend beter presteer het in chemiese ewilibrum as die kontrolegroep $F(1, 65) = 44,53$ $p < 0.0001$. Die post-test gemiddelde punt vir die eksperimentele groep was 41.56 en vir die kontrolegroep 26.58%. Resultate het verder aangedui dat die eksperimentele groep beduidend beter presteer het in metakognisie-vaardighede as die

kontrolegroep $F(1,66) = 21,25$, $p < 0.0001$. Die gemiddelde van metakognitiewe vaardighede vir die eksperimentele groep was 3.13, en vir die kontrolegroep 2.69. Die resultate van hierdie studie toon aan dat metakognitiewe ontwikkeling sy aan sy met konsepsuele verandering plaasvind; gevolglik word aanbeveel dat die ontwikkeling van metakognitiewe vaardighede die basis behoort te vorm van onderrigbesluite oor konsepsuele ontwikkeling.

H C Sieberhagen

SATI no 1001489

Hettie.Sieberhagen@nwu.ac.za

Translator and Editor

082 3359846

018 2994554

CERTIFICATE OF LANGUAGE EDITING

issued on 15 May 2017

I hereby declare that I have edited the language of the thesis

***Promoting conceptual change in a chemical
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by

A Mensah

Student number 25612778

submitted for the degree

Doctor Philosophiae in Natural Science Education

at the Potchefstroom Campus of the

North-West University

The responsibility to accept recommendations and effect changes remains with the author



H C Sieberhagen

SATI no 1001489

ID 4504190077088

Potchefstroom 15 May 2017



NORTH-WEST UNIVERSITY
YUNIBESITHI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Private Bag X6001, Potchefstroom,
South Africa, 2520

Tel: (018) 299-4900

Faks: (018) 299-4910

Web: <http://www.nwu.ac.za>

Institutional Research Ethics Regulatory Committee

Tel: +27 18 299 4849

Email: Ethics@nwu.ac.za

2016-08-02

ETHICS APPROVAL CERTIFICATE OF STUDY

Based on approval by the Ethics Committee of the Faculty of Education Sciences (ESREC) on 01/08/2016, the North-West University Institutional Research Ethics Regulatory Committee (NWU-IRERC) hereby approves your study as indicated below. This implies that the NWU-IRERC grants its permission that provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: The 7E instructional model: a teaching and learning approach to develop deep learning and metacognition of chemical equilibrium.			
Study Leader/Supervisor: Dr N Morabe			
Project Team: Mr A Mensah & Prof A Golightly			
Ethics number:	N	W	U - 0 0 2 4 6 - 1 6 - A 2
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	Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation		
Application Type: N/A	Commencement date: 2016-08-01		Expiry date: 2017-12-01
	Risk:		N/A

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 - without any delay in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.
 - Annually a number of projects may be randomly selected for an external audit.
- The approval applies strictly to the proposal as stipulated in the application form. Would any changes to the proposal be deemed necessary during the course of the study, the study leader must apply for approval of these changes at the ESREC. Would there be deviated from the study proposal without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.
- The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date, a new application must be made to the NWU-IRERC via ESREC and new approval received before or on the expiry date.
- In the interest of ethical responsibility the NWU-IRERC and ESREC retains the right to:
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 - to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process.
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 - it becomes apparent that any relevant information was withheld from the ESREC or that information has been false or misrepresented,
 - the required annual report and reporting of adverse events was not done timely and accurately,
 - new institutional rules, national legislation or international conventions deem it necessary.
- ESREC can be contacted for further information or any report templates via Erna.Conradie@nwu.ac.za or 018 299 4656

The IRERC would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the IRERC or ESREC for any further enquiries or requests for assistance.

Yours sincerely

Prof LA
Du Plessis

Digitally signed by
Prof LA Du Plessis
Date: 2016.08.04
08:53:42 +02'00'

Prof Linda du Plessis

Chair NWU Institutional Research Ethics Regulatory Committee (IRERC)

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DEFINITION OF TERMS

Constructivism

Constructivism is the learning theory that filters through a number of developments in science education. The theory describes knowledge as not truths to be discovered or transmitted, but as emergent, developmental, non-objective viable constructed explanations by humans engaged in meaning-making in cultural and social communities of discourse. (Fosnot, 2005).

Conceptual change

Conceptual change is a term used in the literature to refer to learning from the constructivists' view. It refers to the evolution of students' ideas about a phenomenon as they engage in construction of knowledge (diSessa, 2002). Vosniadou (2008, p.279) considers conceptual change as “opening up of conceptual space through increased meta-conceptual awareness and epistemological sophistication, creating the possibility of entertaining different perspectives and different point of views. Another term used to denote conceptual change is development of conceptual knowledge (Soulios & Psillos, 2016,). Conceptual change instruction in this study is any instructional approach that promotes conceptual change.

Inquiry learning

Inquiry (or enquiry) is a common terminology in many science curricula. Although inquiry in school science curriculum can be traced to as far back as H E Armstrong (Harlen,1999), up till now, the term has no precise definition. In this thesis, inquiry is viewed from the US National Science Education Standards'(NSES) perspective because the description of inquiry by the South African Physical Sciences curriculum document in which this research study is contextualised is consistent with the NSES' interpretive framework of inquiry. The US National Science Education Standards describe inquiry as “a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyse, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking and consideration of alternative explanations” (National Research Council, 1996 p.23). The term inquiry is also described as “instructional strategies and the processes of learning associated

with the activities oriented to inquiry” (Bybee, Powell, & Trowbridge, 2008, p. 55). Recently the National Research Council (2012, p. 44) has considered inquiry as a set of practices with a focus on important practices, such as modeling, developing explanations, and engaging in critique and evaluation i.e. argumentation.

Chemical equilibrium

Chemical equilibrium is a theory which explains chemical reactions based on three ideas: incomplete reactions, reversibility and dynamism (Quilez, 2009). The theory maintains that in a closed system, reactants are not completely used up to form products; but that as products are formed, they decompose to form back reactants. The two opposing reactions occur continuously, even when at the observable level no reaction seems to be happening.

Approach to learning

Approach to learning can be much wider than deep or surface learning (e.g. cognitive approach to learning, behaviourist approach to learning), but for the purpose of this study the focus was on deep and surface learning (Biggs, Kember, & Leung, 2001). Warren (2004, p.9) explains deep and surface learning as “deep learning involves the critical analysis of new ideas, linking them to already known concepts and principles, and leads to understanding and long term retention of concepts so that they can be used for problem solving in unfamiliar contexts. Deep learning promotes understanding and application for life. In contrast, surface learning is the tacit acceptance of information and memorisation as isolated and unlinked facts. It leads to superficial retention of material for examinations and does not promote understanding or long term retention of knowledge and information.”

Metacognition

Metacognition was originally referred to as the knowledge about and regulation of one’s cognitive activities in learning processes (Flavell, 1979; Brown, 1987). Under the umbrella of this inclusive definition a proliferation of metacognitive terms has unfolded through the years. Although there has not been consensus on the defining attributes of metacognition, there are commonalities that reveal a conceptual convergence of the different terms that have been used to describe the construct. These commonalities are that individuals make efforts to monitor their thoughts and actions and act accordingly to gain some control over them (Dinsmore, Alexander, & Loughlin, 2008), i.e. thinking about the thinking process.

Students

The word learner generally refers to someone who learns something. A student is someone who is learning when attending an educational institution. In some nations, the English term is reserved for those who attend university, while a school child under the age of eighteen is called a pupil in English (or an equivalent in other languages), although in the United States a person enrolled in grades K-12 is often called a student (<http://www.personalizelearning.com/2013/04/students-not-students.html>). Students in this research refer to those students who study Physical Science as one of the subjects at the FET level (Grade 10 to 12) in South African schools.

CHAPTER ONE: ORIENTATION, PROBLEM STATEMENT AND FOCUS OF THE STUDY

1.1 INTRODUCTION

This chapter introduces the study, which examines an overarching research question: To what extent does the implementation of conceptual change instruction based on metacognition development promote achievement and metacognition of grade 12 Physical Sciences students in Mpumalanga? This chapter presents the background to the problem and the motivation for this study. This is followed by a brief review of the body of scholarship, problem statement, and the research questions which informed the chosen methodology. The researcher also presents an overview of the research design, methodology and methods. An overview of the pilot testing of research instruments is also presented in this chapter. Finally, this chapter concludes with a layout of the chapter divisions as contained in this thesis.

1.2 BACKGROUND TO THE PROBLEM

There has been a growing concern among science education researchers about effective strategies for teaching scientific knowledge and skills so that students can learn science in a deep and meaningful way and be able to use scientific knowledge in solving problems that humans encounter in their lives. Over the past few decades, science education has experienced a major paradigm shift due to influences from the constructivist learning theory and this has revolutionised the manner in which teachers should teach science and how students are expected to learn. A group of new teaching and learning strategies which define learning as an “active process in which students are active sense makers who seek to build coherent and organised knowledge” has emerged (Mayer, 2004, p. 14). The constructivist learning theory acted as a source for the development of these learner-centred teaching approaches (Hannafin, Hill, & Land, 1997), which are described by Cannon and Newble (2000, p. 16) as “ways of thinking about teaching and learning that emphasise learner responsibility and activity in learning rather than content or what the teachers are doing”. Characteristics of these learner-centred teaching strategies are: (1) activity and independence of the student, (2) a facilitating role of the teacher, and (3) knowledge which is regarded as a tool instead of an aim (Dochy, Segers, Gijbels, & Van den Bossche, 2002). While student-centred teaching strategies can take many different teaching forms in practice as is illustrated above, one recurring aim is fostering deep learning and understanding (Hannafin et al., 1997; Lea, Stephenson, & Troy,

2003; Mayer, 2004) which has now become a key issue in contemporary science curriculum practice.

In South Africa, the first attempt to formally introduce student-centred education in public schools was the 2005 curriculum reforms commonly known as Outcomes Based Education (OBE). Though OBE was hailed by policy makers as a panacea for the poor quality of education in South Africa, its implementation soon revealed a number of constraints including structural inequality, poverty and lack of sufficient support resources in the majority of schools (Spren & Vally, 2010). Spren and Vally (2010) opine that student-centred education has not been implemented in South Africa since these and other important interventions such as teacher training to operate in a student-centred learning and teaching context have not been achieved.

According to Barry (2014), a quarter of the 184 383 students who wrote Physical Science in the 2013 examinations achieved a mark of 50% and above, and only 14,4% obtained 60% and above. Moreover, many of the Physical Sciences candidates, including the A candidates, could not express themselves clearly in questions that require explanation. Despite the existence of several teaching and learning strategies that could guarantee quality teaching and learning, the quality of passes in key subjects such as Mathematics and Physical Sciences, amongst others, is still below desirable levels.

1.3 MOTIVATION FOR THE STUDY

The specific aims of Physical Science in a South African context according to the Curriculum and Assessment Policy Statement (CAPS) include: promoting in students' knowledge and skills in scientific inquiry and problem solving; the construction and application of scientific knowledge; an understanding of the nature of science (NOS) and its relationship to technology, society and environment (Department of Basic Education [DBE], 2011). These aims are consistent with the constructivist view of teaching and learning, and according to the CAPS, should be achieved through the use of student-centred teaching strategies (Department of Basic Education, 2011). Basson and Kriek's (2012) research indicates that, although Physical Science teachers are positive about the content of the CAPS, teachers' lack of training, inadequate support in terms of lesson preparation and resources, as well as the lack of teachers' subject content knowledge and pedagogical content knowledge, particularly in rural and township schools, present serious challenges to the implementation of the CAPS. As a result of these challenges, when Physical

Science teachers attempt to implement student-centred lessons, they end up teaching the traditional way (Ramnarain, 2015).

The percentage of grade 12 Physical Sciences students who achieved at 40% and above in 2011, 2012 and 2013 respectively, were 33.8%, 39.1% and 42.7% in Physical Sciences (Department of Basic Education, 2013). While these statistics generally show an upward trend in overall passes, analysis of performance in individual knowledge areas over the same period does not show a predictable pattern. However, one thing that comes to light is that chemical equilibrium continues to remain among the worst performed knowledge areas in Physical Science's Paper 2 (DBE, 2011; 2012; 2013). According to the National Senior Certificate examination diagnostic reports, the respective average marks in chemical equilibrium questions for 2011, 2012 and 2013 were 31%, 44, 4% and 30, 5% respectively (DBE, 2011; 2012; 2013), all of which indicate poor performances.

Similarly, the Mpumalanga Department of Education diagnostic reports have also indicated poor performances in this knowledge area, stating the student average marks in 2008, 2010, 2013 and 2014 respectively as 18%, 22.5%, 29.4% and 26.6%, all of which represent no achievement or total failure (Mpumalanga Department of Education, 2009; 2011; 2014; 2015). The difficulties identified in both the National diagnostic reports and the Mpumalanga Provincial diagnostic reports were similar. They included students' inability to set up correct K_c (Equilibrium constant) expressions, failure to mathematically manipulate the K_c equation to solve for an unknown concentration of a reactant, interpretation of K_c values and problems with using Le Chatelier's principle to explain the effect of changes in equilibrium conditions on the equilibrium system (DBE, 2011; 2012; 2013 and Mpumalanga Department of Education, 2009; 2011; 2014; 2015).

Studies on students' understanding of chemical equilibrium worldwide have revealed a number of limitations to the learning of chemical equilibrium. These limitations include students' alternative conceptions relating to the nature of chemical equilibrium and poor understanding of the equilibrium law (Solomonidou & Stavridou, 2001), confusion between rate and equilibrium (Banerjee, 1991) and poor understanding of the effects of catalysts, temperature and concentration on equilibrium reactions (Cheung, 2009; Özmen, 2008; Quílez, 2004;). Other studies attributed the persistence of alternative conceptions in chemical equilibrium to problematic language used in chemistry textbooks or misleading representations which may reinforce the alternative conceptions in students' cognitive framework (Pedrosa & Dias, 2000).

According to Furio, Calatayud, Barcenas and Padilla (2000), conceptual change as a deep restructuring occurs not only in the ideas but also in the ways of reasoning, and it is not enough to

take into account students' previous ideas. Indeed, historical and epistemological analyses of theory formation suggest that a paradigm change is not easy, nor can it be reduced to changes that happen exclusively in concepts. In general, these conceptual changes are associated with epistemological and methodological changes, such as new ways of reasoning and new approaches for solving scientific problems.

Besides the barriers to deep learning of chemical equilibrium caused by alternative conceptions, Kousathana and Tsaparlis (2002) identified random errors made by students during problem solving in chemical equilibrium, and attributed these errors to thoughtlessness, or hastiness, or field dependence-independence, or overload of working memory, or a combination of these factors. Furio et al. (2000) use the terms "functional fixedness" and "functional reduction" to explain the defects in procedural reasoning used by students when solving chemical equilibrium problems. Functional fixedness may be referred to as excessive reliance on a problem-solving strategy driven by a need to arrive at the final answer without paying attention to the soundness of the procedure. Functional reduction is defined as a tendency to reason without taking into account all the possible variables that may influence the solution of a problem. These indicate that there is more to students' difficulties regarding learning chemical equilibrium than what perspectives on conceptual change suggest.

1.4 OVERVIEW OF CONCEPTUAL CHANGE IN SCIENCE EDUCATION

Conceptual change research in science education dates back to the 1970s, with a focus on exploring students' misconceptions on science concepts. Following the pioneering work of Posner, Strike, Hewson and Gertzog (1982), the focus of conceptual change research shifted to addressing students' misconceptions through conceptual change instruction. The teaching models developed immediately were based on cognitive conflict strategies (Scott, Asoko, & Driver, 1991), and a number of conceptual change studies have used this approach. Cognitive conflict strategies were based on Piaget's notion of assimilation and accommodation and involve eliciting students' preconceptions and challenging their misconceptions with anomalous data (Posner et al, 1982). Drawing examples from history of science, psychology and education, Chinn and Brewer (1993) argue that response to anomalous data may occur in seven ways: ignoring, rejecting, excluding, abeyance, reinterpreting, peripheral change and theory change. Given the various possibilities of students' responses to anomalous data, the chances of achieving conceptual change through cognitive conflict resolution strategies are limited. Further, criticism of Posner et al.'s (1982) model of conceptual change (Strike

& Posner, 1992) rendered the cognitive conflict strategy theoretically less effective. In response, a number of cognitive models of conceptual change were proposed (Chi & Roscoe, 2002; diSessa, 1993; Vosniadou, 1994). However, critics from the sociocultural perspective argue that conceptual change is not only an internal cognitive process but one that happens in broader situational, cultural, and educational contexts and is assisted by the use of the relevant cultural tools and artifacts (Ivarsson, Schoultz & Säljö, 2002). This leads to the interpretation of conceptual change from multiple perspectives involving cognitive and affective aspects (Treagust & Duit, 2009). It has been observed, however, that actual science classroom practice is far from what conceptual change perspectives propose (Duit & Treagust, 2012). This situation may be due to frustrations for lack of effect on students' learning (Wenning, 2008). Many of the difficulties found in the application of the conceptual change approach in the classroom were related to the complexity of factors intervening in the context of school learning, which conceptual change models do not take into account (Limon, 2001). Indeed, most of the theoretical models propose to explain conceptual change focused mainly on the individual's cognitive processes, not taking into account other individual's characteristics, such as motivation, learning strategies, epistemological beliefs and attitudes. Emerging views on conceptual change consider metacognition as a potential mediator for improvement in conceptual change learning, arguing that improved metacognitive skills are essential for durable and transferable conceptual change learning (Georghiades, 2000; Gunstone, & Mitchell, 1998; Yuruk, Ozdemir, & Beeth, 2003).

Metacognition has been found to be a significant contributor to success in mathematical problem solving (Kramaski, 2004; Mevarech & Kramaski, 2003). The importance of metacognition in learning and problem solving in many different fields has been discussed (Pintrich, 2002). Studies have specifically emphasised the relevance of metacognition in chemistry education (Rickey & Stacy, 2000; Tsai, 2001; Schraw, Brooks, & Crippen, 2005) and have described it as "a key to deeper, more durable, and more transferable learning". Addressing the development of metacognitive knowledge by students in Physical Science teaching is, however, almost absent.

Inquiry as a teaching and learning strategy can give students opportunity to practise metacognitive skills when planned and implemented properly (Kipnis & Hofstein, 2008). When students are involved in an inquiry process that includes all the inquiry skills (e.g. problem identification, formulation of hypothesis, designing experiment, gathering data, analysing data and drawing conclusion about problems and scientific phenomena) in small collaborative groups, they are encouraged to think critically, ask questions and regulate one another's thoughts through

argumentation, especially when data gathered do not support students' hypotheses (Katchevich, Mamlok-Naaman, & Hofstein, 2014).

1.5 PROBLEM STATEMENT

Students' poor performance in chemical equilibrium have been attributed to students' alternative conceptions (Mohideen, Karunaratne & Wimalasiri, 2011; Quilez, 2004), but it is also known that learning is influenced by the learning orientation of students (Zou, Li, Chen, Zhong, & Wang, 2014) and the metacognitive skills at students' disposal (Bodner & Herron, 2002). Feedback from the grade 12 national examinations has recommended giving students more problems to solve, conducting practical work, and conducting content enrichment workshops for teachers on this topic as a solution to the poor performance of students on this topic (Mpumalanga Department of Education, 2009, 2011, 2014 & 2015). These recommendations suggest the implementation of a teaching and learning framework that is student-centred in approach and targeted towards addressing several learning outcome variables concurrently. Owing to lack of such teaching and learning framework, interventions intended to improve performance of students in chemical equilibrium in the Bohlabela district of Mpumalanga province have been implemented in an ad hoc manner, usually on the assumption that teachers' content knowledge on this topic is not sound, without a consideration of other factors that affect learning. For example, teachers are workshopped on content knowledge without being taught more effective methods for delivering content to students; practical work is conducted without any link to science concept learning; and students are often encouraged to practise how to solve more problems in chemical equilibrium without being taught explicitly useful metacognitive skills for self-regulation in independent problem solving. The consequence has been that the performance of Physical Sciences students in this topic continues to remain poor, as shown in the diagnostic reports of matric examinations (Mpumalanga Department of Education, 2009, 2011, 2014 & 2015).

Previous studies in chemical equilibrium have mostly focused on identifying and repairing students' misconceptions based on the assumption that students' conceptual understanding will improve when alternative conceptions are addressed through conceptual change instruction. However, as suggested by Furio et al. (2000) and Kousathana and Tsaparlis (2002), conceptual change is associated with epistemological and methodological changes. In other words, restructuring students' ideas without a corresponding restructuring of views of knowledge and methods of learning will only lead to what Georghiades (2000) refers to as conceptual correlation, i.e. where new conceptions are only applied to the contexts within which they were acquired. Moreover, according to constructivism, knowledge

is constructed by the student and not transmitted (Von Glasersfeld, 1995), therefore if students' ideas about a phenomenon are inadequate, then the knowledge construction process that yielded those ideas should be questioned.

Although the development of learning strategies is at the heart of a student-centred teaching approach, research studies (e.g. Bilgin & Geban, 2006) measuring impact of student-centred teaching approaches in the Physical Sciences have reported an impact on learning outcomes expressed in terms of academic achievement and/or conceptual understanding, leaving the reader to make inferences about the impact on learning strategies. Since the findings generally suggest positive impact on achievement and/or conceptual understanding, the inferences about effect on learning strategies will obviously be positive. In contrast to this expectation, studies investigating this relationship have produced mixed results. Some researchers (Kember, Leung, & McNaught, 2008) have shown that students taking courses in arts subjects score significantly higher on deep learning approaches than students taking courses in science subjects, even when controlled for workload. A possible explanation for the mixed results regarding the effect of student-centred teaching approaches on learning strategies may be that the operationalisation of deep and surface learning approaches on measuring instruments (e.g. questionnaires) may be at variance with the theoretical constructs. This needs to be investigated.

1.6 RESEARCH QUESTIONS/HYPOTHESIS, AIM AND OBJECTIVES

1.6.1 Research questions

This study proposes a framework for the implementation of conceptual change instruction in Physical Science Education within the FET phase. In order to do so, the study was guided by the following overarching research question: To what extent does the implementation of conceptual change instruction based on metacognition development promote chemical equilibrium achievement and metacognitive skills of grade 12 Physical Science students in Mpumalanga? To answer the primary question, three secondary questions were addressed:

1. What is the level of metacognitive skillfulness of grade 12 Physical Science students in solving chemical equilibrium problems?
2. What factors influence students' use of cognitive strategies in solving chemical equilibrium problems?

3. How well do the two measures of learning strategy (learning approach and metacognitive skills) predict achievement in chemical equilibrium based on CEAT scores? How much variance in chemical equilibrium achievement can be explained by scores on these two scales?
4. How can conceptual change instruction be effectively implemented in Physical Sciences to foster deep learning and the development of metacognitive skills?

1.6.2 Research hypotheses

In addition to the research questions, the following hypotheses were tested:

1. Students taught chemical equilibrium through the conceptual change instruction based on metacognition development will:
 - a) achieve significantly better in chemical equilibrium than students taught through the traditional teacher centred approach; and
 - b) develop significantly better metacognitive skills in chemical equilibrium than students taught through the traditional teacher centred approach.
2. Conceptual change instruction based on metacognition development will narrow the achievement gap between high and low achievers in chemical equilibrium.
3. Conceptual change instruction based on metacognition development will not narrow the metacognitive skills gap between high and low achievers.

1.6.3 Aim and objectives

The central aim of this study was to determine the extent to which conceptual change instruction based on metacognition development can promote deep learning and metacognition in chemical equilibrium. The objectives of this study were to:

- 1) determine the level of Physical Science students' metacognitive skilfulness in solving chemical equilibrium problems;
- 2) identify the factors that influence students' use of cognitive strategies in answering high order questions in chemical equilibrium;
- 3) determine how well chemical equilibrium achievement can be explained by the chemical equilibrium metacognitive skills questionnaire (MCAI-CE) and the revised two-factor study process question (R-SPQ-2F);
- 4) determine the effect of conceptual change instruction modelled on metacognition development on students' achievement in chemical equilibrium and the development of metacognitive skills in learning chemical equilibrium, and

- 5) develop a framework for the effective implementation of conceptual change instruction in Physical Sciences to foster deep learning and develop students' metacognition.

1.7 RESEARCH DESIGN AND METHODS

1.7.1 Research design

An exploratory sequential mixed method research design was employed to investigate the extent to which conceptual change instruction based on metacognition development can promote deep learning and metacognition in learning chemical equilibrium. Mixed method research is defined as “the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods approaches, concepts or language into a single study” (Johnson & Onwuegbuzie, 2004, p. 17).

1.7.2 Methodology

The methodology of this study was informed by the pragmatist philosophy. Pragmatists are concerned with “what works” and with solutions to problems (Creswell, 2007, p.22). Thus, instead of a focus on methods, the most important part of research is the problem being studied and the questions asked about this problem. This study used multiple qualitative and quantitative methods of data collection to best answer the research question, and employed multiple participants. In this study qualitative and quantitative approaches were used to address the different aspects of the research problem.

1.7.3 Sampling strategy

1.7.3.1 Qualitative research

Seven Physical Science students from the Mathematics, Science and Technology (MST) FET schools who volunteered to participate were sampled for the qualitative phase of the study. According to Ritchie, Lewis and Elam (2003), qualitative research seeks for in-depth account of the phenomenon being studied and therefore yields information that is rich and detailed. Generating and analysing data from large samples may compromise the rigorousness of the qualitative procedure, or is simply unmanageable. While at the same time observing more than one participant, enables the researcher to observe a wider range of responses (Charters, 2003). Subsequently, using a sample of seven students enabled a wider range of the phenomenon (metacognitive skills and students' difficulties in solving chemical equilibrium problems) to be observed while keeping the sample within manageable levels.

1.7.3.2 Quantitative research

For the quasi-experimental study, two Physical Science classes (70 students) in the public schools in the category of Mathematics, Science and Technology (MST) secondary schools in the Bohlabela district of South Africa were selected, based on ease of access by the researcher (Ritchie, Lewis & Elam, 2003). The two selected classes were randomly assigned to experimental and controlled groups of thirty-five (35) students each. Random assignment of classes to experimental and controlled groups was obtained by tossing a coin. Five (5) MST secondary schools from the Bohlabela district were conveniently sampled to participate in the pilot testing of research instruments.

1.7.4 Methods of data generation

1.7.4.1 Qualitative research.

The qualitative research used the think-aloud protocols (TAP) approach to investigate students' difficulties in solving chemical equilibrium problems. In the think-aloud method, "the subject is asked to talk aloud while solving a problem, and this request is repeated if necessary during the problem-solving process, thus encouraging the subject to tell what he or she is thinking" (Van Someren, Barnard & Barnard, 1994, p. 26). Students were given four chemical equilibrium tasks to perform and think aloud so that their cognitive processes and metacognitive skills could be observed. Field work in this qualitative phase of the study lasted for a week. All think-aloud sessions were video recorded and stored electronically on a computer hard drive.

1.7.4.2 Quantitative research

Prior to the implementation of the intervention, the Chemical Equilibrium Metacognitive Activity Inventory (MCAI-CE) and a Chemical Equilibrium Achievement Test (CEAT) were administered as pre-tests. Following the pre-tests, the experimental and controlled groups were taught chemical equilibrium by the researcher. The experimental group was taught by the conceptual change based on metacognition development approach, while the control group was taught using the traditional teacher-centred approach. The teaching of chemical equilibrium lasted for two weeks. After the teaching, a post-test was administered to both experimental and control groups. However, the control group was exposed to the conceptual change instruction based on metacognition development after scoring the post-test. Data collection in this phase lasted for four weeks. The CEAT was scored by the researcher using a marking memorandum, after which two moderators

scored the test to check for consistency in marking. The marks were stored both in a hard copy form and electronically on the computer. Data obtained using the MCAI-CE were entered on a SPSS spread sheet in form of codes.

1.7.5 Methods of data analysis

1.7.5.1 Qualitative methods

Students' think-aloud protocols were analysed by transcribing protocols into texts and segregating them into episodes. Students' chemical equilibrium problem-solving strategies were analysed by developing coding schemes and using these to code think-aloud protocol episodes. The level of metacognitive skillfulness was assessed by using a three-point rubric indicating unacceptable, low and high levels of awareness. Trustworthiness of the analysis was ensured by computing percentages of intercoder agreements. Errors committed while solving chemical equilibrium problems were analysed using Kousatha and Tsapalis' (2000) classification schemes for problem solving errors.

1.7.5.2 Quantitative methods

Quantitative data were analysed using statistical techniques such as means and standard deviations, *t*-test, multiple regression and ANCOVA. Independent *t*-test was used to compare pre-test means scores of experimental and control groups. Multiple linear regressions were used to determine how well learning approach and metacognitive abilities predict academic achievement in learning of chemical equilibrium. The effect of conceptual change instruction based on metacognition development on students' achievement in chemical equilibrium and metacognitive skills was analysed using one-way ANCOVA with the Physical Science achievement scores and metacognitive skill as the covariates, teaching strategy as the independent variable and the post-test as the dependent variable. ANCOVA is appropriate for this data analysis because it controls for any difference in pre-test scores as a result of non-randomization of subjects in the experimental and controlled groups (Pallant, 2011). Cronbach's alpha was used to determine the reliability of the R-SPQ-2F, CEAT and MCAI-CE. All statistical analyses were done. Practical significance of the conceptual change instruction based on metacognition development was determined by computing Eta Square and interpreted using Cohen's (1988) criteria.

1.8 DEVELOPMENT AND TESTING OF INSTRUMENTS

All the three research instruments (CEAT, MCAI-CE & R-SPQ-2F) were pilot tested using a sample of students with similar characteristics as those of the actual study. During the pilot test, a sample of students were given CEAT to write and then later MCAI and R-SPQ-2F. Reliability of the instruments were determined by using Cronbach's Alpha (Pallant, 2011) Items that did not seem to be reliable enough were deleted. According to Pallant, Cronbach Alpha values below 0.7 are considered unacceptable.

1.8.1 The Chemical Equilibrium Achievement Test (CEAT)

The CEAT was constructed by the researcher. The test items were based on students' alternative conceptions and difficulties in learning chemical equilibrium identified in the literature (e.g. Ozmen, 2008; Tyson, Treagust & Bucat, 1999) and chemical equilibrium items in past matric questions that were very poorly answered. The test covered all content aspects of chemical equilibrium as prescribed in the Physical Sciences CAPS document (DBE, 2011). It consists of 21 two-tier multiple choice items on concepts of chemical equilibrium and six (6) essay type questions based on equilibrium graph interpretations, and calculations involving K_c . Content validity was addressed by using a test table of specification.

1.8.2 The Chemical Equilibrium Metacognitive Activity Inventory (MCAI-CE)

The chemical equilibrium metacognitive activity inventory (MCAI-CE) used in this study was developed by adapting the metacognitive activity inventory (MCAI) developed by Cooper and Sandi-Urena (2009). The MCAI was originally developed for use in the university and consists of items with words or sentence structure that may be too difficult for high school students to understand. Moreover, the items were written in general terms and one had to imagine learning a specific subject or topic to be able to respond to an item appropriately. The adaptations effected included increasing the number of items from 28 to 32, restructuring some of the items, omitting difficult words and replacing with simpler ones and making each item specific to the learning of chemical equilibrium.

1.8.3 The Revised Study Process questionnaire (R-SPQ-2F)

The R-SPQ-2F was developed by Biggs et al. (2001) and consists of 20 items measuring learning approach in general. It was validated using a sample of university students, so some of the items contain words such as lectures, lecturers, course outline readings, which are applicable at the

university but can confuse high school students. These words were replaced with more appropriate ones. For instance, lecturers was replaced by teachers; lectures by lessons; course outline by work schedule; and readings by textbooks/study guides. R-SPQ-2F was modified to be topic-specific because it has been shown that learning approach is discipline-specific (Jones, Reichard, & Mokhtari, 2003) and could probably be topic-specific. For example, in the original instrument, the sentence “I find that studying academic topics can at times be as exciting as a good novel or movie” was adapted to read “I find that studying chemical equilibrium can at times be as exciting as a good novel or movie.” Each of the 20 items was rewritten to reflect the topic the student would be thinking about while responding to the items.

1.9 CHAPTER DIVISIONS

The outlines of the remaining chapters of this thesis are as follows:

Chapter 2: Chemical equilibrium and conceptual change. Research on chemical equilibrium and learning and teaching chemical equilibrium is discussed in order to support reconceptualisation of conceptual change.

Chapter 3: Metacognition and learning. Chapter 3 places this study within a broader perspective of deep learning, discusses issues relating to metacognition, including its meaning, development, measurement and its role in leaning.

Chapter 4: Conceptual instruction in science education. Conceptual change instruction in science education focusses on using inquiry-based instructional approaches to promote conceptual change. The meaning and role of inquiry in Science education, models of inquiry instructional strategies as well as its limitations, are explored in chapter 4.

Chapter 5: Research methodology. The methodology of this study is justified and explained in detail.

Chapter 6: Presentation of data and analysis. This chapter presents the analysis of data and the results of the study.

Chapter 7: Discussions and interpretations. In this chapter discussions and interpretations extract meaning from the findings of the study.

Chapter 8: Conclusions. Conclusions are drawn, and the chapter provides a summary of the entire study.

Figure 1.1. shows a map of review of literature in this study. As indicated in Figure 1.1, chapters 2, 3 and 4 consist of review of literature that informed the conceptual framework and the methodology of this study.

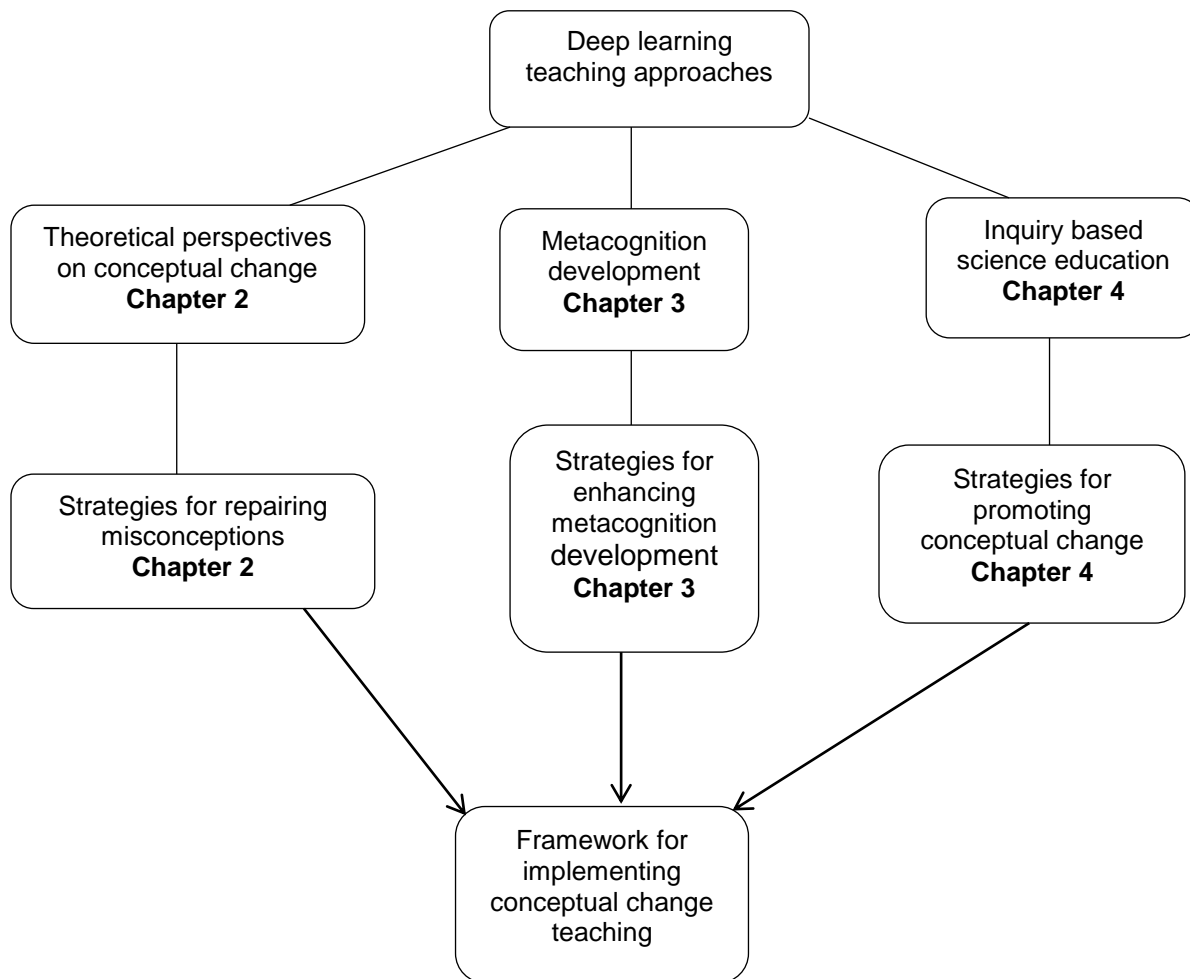


Figure 1.1: literature review map.

1.10 SUMMARY

This chapter presented the orientation and overview of the thesis structure. The motivation for this study provided the contextualisation for the work, and presented the problem statement, research questions/hypothesis and aims and methodology. This section was concluded by a description of the chapter division. In chapter two, the effect of conceptual change on learning chemical equilibrium and the implications on theoretical perspective on conceptual will be discussed.

CHAPTER TWO: CONCEPTUAL CHANGE AND CHEMICAL EQUILIBRIUM

2.1 INTRODUCTION

This chapter presents a thorough literature review on conceptual change instruction used for teaching chemical equilibrium. The aim is to establish the design of conceptual change intervention that will be most likely to benefit students and teachers of Physical Science. The chapter begins with a discussion on the theoretical perspectives on conceptual change and then addresses ontological and epistemological issues, and their implications for conceptual change models. The discussion also delves into early studies in chemical equilibrium to gain insight into students' difficulties in learning chemical equilibrium. The researcher then presents a synthesis and analysis of conceptual change studies in chemical equilibrium to support a metacognition development approach to conceptual change learning. The chapter concludes by arguing that multifariousness of conceptual change intervention was key to the development of more holistic metacognition and improved conceptual change learning.

2.2 THEORETICAL PERSPECTIVES ON CONCEPTUAL CHANGE

Since the middle of the 1970s, research has shown that students have intuitive or naïve ideas about scientific phenomena, which have been labelled “misconceptions”, “alternative conceptions”, “alternative frameworks”, “naïve theories”, etc. in the literature. These ideas interfere with students' learning of school science and produce unintended learning outcomes. Since then, many efforts have focused on changing these ideas in ways that can lead students to a correct understanding of science concepts. In Posner, Strike, Hewson and Gertzog's (1982) view, learning as conceptual change means a transition from an initial conception about a phenomenon, C1, regarded as naïve theories or misconceptions or alternative conceptions to a final conception about the phenomenon C2, consistent with scientifically accepted views. This model of conceptual change assumes that each child comes to school with misconceptions about natural phenomena that are well articulated, symbolically represented and perhaps held in high esteem as paradigms by a community of scientists in Kuhn's notion (Kuhn, 1970). These alternative conceptions need to be elicited, challenged by explaining or demonstrating contrary examples, and corrected by providing a more general concept that the student will accept and assimilate. The aim of instruction from this view of conceptual change is to guide students towards accepting scientific views and incorporating these in their cognitive schemes.

Posner et al (1982) outline four conditions under which conceptual change will occur. (a) There must be dissatisfaction with current conceptions; (b) a new conception must be intelligible; (c) a new conception must appear initially plausible; and (d) a new conception should suggest the possibility of a fruitful research programme. Strike and Posner (1992) revised Posner et al.'s (1982) notion of conceptual change and stated that, in order to describe students' conceptual ecology, several factors should be considered, such as motives and goals, as well as their instructional and social sources. Furthermore, Strike and Posner (1992) shifted the limits of the learners' conceptual ecology to include current conceptions and misconceptions interacting with other components of the conceptual ecology, and they also proposed a developmental and interactionist view of the conceptual ecology.

diSessa (2002) points out the limitations of conceptual change research and criticizes it for lack of theoretical accountability concerning the nature of the mental entities involved in the process of conceptual change. diSessa (2002) concurs with Strike and Posner (1992) and also proposes a conceptual ecology approach, arguing that conceptual change involves organization and reorganization of a large number of diverse kinds of knowledge in the students' conceptual ecology, into complex systems. He identifies two different kinds of mental entities that get organized and reorganized in the process of conceptual change as p-prims (phenomenological primitives) and coordination classes. diSessa (1993, p.112) explains the meaning of phenomenological and primitive as:

They are phenomenological in the sense that they often originate in nearly superficial interpretations of experienced reality. They are also phenomenological in the sense that, once established, p-prims constitute a rich vocabulary through which people remember and interpret their experience. They are ready schemata in terms of which one sees and explains the world. There are also two senses of primitiveness involved. P-prims are often self-explanatory and are used as if they needed no justification. But also, primitive is meant to imply that these objects are primitive elements of cognitive mechanism - nearly minimal memory elements, evoked as a whole, and they are perhaps as atomic and isolated a mental structure as one can find.

diSessa (2002, p. 38) claims p-prims constitute the bulk of intuitive physics, the precursor knowledge that gets reconstructed into schooled competence with Newtonian physics. He defines coordination class as a systematic collection of strategies for reading a certain type of information out from the world. diSessa and Sherin (1998) define two structural components of a coordination

class: the set of read out strategies which involves “integration” and “invariance”, and the causal net which is intuitive expectation of a cause or theories that lie behind observations. Integration is the ability to coordinate observations or aspects in a single situation in order to read the required information, while invariance refers to the ability to read out the same information reliably in different situations (p. 1172). According to diSessa and Sherin (1998), the causal net of naïve students consists of p-prims and is the locus of difficulty in learning concepts of school physics. Moreover, diSessa and Sherin propose that both invariance and integration may pose difficulties in “recruiting and reorganizing” prior causal net knowledge, adding that invariance may be extremely problematic because different p-primes are evoked in different situations. diSessa’s (2002) claim of students’ knowledge structure as a collection of independent knowledge elements is strengthened by Potvin (2017) through pieces of evidence presented from mental chronometry and neuroimaging that support the coexistence of multiple students’ conceptions about phenomena. .

Vosniadou (2002) argues that naïve physics is neither a collection of unstructured knowledge elements nor a collection of stable misconceptions that need to be replaced, but rather a complex conceptual system that organizes students’ perceptual experiences and information they receive from the culture into coherent explanatory frameworks that make it possible for them to function in the physical world. To Vosniadou, the process of learning science is a slow and gradual one, during which aspects of scientific information are added onto the initial explanatory framework, destroying its coherence until it is restructured in ways that make it consistent with currently accepted scientific views. Vosniadou (1994) distinguishes between a naïve framework theory of physics and specific theories. Naïve framework theory is built early in infancy and consists of certain fundamental ontological and epistemological presuppositions not available to conscious awareness and hypothesis testing, whereas specific theories describe the internal structure of the conceptual domain within which concepts are embedded.

According to Vosniadou (1994), conceptual change proceeds through the gradual modification of one’s mental model of the physical world, achieved either through enrichment or through revision. Enrichment involves the addition of information to existing conceptual structures, while revision may involve changes in individual beliefs or presuppositions or changes in the relational structure of a theory. Revision may happen at the level of the specific theory or at the level of the framework theory. Vosniadou considers revision at the level of the framework theory to be the most difficult type of conceptual change and the one most likely to cause misconceptions.

Vosniadou and Ioannides (1998) identify two types of conceptual change: spontaneous changes in which initial conceptual structures can change as a result of children's enriched observations in the cultural context, or because of other kinds of cultural learning (such as language learning), and instructionally-based changes which are products of science instruction which could result in synthetic mental models (misconception) or scientifically correct mental models. In order to explain the spontaneous or instruction-based kinds of conceptual changes, they make the following assumptions: (a) knowledge acquisition is a gradual process during which existing knowledge structures are continuously enriched and/or restructured; (b) students are not aware of the hypothetical nature of the presuppositions and beliefs that constrain their learning; (c) the explanatory frameworks novices use lack the systematicity and coherence of the theory of physics used by experts.

Chi and Roscoe (2002) also emphasize that even if the nature of misconceptions and conceptual change have been discussed for several decades within different research contexts, the literature only offers a fuzzy picture of what exactly misconceptions are, what constitutes conceptual change, and why conceptual change is difficult. They suggest that misconceptions should be considered as ontological miscategorisations of concepts. From this perspective, conceptual change can be viewed as a simple shift of a concept across lateral categories. They argue that this process is difficult if students lack awareness of when a shift is necessary and/or lack an alternative category to shift into. Ivarsson, Shoultz and Säljö (2002) support a sociocultural view of conceptual change as an alternative to the cognitive view. They question the claim that children hold such mental models that are inconsistent with scientific models, and argue that such mental models may be a product of the investigative methods used. The authors claim that cognition is the use of tools, so conceptual change involves the development of tool-using practices. Mayer (2002) compares and contrasts four perspectives of conceptual change: Vosniadou's synthetic meaning view, Chi and Roscoe's misconception repair view, diSessa's knowledge-in-pieces view, and Ivarsson, Schoultz, and Säljö's sociocultural view. The four perspectives are compared in terms of what changes during conceptual change, who changes, how the change occurs, where the change takes place, the role of prior knowledge, and whether there is research evidence. In conclusion, he proposes a reconciliation of alternative views of conceptual change in search of answers to the age-old question of how best to intervene for students to benefit most.

2.3 EPISTEMOLOGICAL PERSPECTIVES ON CONCEPTUAL CHANGE

Naïve knowledge structure coherence is usually viewed from two prominent but competing broad perspectives: (1) knowledge as theory perspectives and (2) knowledge as element perspectives. Essentially naïve knowledge may most accurately be represented as a coherent unified framework of theory-like character (eg. Chi & Roscoe, 2002; Posner et al., 1982; Vosniadou, 1994) or considered as an ecology of quasi-independent elements (diSessa, 2002).

Ozdemir and Clark (2007) argue that these two perspectives imply different pathways for implementing conceptual change in the classroom. The cognitive conflict model (also conceptual conflict) assumes that naïve knowledge has a theory-like nature and possesses some degree of explanation power (Posner et al., 1982; Strike & Posner, 1992). This model assumes that conceptual change occurs by making students dissatisfied with their existing conceptions and then rendering the scientific conceptions intelligible, plausible, and fruitful (Hewson & Hewson, 1984; Posner et al., 1982). This model assumes that when conceptual change occurs, the new conception replaces the old conceptions. On the other hand, the cognitive perturbation model assumes that conceptual change takes place in a specific direction when a cognitive scheme, instead of producing the expected result, leads to perturbation, and perturbation, in turn, to an accommodation that maintains or re-establishes equilibrium (von Glaserfeld, 1995). The cognitive perturbation model involves step-by-step learning of concepts based on the understanding that paths of conceptual change for different students or groups of students are idiosyncratic, diverse, and context sensitive (Li, Law & Lui, 2006).

Following the lack of consensus concerning the nature of naïve knowledge, research has begun evaluating the comparative effectiveness of the cognitive conflict and cognitive perturbation approaches to conceptual change. For example, Dega, Kriek and Mogese (2013) report that conceptual change instruction modelled on cognitive perturbation principles is more effective in promoting understanding of concepts in electricity and magnetism than the one modelled on the cognitive conflict principle. This result is not surprising, given that the conflict resolution process in the cognitive conflict model has been flawed for being at odds with constructivism (Smith, diSessa & Roschelle, 1993). The cognitive conflict model assumes that new information replaces the existing knowledge only after the student finds it to be intelligible, plausible and fruitful. This assumption limits the knowledge restructuring process to assimilation of information, suggesting direct presentation of new information by the instructor. However inducing cognitive conflict in conceptual change instructions is essential, though not sufficient, to cause conceptual change (Lee

& Byun, 2012). Thus, the incorporation of conflict induction in a conceptual change instruction is still relevant.

The degree of conceptual change is determined by the type of knowledge processing activities that follow the conflict; that is, whether deep processing or surface processing strategies are employed (Chan, Burtis & Bereiter, 1997). Engaging in deep processing requires a high level of metacognitive reflection and control (Rickey & Stacy, 2000) and mature epistemological beliefs (Windschitl, 1997). Such reflection may cause recognition of discrepancies in the knowledge building process. The revision of cognitive operations can lead to rectification of the discrepancy, resulting in conceptual change. This is the mechanism that underlies the cognitive perturbation model of conceptual change (Li, Law & Lui, 2006).

Epistemological beliefs are individually held theory-like structures (Stathopoulou & Vosniadou, 2007) not available to conscious awareness and hypothesis testing (Vosniadou & Ioannides, 1998). These epistemological beliefs underlie the knowledge building process and influence conceptual change positively or negatively, depending on whether they are mature or immature beliefs (Windschitl, 1997). Cho, Lankford and Wescott (2011) report that students' epistemological beliefs significantly correlate with their views on Nature of Science (NOS) and conceptual change. However, there is no significant relationship between NOS views and conceptual change. This suggests that the relationship between NOS and conceptual change is mediated by epistemological beliefs. Nevertheless, there is a direct link between epistemological beliefs and metacognitive skillfulness with mature epistemological beliefs associated with high metacognitive skillfulness (Güven & Belet, 2011; Jena & Ahmad, 2013). Moreover, there is evidence that training in metacognitive skillfulness has a positive influence on students' NOS views (Abd-El-Khalick & Akerson, 2009; Çetinkaya & Çakıroğlu, 2013) as well as on students' conceptual understanding (Georghiades, 2006, Yürük and Eroğlu, 2016).

Thus, metacognition is key to improving students' epistemological beliefs, NOS views as well as conceptual understanding. Since metacognition is trainable (Georghiades, 2006; Kramarski, 2004; Mevarech & Kramarski, 2003; Özsoy & Ataman, 2009), a conceptual change model should consider as its main agenda the development of metacognitive awareness. However, given the multidimensional nature of the construct and other contextual factors that influence learning and the complex relationships that exist among these factors (Limon, 2001), designing a conceptual change learning environment that promotes improved metacognitive skillfulness is a difficult task. Due to the intricacy of conceptual change learning, metacognitive skillfulness (and for that matter

conceptual understanding) will improve to the extent that a variety of instructional techniques are implemented in the instructional process. In the following section the difficulties students face when learning chemical equilibrium are discussed.

2.4 STUDENTS' DIFFICULTIES IN LEARNING CHEMICAL EQUILIBRIUM

One concept in chemistry that has been posing conceptualization difficulties is chemical equilibrium. One of the reasons for these difficulties is the complexity of the concept, which researchers say demands the understanding of a large number of subordinate concepts. Another reason for difficulties is the abstract nature of the concept (Quilez, 2009). Students' attempts to learn this concept have resulted in construction of faulty mental models. Early research on learning the meaning of chemical equilibrium has documented a number of students' misconceptions on chemical equilibrium, related to dynamism, reversibility and completeness of reaction. For instance, equilibrium is seen by students as oscillating like a pendulum (Bergquist & Heikkinen, 1990); students lack awareness of the dynamic nature of chemically equilibrated state (Gorodetsky & Gussarasky, 1986); students associate chemical equilibrium with static balance (Maskil & Cachapuz, 1989); students believe that the forward reaction goes to completion before the reverse reaction starts (Wheeler & Kass, 1978).

Furio, Calatayud, Barcenas and Padilla (2000) assessed the reasoning difficulties of grade 12, first and third year university students on chemical equilibrium using four written items. Analysis of students' responses revealed that Le Chatelier's principle was the main tool used to explain changes to equilibrium caused by addition of a solids, changes in pressure, temperature and addition of inert gas at constant pressure. In most cases, wrong answers resulted from students' application of Le Chatelier's principle in contexts where it was not applicable, while in some cases wrong answers were caused by misunderstanding of the principle. Furthermore, it was found that no student had applied Le Chatelier's principle on changes in temperature in physical equilibrium suggesting context dependent reasoning (Hamza, & Wickman, 2008). Using a similar research approach, Solomonidou and Stavridou (2001) surveyed the preconceptions of 175 Greek students (aged 17-18) in order to detect their alternative conceptions of and learning difficulties pertaining to chemical equilibrium. The students were asked to respond to six-item questions and also produce drawings of mental representations in one of the items. The students' answers to a written questionnaire showed that they had inadequate representations of systems of substances at chemical equilibrium related to the empirical and the atomic level (85%). Students also predicted that a reaction might occur despite the lack of basic reactants, and failed to predict that a reaction could proceed from products to

reactants at the initial state. Moreover, students manifested serious difficulties in equilibrium shift, made overextended use of the Le Chatelier principle, and applied intuitive personal rules instead of the equilibrium constant law.

Bilgin, Uzuntiryaki and Geban (2003) surveyed alternative conceptions held by high school students regarding the concepts of chemical equilibrium. A written test was administered to 216 grade 11 students after their formal class schedule. The test included 47 multiple choice and true-false items. An interview was also conducted with 20 students to establish their reasons for alternative conceptions, using open-ended questions. Analysis of responses revealed widespread alternative conceptions among students in the areas related to (1) approaches to chemical equilibrium, (2) characteristics of chemical equilibrium, (3) changing chemical equilibrium conditions, and (4) adding a catalyst. The results of the study confirmed most of the alternative conceptions reported in earlier studies (e.g. Gorodetsky & Gussarasky, 1986). In addition, the following new alternative conceptions were identified by these authors: When approaching equilibrium, the decrease in concentration of reactants is equal to the increase in concentration of product; at equilibrium, the concentrations of reactants and product change with time (22.9%); at equilibrium, the rates of forward and reverse reactions are equal but not constant (34.4); at equilibrium, the rates of forward and reverse reactions are not equal (39.8%); adding more reactant at equilibrium instantaneously decreases the rate of reverse reaction (48.9%); after equilibrium is achieved, decreasing volume of the system at constant temperature instantaneously decreases the concentrations of all species (26.8%).

Quílez (2004) confirms some findings of Furio et al. (2000) and Solomonidou and Stavridou (2001). In her study she analyses the written responses and reasons given by both high school and fourth-year University students as well as by pre-service and in-service teachers on two questions that deal with changes in concentration or partial pressures of the gases involved in chemical equilibrium systems. She reports that Le Chatelier's qualitative statements were the main and almost exclusively conceptual tools used to predict equilibrium shifts when changing pressure, volume or mass. Le Chatelier's principle was given personal meanings. In some cases, incorrect interpretations led students to state correct shift predictions, while in others it did not. Many teachers erroneously associated changes in partial pressure caused by a variation in the volume of the equilibrium vessel with equilibrium shift mass changes. Changes in concentration caused by a variation in the volume of the equilibrium vessel were mainly associated with equilibrium shift→mass changes. Another finding by Quílez (2004) was that equilibrium law was not used at all by students; merely a minor

number of teachers did mention the equilibrium constant in their explanations. Thus, few correct answers were established. Furthermore the author asserts that gas behaviour misunderstandings are one of the most important obstacles when coping with changes in partial pressure due to changes in both mass and volume, as she found that many responses concentrated on physical behaviour of gases, instead of going beyond using the equilibrium law.

Van Driel (2002) explored which types of reasoning, both at the macroscopic and at the corpuscular level, would either promote or hinder the students conceptual change process. Based on the constructivist view of learning, he designed a courseware which included assignments to challenge students' existing conceptions and stimulated active student engagement through small-group discussions and hands-on experiments with the system of cobalt (II) tetrachloride and cobalt (II) hexahydrate complexes in iso-propanol. In the experiment, students placed a cold pink solution and a warm deep blue solution together in a water bath at 55⁰C, and a purple solution that formed in each case at a constant, intermediate temperature was supposed to be proof that the chemical conversion did not proceed to completion. The research methodology incorporated the constant comparative method which involved the comparison of students' reasoning in discussions with their written answers, as well as researcher triangulation which aimed at agreement among individual researchers about the interpretation of students' reasoning in the data. Results revealed that observation from the students' experiment was the cause for students accepting the reversibility and incomplete reaction concepts, and their willingness to accept the dynamic concept of chemical equilibrium. However, another problem was observed by the author: "many students appeared to separate the two opposite reactions in either space or time" (p. 208). Furthermore, the author found out that students were aware that changes on the macroscopic level (colour of solution) were caused by something going on inside (unobservable reaction) the system, but could not describe this in corpuscular terms. These results suggest a sequence of learning chemical equilibrium within the context of constructivism: reversibility → incomplete reactions → dynamism. The author also points out the need to explicitly help students distinguish between observable and unobservable processes of the chemical equilibrium system to resolve any alternative conception that may arise through teacher-student discussions.

Ganarasa, Dumon and Larchera (2008) showed that the concept of chemical equilibrium had not yet acquired the status of an integrating and unifying concept for the majority of prospective Physical Sciences teachers. In their study, Ganarasa et al. investigated whether the concept of chemical equilibrium had become an operational and functional knowledge to explain and predict chemical

phenomena involving chemical equilibrium. A paper-and-pencil questionnaire consisting of eight open ended items was administered to 173 students from five teacher training institutes of universities in France. Analysis of results revealed that for a majority of students, conceptualization of chemical phenomena involving chemical equilibrium was based only on the chemical reaction concept. Weak links between observable chemical phenomena and theoretical knowledge were also observed by the authors. The findings of the above study support diSessa's (2002) view of novice students' knowledge structure as a collection of unrelated elements.

Demircioğlu, Demircioğlu, & Yadigaroğlu (2013) also investigated chemistry student teachers' levels of understanding and alternative conceptions concerning chemical equilibrium. The sample consisted of 97 chemistry student teachers. A test consisting of 13 two-tier multiple choice questions was used to collect data. The results of this study confirmed many alternative conceptions that had been identified in previous studies. In addition, the following misconceptions were identified: when the temperature is changed, whether the reaction is endothermic or exothermic does not affect the equilibrium (31.9%); when a substance is added to equilibrium system, equilibrium will shift to the side of addition (23.7%). The fact the above study confirms many of the previously identified alternative conceptions in chemical equilibrium is consistent with the theory-like perspective of students' misconceptions in chemical equilibrium. At the same time the revelation of new misconceptions by some of the pre-service teachers reported in the above study suggests that misconceptions are idiosyncratic.

Before students are formally introduced to chemical equilibrium, it is a common practice to introduce them to chemical kinetics concepts first, where they learn that increase in concentration, temperature and pressure (for gaseous reactants) and the presence of catalyst increase the rate of a chemical reaction. These ideas are learned within the context of chemical reactions that proceed in one direction to completion. It appears that, when students formally learn chemical equilibrium, they tend to tacitly apply reasoning based on the rate of reaction without distinguishing between chemical kinetics and chemical equilibrium. For example, students' belief that increasing temperature after equilibrium is established, results in increase in concentration of products and decrease in concentration reactants even when the forward reaction is exothermic (Bilgin, Uzuntiryaki & Geban, 2003). Furthermore, the rate of forward reaction becomes greater than the rate of the reverse reaction following an increase in temperature (Bilgin, Uzuntiryaki & Geban, 2003). In the next section an analysis of conceptual change studies that attempt to address students' misconceptions in chemical equilibrium is presented.

2.5 EFFECTIVENESS OF CONCEPTUAL CHANGE INSTRUCTION ON STUDENTS' UNDERSTANDING OF CHEMICAL EQUILIBRIUM

Investigations into teaching and learning of chemical equilibrium can be traced along two main lines of research: studies that use refutation texts with other instructional techniques and studies that combine small group discussions with other instructional techniques. Refutation text is a text structure that challenges readers' misconceptions (Tippett, 2010). Refutation text passages always contain two components: the statement of a commonly held misconception, and an explicit refutation of that misconception with emphasis on the currently accepted scientific explanation (Tippett, 2010). A third component, a signal or clue that alerts the reader to the possibility of another conception, may also be present. Canpolat, Pınarba, Bayrakçeken and Geban (2006) used refutation texts and demonstration to create cognitive dissonance and analogies to help in the assimilation of scientific concepts. Their study employed a pre-test/post-test quasi-experimental design. The control group received instruction through the traditional teacher-centred approach while the experimental group was instructed through the conceptual change approach. The treatment conditions involved a liquid transfer analogy, illustrating how a reaction proceeded from start to equilibrium, graphing of data obtained from the analogy, demonstrations of effect of changing equilibrium conditions, question and answer session, discussion, use of diagnostic questions and explicitly drawing students' attention to misconceptions. The results showed that the students in the experimental group performed significantly better compared to the control group. Önder (2006) used refutation text to elicit students' misconceptions and to create cognitive dissonance and demonstration and analogy to aid assimilation of new concepts in solution equilibrium for the experimental group, while the control group was instructed by lecture/discussion method. The students in the experimental group had opportunities to discuss their ideas in small groups before the scientifically accepted explanations were given. Analysis of post-test showed that students in the experimental group performed significantly better than those in the control group. Similarly, in 2007 Özmen (2007) used refutation texts in remediating high school students' misconceptions concerning chemical equilibrium. A quasi-experimental design was used in the study. While the experimental group received a refutation text instruction, the control group received a traditional lecture method instruction. The refutation texts were based on a three step cognitive dissonance resolution strategy where students' misconceptions were first activated through elicitation questions, followed by a prediction phase, and then presentation of correct scientific explanations supported by examples. The results of the study indicated that the students in the experimental group showed significantly

greater levels of achievement than the students in the control group. Moreover, in both groups the percentages of students' misconceptions decreased; however the experimental group did better than the control group. Atasoy, Akkus, and Kadayifci (2009) used Predict-Observe-Explain (POE) demonstration to elicit misconceptions and refutation texts to highlight misconceptions while analogies and concept maps were used to aid assimilation of new concepts. In this study, a pre-test/post-test quasi-experimental design was employed. The control group was instructed by the traditional lecture method while the experimental group was instructed by the conceptual change approach. Results showed that the conceptual change approach was statistically more effective than traditional instruction in terms of students' conceptual understanding.

Mills and Alexander (2013) define small group teaching as "any teaching situation in which dialogue and collaboration within the group are integral to learning" (p.4). The discussion is usually conducted on a problem. The small group is a more personal situation; it provides opportunities for a high level of interaction between teacher and students and among students. Such interaction can foster active student engagement and learning at a high conceptual level, and can help students to achieve a sense of independence and responsibility for their own learning (Kelly & Stafford, 1993). Small group discussion was used by Akkus, Kadayifci, Atasoy and Geban (2003) to promote understanding of chemical equilibrium in a quasi-experiment study. The control group received traditional instruction involving sessions utilizing lecture/discussion methods to teach concepts while the experimental group received instruction based on conceptual change within the context of small group discussion. The conceptual change approach consisted of a four-stage teaching experience:(1) students in small groups made a prediction about a situation using their preconceptions from which their misconceptions were identified; (2) the teacher fostered cognitive dissonance by providing possible answers which were misconceptions of the phenomenon in question and suggesting counter-questions for students to consider \in their group discussions; (3)the students were provided with the condition to test their preconceptions and note their misconceptions in the concept, and (4) an explanation of the scientifically correct concept in the context of prediction questions, with feedback on the prediction questions, was given by teacher. Results indicated that the students who used the conceptual change principles-oriented instruction obtained significantly higher scores than those taught by traditional instruction in terms of achievement related to chemical equilibrium concepts.

Bilgin (2006) employed a pre-test/post-test quasi-experimental design to investigate the effect of small group discussion on students' understanding of chemical equilibrium. The treatment

comprised a sequence of activities as follows: first the teacher gave a short lecture on topics related to chemical equilibrium concepts; then students were put into groups of four and handed a worksheet. Students were asked to answer questions individually, and then two students from each group discussed the questions, and wrote their explanations on their worksheets. Finally, students discussed and shared their ideas with other group members, reached consensus, and wrote their explanations as a group. When groups had completed their work for each question, the teacher asked some of the groups to explain their findings for the whole classroom. During the discussion period, the teacher helped students having difficulty in finding relationships among concepts by giving them simple clues, reminding them of related parts of the lecture, and giving feedback about their possible misconceptions. In the control group, students were instructed with traditional lecture instruction. Results showed a statistically significant difference between the experimental and control groups' post-test mean scores in favour of the experimental group. Around the same period, Bilgin and Geban (2006) investigated the effect of cooperative learning based on conceptual change conditions on students' understanding and achievement in chemical equilibrium. Initially chemical equilibrium problems (both conceptual and numerical) were handed to students as worksheets to solve individually and then discuss their solutions in groups in order to arrive at shared ideas. Next, the teacher provided the scientifically accepted ideas and also gave feedback. The groups then performed the analogies in order to understand the scientific concepts fully and also recognize the mistakes they committed in the initial problem solving situation. Finally, students applied the scientific ideas in solving other problems. Students took three quizzes individually within the last three weeks after they had completed their group study. The quizzes were scored, corrected and graded by the instructor and the students reviewed their quizzes after the correction. This helped students to see their in-group performances and progressions. The first three groups in rank of success were rewarded for their improvement according to their scores on the quizzes. The control group was instructed through the traditional lecture/discussion and worksheet study approach, but did not take any quiz. Results revealed a very significant effect of the conceptual change intervention.

Another research tradition that has informed research into teaching and learning of chemical equilibrium is argumentation. An argument is an attempt to establish truth and commonly consists of a claim that may be justified by either observable evidence, warrants (that relate the data to the claim), backings (the premises of the warrant), or qualifiers (the limits of the claim) (Osborne, 2010). Kaya (2013) investigated the effect of argumentation on pre-service teachers' conceptual

understanding of chemical equilibrium using a quasi-experiment design. The control group received instruction through the lecture method while the experimental group was instructed through argumentation activities. At the beginning of the argumentation activities, the students were asked to answer the questions by either justifying their answers or selecting one situation from two given ones and justify their answer. Then, the instructor started a whole-class discussion and the students shared their ideas by explaining what they had written in the task. During whole-class discussion, the teacher gave feedback to the students about their arguments in terms of the quality of these arguments. Analysis of data revealed that the argumentation intervention was more effective than traditional lectures in promoting students' understanding of chemical equilibrium. Aydeniz and Dogan (2016) explored the effect of argumentation on preservice teachers' understanding of chemical equilibrium using the post-test only quasi-experimental design. The control group received instruction through the lecture method with traditional laboratory experiments while the experimental group was instructed through argumentation activities. Results indicated that the argumentation was more effective in fostering pre-service teachers' understanding of chemical equilibrium than the traditional lecture method.

Articles on teaching and learning chemical equilibrium included in this review were located by conducting an electronic search of 13 databases including Google Scholar, JSTOR and Ebsco Host, and the internet. The key words combination entered were "chemical equilibrium and conceptual change." This resulted in retrieving nine articles. In addition, references of the articles that were retrieved were checked to determine which articles were relevant (Randolph, 2009). This process resulted in the identification of ten additional articles. A total of twenty articles were retrieved. The following inclusion criteria were used to select articles for analysis: (1) the study used experimental or quasi-experimental design, (2) ANCOVA statistics were used to analyse data (3) effect size statistics were reported or information was made available for computation of effect size. The reason for including only those studies that used experimental or quasi-experimental designs is that the use of comparison groups minimizes threats to internal validity of results (Trochim, 2000). The reason for including only the studies that used ANCOVA as data analysis is that even if treatment and control groups do not differ significantly on the pre-test, there may be other unmeasured variables on which groups differ prior to the intervention that may confound the results (Field, 2005). Moreover, inclusion of pre-test as covariate in ANCOVA permits a better evaluation of the intervention as it controls for any pre-existing difference between treatment and control groups. Following the criteria specified above, seven articles were selected for analysis. The analysis was

done by considering the different types of instructional techniques used in a study, whether misconceptions were elicited prior to instruction or not, and the effect size. Table 2.1 shows the analysis.

Table 2.1: Instructional techniques used by researchers in teaching experimental group chemical equilibrium and their effect sizes

Study	Instructional techniques	Number of instructional techniques	Was misconception elicited prior to instruction?	Effect size (Eta Square)
Bilgn & Geban (2006)	Analogy, worksheet, three quizzes, small group discussions	6	Yes	0.97
Atasoy, Akkus & Kadayifci (2009)	Refutation texts, analogy, demonstration, concept map, whole-class discussions	5	Yes	0.59
Önder (2006).	Refutation texts, analogies, demonstrations, discussions	4	Yes	0.47
Canpolat, Pınarba,, Bayrakçeken, & Geban (2006)	Refutation texts, analogy, demonstration, whole-class discussions	4	Yes	0.44
Bilgin (2006)	Modelling, worksheet, small group discussions	3	No,	0.37
Kaya (2013)	Argumentation practice, worksheet	2	No	0.14
Akkus, Kadayifci, Atasoy, & Geban (2003)	Worksheet, small-group discussions	2	Yes	0.13

Looking at Table 2.1, it appears that studies that tend to produce large effect sizes also involved the elicitation of misconceptions prior to instruction, but the researcher did not base the analysis on the place of elicitation of misconceptions in the instructional sequence for two reasons: first, there are only two studies in which elicitation of misconceptions was not done prior to instruction; secondly, the effect sizes for the two studies in which misconceptions were not elicited prior to instruction differ, suggesting that other factors may be at play. The pattern of relationship which is apparent is that, as the number of intervention techniques used reduces, the effect size decreases. A Pearson correlation revealed a very strong positive relationship between the number of techniques per

intervention and effect size ($r = .97$, $p = .000$), meaning number of intervention techniques accounted for 94% of the variance in effect size. This result suggests that each technique made a unique contribution to the variance explained by the intervention leading to a larger proportion of explained variance as the number of instructional techniques within the intervention increases.

The analysis of studies in chemical equilibrium shows that the more the instructional techniques in an intervention, the better the practical significance of the intervention. Each instructional technique accomplishes particular objective(s) which are part of a broader purpose of the intervention. Analogies and demonstrations in an intervention promoted spontaneous conceptual change through enriched observation provided by these techniques (Vosniadou & Ioannides, 1998). The use of analogy and demonstration on different occasions in the instructional sequence helped students to focus on the specific aspects of the chemical equilibrium concept across multiple contexts (Özdemir & Clark, 2007). Each of these techniques highlighted an important aspect of the equilibrium concept which enabled students to easily see and differentiate between them, and engage in conflict resolution and coherence building between ideas (Parnafes, 2007). Also, demonstrations served as external source of motivation required for engagement with the learning material.

Refutation texts served as metacognition enhancement tool that created awareness of the existence of misconceptions and also encouraged metacognitive reflection which improved reading and text comprehension during problem solving (Karami & Hashemian, 2012; Martínez, 2011; Tavakoli, 2014). This behaviour was transferred to word problem solving leading to improved understanding of problem and better performance. Group discussions encouraged students to engage in metacognitive co-regulation during conceptual change learning. As students collaborated during group discussions, they expressed their ideas in public, defended them in the face of questions from peers, questioned others' ideas, and were forced to elaborate, clarify, and re-organise their own thinking processes (Borkowski, Chan & Muthukrishna, 2000). The collaborative environment provided by group discussion promoted the development of metacognitive regulation (Schraw, Crippen & Hartley, 2006).

Keys, Hand, Prain and Collins (1999) argue that students' attempts either to read text or construct text involves them in processes in which they have to engage their own understandings to construct meaning for the science topics they are studying. Therefore, encouraging students to read text and to write is a way to encourage the negotiation of meaning and construction of knowledge. In a study by Bilgin and Geban (2006), students took three quizzes in addition to worksheets, discussions and analogies. The process of reading, writing and reviewing that characterizes quiz writing offers three

additional learning episodes for the development of students' metacognitive skills (Avci, 2014; Hand, Wallace & Yang, 2004). The researcher hypothesizes that metacognition mediates the relationship between number of instructional techniques and effect size. As metacognition is a multidimensional construct, each instructional technique within the intervention influences a specific component of this construct, resulting in a more improved metacognitive awareness. The development of a more complete metacognitive awareness, granted by employing multi-technique intervention, also makes the conceptual change learning more permanent – hallmarks of effective conceptual change learning (Georghiades, 2000).

Conceptual change theories have given a multiple perspective to the nature of naïve cognitive structures with regard to science concepts and the processes of conceptual change. Each perspective suggests a specific line of action in knowledge restructuring process. The researcher subscribes to the view that high level conceptual change is a complex process that no single conceptual change theory could sufficiently account for, as so many factors come to play during the process of conceptual change (Limon, 2001). The multiplicity of perspectives on conceptual change should be regarded as indicative of this complexity rather than contradictory views. Each perspective should be viewed as an account of a unique aspect of conceptual change, necessary but not sufficient for addressing issues in conceptual change on a large scale. According to diSessa and Sherin (1998), the causal net of naïve students consists of p-prims, and that poses difficulty in learning concepts of school science. Vosnaidou (1994) considers restructuring at the level of the framework theory to be the most difficult type of conceptual change to achieve. Thus, the researcher believes diSessa's p-prims and Vosnaidou's framework theory account for different facets of difficulty posed by intuitive knowledge in the process of conceptual change. Furthermore, Vosnaidou's description of naïve framework theory as consisting of certain fundamental ontological and epistemological presuppositions not available to conscious awareness and hypothesis testing, suggests a need for instruction to take into account the development of metacognition (Vosniadou, 2003; Vosniadou, 2007) as well as the nature of science understandings and the relationship between views on nature of science and conceptual change. Finally, Ivarsson, Shoultz and Säljö's (2002) notion of conceptual change as the development of tool-using practices emphasizes the need for using appropriate visual aids in promoting conceptual change.

2.6 SUMMARY

The findings from this review support views on conceptual change which consider metacognition as a potential mediator for improvement in conceptual change learning. The review of research into

promoting conceptual change in chemical equilibrium has revealed that different instructional techniques can be used to enhance students' understanding of concepts. Moreover, a combination of instructional techniques is likely to yield better results than a single technique. Furthermore, it is evident from the existence of different theoretical perspectives that conceptual change is a complex process. Conceptual change is multifaceted, with each perspective forming a face of this process. Focusing on the development of metacognition will be a way to reconcile all these theoretical perspectives in promoting conceptual change. Future research in fostering students' understanding of chemical equilibrium should include measurement of students' metacognitive skills in order to confirm this proposition. In the next chapter the development of metacognition and its role in learning will be discussed.

CHAPTER THREE: METACOGNITION AND LEARNING

3.1 INTRODUCTION

This chapter begins with a review of various definitions of metacognition. It continues with the discussion of different conceptualisations of metacognition. Subsequently, the chapter examines the relationship between metacognition and other concepts related to thinking, and then continues with the discussion on the development of metacognition. The discussion also delves into the effect of metacognitive training on learning and further on issues on assessment of metacognition. Finally a summary of the review and suggestion for the way forward in metacognition research are given.

3.2 DEFINITION OF METACOGNITION

The term metacognition was introduced by John Flavell in the early 1970s based on the term metamemory he previously conceived (Flavell 1971). Flavell (1979) viewed metacognition as students' knowledge of their own cognition, defining it as "knowledge and cognition about cognitive phenomena" (p. 906). Metacognition is often referred to in the literature as "thinking about one's own thinking" (Cooper & Sandi-Urena, 2009), or as "higher order cognitions about cognitions" (Veenman, Van Hout-Wolters & Afflerbach, 2006). It is usually related to students' knowledge, awareness and control of the processes by which they learn (Brown, 1987, Garner & Alexander 1989), and the metacognitive student is thought to be characterised by the ability to recognise, evaluate and reconstruct existing ideas (Gunstone, 1991). Flavell's definition of metacognition was followed by numerous others, often portraying different emphases on mechanisms and processes associated with metacognition. For example, Paris and Winograd (1990) identify two essential features in their definition of metacognition: self-appraisal and self-management of cognition. Self-appraisal of cognition comprises reflections about students' knowledge state and abilities during the learning process, while self-management refers to metacognition in action; that is, mental processes that help to "orchestrate aspect of problem solving" (Paris & Winograd, 1990, p. 8). Metalearning (White & Gunstone 1989), deuterio-learning (Bateson, 1983) and mindfulness (Salomon & Globerson, 1987) are terms also used in the body of literature to describe an awareness of problems, situations, and ways of thinking and talking about them. The number of definitions, terms and analyses of what metacognition stands for has been the cause for some confusion in the literature. Weinert (1987), for instance, speaks of a "vague" and "imprecise" working definition of metacognition. Similarly, Adey and Shayer (1994) referred to

confusion among science educators over not only the meaning of the term ‘metacognition’, but also its actual recognition. Since the introduction of the term by Flavell, “metas” (e.g. metalistening, metacommunication, metapersuasion) has proliferated in the literature (Kluwe, 1987), Flavell (1987) remarks that, although metacognition is usually defined as knowledge and cognition about cognitive objects (i.e. about anything cognitive), the concept could reasonably be broadened to include anything psychological, rather than just anything cognitive. In his attempt to identify where metacognition fits into psychological space, Flavell (1987) suggests that concepts that may be related to metacognition include executive processes, formal operations, consciousness, social cognition, self-efficacy, self-regulation, reflective self-awareness, and the concept of psychological self or psychological subject. Watts (1998), for instance, argues that “meta-affection” stands very close to the notion of metacognition, which focuses on the affective dimension of learning, defining this as “the conscious awareness, monitoring, regulation and evaluation of intra-personal and interpersonal affective activity” (p.8). Papaleontiou-Louca (2008) links metacognition to Vygotsky’s socio-constructivist theory (Vygotsky, 1978), describing it as a precursor to metacognitive theory, arguing that many cognitive acts are initially experienced in social settings, but in time, the results of such experiences become internalised. Papaleontiou-Louca (2008) posits that the definition of metacognition has been broadened and includes not only “thoughts about thoughts” as it was before considered, but also the following notions: knowledge of one’s knowledge processes, and cognitive and affective states; and the ability to consciously and deliberately monitor and regulate one’s knowledge processes, and cognitive and affective states (p.3).

Metacognition has also been conceptualised as state or trait construct (O’Neil Jr. & Abedi, 1996). By a state construct, metacognition refers to a transitory state within people in intellectual situations, which varies in intensity, changes over time, and is characterised by planning, monitoring or self-checking, cognitive/affective strategies, and self-awareness. Trait metacognition is regarded as a relatively stable individual difference variable to respond to intellectual situations with varying degrees of state metacognition. In the present study metacognition is regarded as efforts students make to monitor their thoughts and actions and to act accordingly in order to gain some control over these (Dinsmore, Alexander, & Loughlin, 2008).

3.3 COMPONENTS OF METACOGNITION

Metacognition was originally thought to have two constituent parts: knowledge about cognition and monitoring of cognition (Cross & Paris, 1988; Flavell, 1979; Shraw, 1998; Schraw, Crippen &

Hartley, 2006; Schraw & Moshman, 1995). Several frameworks have been developed for categorizing types of knowledge about cognition. For example, Flavell (1979) defines metacognitive knowledge as knowledge about one's own cognitive strengths and limitations, including the factors (both internal and external) that may interact to affect cognition. He classifies such knowledge into three types: (1) "person" knowledge, which includes anything one believes about the nature of human beings as cognitive processors; (2) "task" knowledge, which includes knowledge about the demands of different tasks; and (3) "strategy" knowledge, which is knowledge about the types of strategies likely to be most useful. Flavell notes that these different types of knowledge can interact, as in the belief that one should use strategy A rather than strategy B to solve task X rather than task Y. Metacognitive experiences refer to "conscious cognitive or affective experiences that accompany and pertain to any intellectual enterprise" (Flavell, 1979, p. 907). Metacognitive experiences can influence cognitive goals or tasks, metacognitive knowledge, and cognitive actions or strategies in three ways: in the first place, they can lead one to establish new goals and to revise or abandon old ones; secondly, metacognitive experiences can affect one's metacognitive knowledge base by adding to it, deleting from it, or revising it; and in the third place, metacognitive experiences can activate strategies aimed at either of two types of goals – cognitive or metacognitive.

Subsequent metacognition researchers have offered a slightly different framework for categorizing knowledge of cognition. For example, several researchers have used the concepts of declarative and procedural knowledge to distinguish cognitive knowledge types (Cross & Paris, 1988; Schraw et al., 2006; Schraw & Moshman, 1995). Declarative knowledge is referred to as classification of knowledge found in long-term memory (Anderson, 1983) that deals specifically with factual information and can be best described as knowing "what" (Brunning, Schraw, Norby & Ronning, 2004). According to Jonassen, Beissner and Yacci (1993), declarative knowledge "represents cognisance or awareness of some object, event or idea" and it "enables students to come to know, or define, which form the bases for thinking about and using those schemas" (p. 3). Erman (2017) reports that incomplete and inaccurate factual information about covalent bond received from teachers and textbooks was the cause of students' misconceptions about covalent bond. Kuhn and Dean (2004) characterize declarative knowledge broadly as epistemological understanding, or students' understanding of thinking and knowing in general. Schraw et al. (2006) portray declarative cognitive knowledge as knowledge about oneself as a student and what factors might influence one's performance. Conceptual knowledge represents a higher level of declarative knowledge and it

involves the “integration of declarative knowledge into useful knowledge structures” (Jonassen et al., 1993, p. 4). Procedural knowledge involves awareness and management of cognition, including knowledge about learning strategies (Cross & Paris, 1988; Schraw et al., 2006). In simpler terms, procedural knowledge refers to how declarative knowledge is used and it develops through conceptual knowledge (Jonassen et al., 1993). By this description procedural knowledge may involve heuristics, algorithms and learning strategies. Schraw et al. (2006) refer to conditional knowledge as knowledge of why and when to use a given strategy. According to Schunk (2012), conditional knowledge is a form of declarative knowledge because it is “knowledge that”. Conditional knowledge is believed to exist in the long-term memory as propositions in networks, linked with the declarative and procedural knowledge to which it applies, and it helps students select and employ declarative and procedural knowledge to fit task goals.

The other component of metacognition is regulation of one’s cognition, which many researchers have argued includes activities of planning, monitoring, and evaluation (Cross & Paris, 1988; Paris & Winograd, 1990; Schraw & Moshman, 1995; Schraw et al., 2006; Whitebread et al., 2009). Planning involves identification and selection of appropriate strategies and allocation of resources, and can include goal setting, activating background knowledge, and budgeting time. Monitoring involves attending to and being aware of comprehension and task performance and can include self-testing. . Evaluation is defined as “appraising the products and regulatory processes of one’s learning,” and includes revisiting and revising one’s goals (Schraw et al., 2006, p. 114). Tuysuzoglu and Greene (2015) argue that metacognitive monitoring and metacognitive control considered separately with regards to their role in self-regulation in learning may obscure the relationship between these two variables. They base their argument on the premise that not all monitoring behaviours translate to control behaviours. They coined the term “contingent metacognitive behaviour” to represent monitoring and control and identified two categories as “adaptive metacognitive behaviour” (i.e., when monitoring results in metacognitive control) and “static metacognitive behaviour” (i.e., when monitoring does not result in metacognitive control).

Researchers have observed a relationship between cognitive knowledge and cognitive monitoring. For example, Flavell (1979) argues that metacognitive experiences that allow one to monitor and regulate one’s cognition play a major role in the development and refinement of metacognitive knowledge. In turn, Schraw (1998) cites a number of empirical studies demonstrating that cognitive knowledge appears to facilitate cognitive regulation. He notes that such studies have found cognitive knowledge and cognitive regulation to be correlated with one another at about $r = .50$,

which suggests that around one-quarter of the variance in cognitive knowledge is attributable to cognitive regulation and vice versa.

Flavell (1979) discusses cognitive monitoring in the context of cognitive experiences, which are insights or perceptions that one experiences during cognition, such as, “I’m not understanding this.” Flavell notes that these experiences serve as quality control checks that help students revise their goals. Haller, Child and Walberg (1988) identify three clusters of mental activity inherent in metacognition within the context of reading comprehension, including awareness, monitoring, and regulating. According to this framework, awareness entails recognition of explicit and implicit information and responsiveness to text dissonance or inaccuracies. Monitoring involves goal setting, self-questioning, paraphrasing, activating relevant background knowledge, making connections between new and previously learned content, and summarizing to enhance comprehension during reading. Finally, regulating refers to “compensatory strategies to redirect and bolster faltering comprehension” (p. 6).

Efklides (2001, 2006, & 2009) proposes a model of metacognition consisting of three components, namely, metacognitive knowledge (MK), metacognitive experiences (ME) and metacognitive skills (MS). Like Flavell (1979), Efklides states that MK is declarative in nature, and encompasses information regarding persons (the self and the others as cognitive processors as well as their ME), tasks, strategies and goals. In addition Efklides’ MK includes epistemological beliefs, which comprises knowledge of the criteria for validity of knowledge. Metacognitive experiences (ME) refer to the manifestations of the online monitoring of cognition during information processing as one engages in solving a task. They comprise metacognitive feelings, metacognitive judgments/estimates, and online task specific knowledge. Research studies suggest that students tend to be overconfident when estimating exam performance (de Bruin, Kok, Lobbetael, J., & de Grip, 2017; Foster, Was, Dunlosky, & Isaacson, 2017) and this can have negative consequences on the metacognitive monitoring and control decisions that students make, especially low achievers (Mathabathe & Potgieter (2014). Metacognitive skills (MS) constitute the control function of metacognition, that is, what the person deliberately does to control cognition.

3.4 RELATIONSHIP OF METACOGNITION TO OTHER LEARNING CONCEPTS

Researchers in cognitive psychology have linked metacognition to a number of other constructs, including metamemory, critical thinking, and motivation (e.g. Mark, 2016). Metamemory, for example, is closely related to metacognition, particularly cognitive knowledge. Metamemory is

knowledge about memory processes and contents, and consists of two components that closely mirror the declarative and procedural aspects of cognitive knowledge (Schneider & Lockl, 2002, p. 5). Variables which correspond to declarative knowledge refer to “explicit, conscious, factual knowledge that performance in a memory task is influenced by a number of different factors or variables” (p. 6). Sensitivity, which corresponds to procedural knowledge, is knowledge about when a particular memory strategy might be useful. According to Schneider and Lockl (2002), most developmental studies of metacognition have actually focused on the construct of metamemory, particularly on its procedural dimension.

Critical thinking also relates to metacognition. Definitions of critical thinking vary widely, but common elements of most definitions include the following component skills: analysing arguments (Ennis, 1985; Facione, 1990; Halpern, 1998; Paul, 1992); making inferences using inductive or deductive reasoning (Ennis, 1985; Facione, 1990; Paul, 1992, Willingham, 2007); judging or evaluating (Case, 2005; Ennis, 1985, Facione, 1990; Lipman, 1988; Tindal & Nolet, 1995); and making decisions or solving problems (Ennis, 1985; Halpern, 1998; Willingham, 2007).

In addition to skills or abilities, critical thinking also entails dispositions. These dispositions, which can be seen as attitudes or habits of mind, include open- and fair-mindedness, inquisitiveness, flexibility, a propensity to seek reason, a desire to be well-informed, and respect for and willingness to entertain diverse viewpoints (Bailin, Case, Coombs & Daniels, 1999; Ennis, 1985; Facione, 1990; Halpern, 1998; Paul, 1992). Finally, there appear to be both general and domain-specific aspects of critical thinking, which suggests that instruction should represent a fusion of preparation in general critical thinking principles, as well as practice in applying critical thinking skills within the context of specific domains (Facione, 1990; Paul, 1992).

Flavell (1979) and Martinez (2006) maintain that critical thinking is subsumed under metacognition. Flavell argues, for example, that the definition of metacognition should include critical thinking when he posits that “critical appraisal of message source, quality of appeal, and probable consequences needed to cope with these inputs sensibly” can lead to “wise and thoughtful life decisions” (p. 910). Martinez defines critical thinking as “evaluating ideas for their quality, especially judging whether or not they make sense”, and sees it as one of three types of metacognition, along with metamemory and problem solving (p. 697). Kuhn (1999) equates critical thinking with metacognition. Similarly, Hennessey (1999) identifies a list of metacognitive skills that are quite similar to skills commonly included in definitions of critical thinking: (1) considering the basis of one’s beliefs; (2) temporarily bracketing one’s conceptions in order to assess competing

conceptions; (3) considering the relationship between one's conceptions and any evidence that might or might not support those conceptions; (4) explicitly considering the status of one's own conceptions; and (5) evaluating the consistency and generalisability inherent in one's conceptions. Schraw et al. (2006) however, see both metacognition and critical thinking as being subsumed under self-regulated learning, which they define as "our ability to understand and control our learning environments" (p. 111). At the very least, metacognition can be seen as a supporting condition for critical thinking, to the extent that monitoring the quality of one's thought makes it more likely that one will engage in high-quality (critical) thinking. Runisah, Herman and Dahlan (2017) report that 5E learning cycle with metacognitive technique was more effective in developing students' mathematical critical thinking skills than 5E learning cycle without metacognitive technique. In another study Gholami et al., (2016) report that both critical thinking and metacognitive skillfulness are enhanced significantly by problem based learning compared to traditional lecture approach. .

Several researchers highlight the link between metacognition and motivation (Cross & Paris, 1988; Eisenberg, Valiente and Eggum, 2010; Martinez, 2006; Paris & Winograd, 1990; Ray & Smith, 2010; Schraw et al., 2006; Whitebread et al., 2009). Gottfried (1990) defines academic motivation in particular as the "enjoyment of school learning characterised by a mastery orientation; curiosity; persistence; task-endogeny; and the learning of challenging, difficult, and novel tasks" (p. 525). In the context of metacognition, motivation is defined as "beliefs and attitudes that affect the use and development of cognitive and metacognitive skills" (Schraw et al., 2006, p. 112). According to Schraw et al. (2006) motivation has two primary subcomponents: (1) self-efficacy, which is confidence in one's ability to perform a specific task and (2) epistemological beliefs, which are beliefs about the origin and nature of knowledge. Cross and Paris (1988) note that metacognition includes affective and motivational states. Similarly, Martinez (2006) argues that metacognition entails the management of affective states, and that metacognitive strategies can improve persistence and motivation in the face of challenging tasks. Paris and Winograd (1990) concur that arguing that affect is an inevitable element of metacognition, because as students monitor and appraise their own cognition, they will become more aware of their strengths and weaknesses. Eisenberg, Valiente and Eggum (2010) review the research on young children's emotion-related self-regulation, which is the "set of processes used to manage and change if, when, and how one experiences emotions and emotion-related motivation and physiological states and how emotions are expressed behaviorally" (p. 681). Eisenberg et al. (2010) define one subskill, known as effortful control (EC), as "the efficiency of executive attention – including the ability to inhibit a dominant

response and/or activate a subdominant response, to plan, and to detect errors” (p. 682). Eisenberg et al. argue that EC is indirectly related to academic success through motivation. The authors explain the relationship as follows: children high in EC are more likely to behave in productive, pro-social ways; they are more socially competent and are generally rated as having higher quality interactions with others. Such pro-social children are more likely to engage in school to the extent that they feel socially comfortable. This increased motivation is then hypothesised to lead to higher achievement. Eisenberg et al. (2010) conclude that the extant empirical research tends to support this proposed link, suggesting that interventions designed to improve students’ EC may lead to better peer interactions, higher engagement with schoolwork, and improved learning outcomes. For example, pre-schoolers’ EC predicted future SAT (Scholastic Assessment Test) scores and also correlated with interpersonal skills and motivation. Ray and Smith (2010) echo this conclusion, arguing that EC predicts kindergarten students’ future reading and math abilities.

Metacognition has also been linked to executive function. Executive functioning has been studied from different theoretical perspectives, and as such, like with metacognition, there has not been consensus among researchers about the defining attributes of executive function. However, Barkley (2011) provides a neuroscience definition of executive function as “those neuropsychological processes needed to sustain problem-solving toward a goal” (p. 41). Doty (2012) describes these processes as brain-controlled functions that guide various functions of the body such as planning, solving problems, organising and directing the body to carry out daily activities. Moreover, Doty argues that executive functioning involves developing initiatives, making appropriate decisions, considering consequences, working memory, prioritising, paying attention, focusing on important details, working toward a goal, shifting, and stopping with a finished action or task. Research in executive function has been going on side by side with metacognition, but it was not until recently that metacognition and executive function were explicitly regarded as the same construct. Empirical studies are now establishing links between metacognition and executive functions (Bryce, Whitebread & Szűcs, 2015; Claudia, Roebers, Cimeli, Röthlisberger, & Neuenschwander, 2012). Roebers and Feurer (2016) argue that executive function and procedural metacognition share theoretical features, undergo similar developmental trajectories, and are associated with comparable brain regions. Self-regulation is a terminology that has links with metacognition. This term has also been used interchangeably with executive function and metacognition (Borkowski, Chan & Muthukrishna, 2000), and is considered to be synonymous to executive function.

Biggs (1988) reports that deep and achieving approaches to learning result from students with the most effective metacognitive awareness of their learning approach. Chin and Brown (2000) report that when using a deep learning approach in group laboratory activities in Chemistry, students displayed more cognitive self-appraisal and regulatory control of the learning process through ongoing reflective thinking but when using a surface approach students engaged in less self-monitoring and self-assessment. Case and Gunstone (2002) conceptualized metacognitive development as a “shift in a student’s approach to learning” (p. 463). García, Cueli, Rodríguez, Krawec, and González-Castro (2015) also report a significant relationship between students’ approaches to learning and metacognitive knowledge during Mathematics problem solving with high levels of metacognitive knowledge associated with deep approaches. Since metacognition has no precise definition, the relationship between metacognition and learning approach suggests that learning approach is another dimension of metacognition. Therefore, a student’s level of metacognition may become operational in the student’s approach to learning and the term deep learning. In this case, the deep learning approaches may be viewed as closely associated with occurrence of high levels of metacognitive activities. The relationship of metacognition with other learning concepts as well as the fact that there is no agreement among researchers about its definition, supports the view that metacognition is a multidimensional construct. Therefore, metacognition may be operationalised in different ways and its development may be understood from different perspectives. In the next section, the development of metacognition will be discussed.

3.5 DEVELOPMENT OF METACOGNITION

Metamemory was one of the first components of metacognition to be studied. It was from the study of metamemory that Flavell (1971) constructed his model of metacognition. As described by Flavell and Wellman, metamemory involves knowledge of one’s own memory, how it works, what factors may influence it, what strategies may be useful in helping us to remember things, as well as ongoing control and monitoring of our memory (Flavell, 1971; Flavell & Wellman, 1977).

Summarizing the results of early studies in metamemory, Flavell (1979) argues that young children are quite limited in their metacognition and do relatively little monitoring of their own memory, comprehension, and other cognitive enterprises. Hennessey (1993) found in her study of grade 1 to 6 science students that, older students in grade 4 to 6 were more likely to engage in metacognitive activity than their younger counterparts. Schwanenflugel, Fabricius and Alexander (1994) also

found that children as young as eight were aware of their mental processes, but they argue that even though younger children are capable of metacognitive awareness, they often do not put this into practice. One reason for this may be that deployment of metacognitive strategies is too demanding, given young children's limited attentional resources (Schneider & Bjorklund, 1998). Fang and Cox (1999) report that they found evidence of metacognitive awareness among pre-schoolers, aged four to five years. The children were asked to dictate their favourite story to an adult for the purposes of sharing it with another child. Evidence was found, relating to awareness of their own planning and cognitive processes, monitoring of the dictating process and awareness of needs of their listener

A longitudinal study by Lockl and Schneider (2006) sought to find the relationship between theory of mind, language and metamemory. Through a series of tests and interviews with children four to five years old over two years, they found that metamemory improves over the pre- and early school years, as does the understanding of mental state language. The study found a good deal of individual variation in the results so that children who were advanced in these areas at age four and a half maintained that advantage, and children who were behind at the start remained behind the group and were still behind at the end of the study. This has implications for education – the focus of interventions for improvement of metamemory should be on students with low metamemory abilities since these students are less likely to benefit from the natural process of metamemory development. In addition, the study found that children's ability on theory of mind tests, such as the false belief tests, predicted their ability on metamemory tests, and that children who passed these tests had a better understanding of metacognitive vocabulary. However, the relationship between language, theory of mind and metamemory, was complex and reciprocal. The study found that while children need to understand metacognitive vocabulary to develop metamemory, developing metamemory aids development of metacognitive language.

Larkin's (2007) research with children found a good deal of individual difference in terms of metamemory and also some sophisticated understanding of memory processes. The study involved forty five to six year old children randomly selected from 6 grade 1 classes in one London borough. Kim's Game test was used to collect data. Sixteen objects – some small plastic toys, e.g. a fish, a frog, a parrot, and some natural items, e.g. a shell, a stone, a leaf - were shown to each child. The child was then asked to do anything s/he wanted to help him/her to remember the items. After two minutes the items were covered up and the child was asked to recall as many as possible. Then the child was asked what s/he had done to help them to remember so many items; whether it was easy or difficult to remember them and why; how it could be made easier; what advice s/he would give to

a friend who wanted to remember as well as s/he had, and finally which “bit of him/herself” did the remembering and how it did that. Results showed that all the children used some kind of strategy to remember the items; these included naming them, grouping them into categories and telling stories with them. However, there were some differences in the way children accounted for memory performance. For a small proportion of children (less than ten per cent), remembering was largely a mysterious process; it was linked to “cleverness” but was seen as largely automatic. These children had some understanding that remembering was connected with the brain, but they said it was really done by the eyes and could not be explained. They placed a great deal of faith in adults’ memory, especially their mothers, who they claimed never forgot anything. A second group of children (about 20 per cent) had more understanding of the use of external agencies in remembering – they might make use of their mother to remind them of things. Some children in this category linked forgetting to feeling sad, and had a view of their brains as a kind of store house which needed to be periodically cleaned out before more information could be stored.

However, Larkin’s study (2007) found that the largest percentage of the children had a more sophisticated view of memory and remembering. For instance, they mentioned using strategies such as making stories out of the objects, putting them in alphabetical order or grouping them. One child referred to “sorting out” and “sorting in” – meaning firstly putting the objects one at a time into a circle made from his necklace (he called this “sorting in”) and then removing them one at a time, while saying their names again (he called this “sorting out”). The child claimed that this helped him to remember the objects and he did indeed get all 16 objects correct. Some children referred to the importance of touching the objects, as the feel of the object could then be stored in your memory and would help you to recall it. The children in this category also had some ideas about where their memory was located and how it functioned. They distinguished between remembering and learning and between remembering and thinking. One child said “we can learn by watching others but we cannot remember that way”. Moreover, Larkin (2007) found that other children linked remembering to concentration and the need to work hard at it. They also understood that their memory is fallible and is linked to emotional experiences

Schneider (2008) followed 174 children from the ages of three to five, investigating the relationship between theory of mind at age three and subsequent development of metamemory. Theory of mind (ToM) refers to the “ability to estimate mental states, such as beliefs, desires, or intentions, and to predict other people’s performance based on judgments of their mental states” (p. 115). Schneider also examined the role of language ability in the development of metamemory. In the first place he

found that both ToM and language ability increased steadily with age. Secondly, he was able to show that the stability of the ToM construct was only moderate at the beginning, but increased subsequently, reaching levels of stability similar to those found for the language tests. This finding, Schneider contends, clearly points to a continuity in ToM development. Further, there was a strong relationship between language ability and both ToM and metamemory. Strong language ability at age three was a salient predictor of metamemory at age five. Schneider hypothesised that early ToM competencies can be considered a precursor of subsequent metamemory. Although results suggest that declarative metacognitive knowledge tends to increase with age, developmental trends for procedural metacognitive knowledge, particularly as it relates to monitoring task demands in relation to abilities, are less clear. Knowledge of most facts about memory is already impressive by 11 or 12 years of age. Nonetheless, declarative metamemory is not complete by the end of childhood. Based on previous studies Geurten & Willems (2016) argue that, as early as age three, children use monitoring and control skills to reflect on their memory operations and regulate their task performance. They further claim that four year old children apply these metacognitive skills to detect cues in their environment and use them to guide their memory decisions heuristically.

Schraw and Moshman (1995) define metacognitive theories broadly as systematic frameworks used to explain and direct cognition, metacognitive knowledge, and regulatory skills. Explaining the difference between metacognitive theory and metacognitive knowledge, Schraw and Moshman (1995) give two characteristics of metacognitive theory: firstly, a metacognitive theory allows an individual to integrate diverse aspects of metacognition within a single framework; secondly, a metacognitive theory coordinates beliefs or postulates that allow individuals to predict, control, and explain their cognition, the cognition of others, or cognition in general (p. 357). Schraw and Moshman (1995) believe metacognitive theories change gradually over time and propose three different metacognitive theories indicative of this change: (1) tacit, (2) explicit but informal, and (3) explicit and formal. Schraw and Moshman summarize the characteristics and the relationship among the three metacognitive theories:

We have proposed three types of metacognitive theories and considered how each differs from the others. These theories form a naturally occurring hierarchy of knowledge about cognitive and metacognitive processes. At one end of this continuum are tacit theories, which provide limited guidance and explanatory power. These theories are characterized by loosely systematised knowledge and postulates that are not known consciously by the theorist. Informal theories are partially accessible to the theorist and presumably play a

greater role in self-regulation. Formal theories provide an explicit framework for understanding and regulating one's cognition. Moreover, because their formal and empirical aspects are explicitly distinguished, they are more subject than informal theories to purposeful and rigorous evaluation (p.362).

In their discussion about metacognitive theory, Schraw and Moshman (1995) trace the origins of metacognitive theories to three sources: cultural learning, individual construction, and peer interaction, believing that these sources are not mutually exclusive pathways to self-regulation, but interrelated.

Kuhn (2000) argues that metacognition emerges early in life, in forms that indicate what is to come, and follows an extended developmental course during which it becomes more explicit, more powerful, and hence more effective, as it comes to operate increasingly within the individual's consciousness. Kuhn's (2000) framework of metacognition consists of two levels: (1) meta-strategic knowing which refers to meta-knowing about procedural knowing and (2) metacognitive knowing which refers to meta-knowing about declarative knowing. Kuhn (2000) further divides meta-strategic knowing into meta-task knowledge, which is knowledge about task goals; and meta-strategic knowledge, which is knowledge about strategies available for one to address these goals. While some declarative aspect of meta-knowing and theory of mind develops early in childhood, Kuhn argues that meta-strategic knowledge develops much later, and while young children might be taught some memory or other cognitive strategies, they are unlikely to use these spontaneously. The conscious use of strategies is a metacognitive act which involves monitoring performance and deciding when to use a strategy, selecting the appropriate strategy and evaluating the effect of its use through more monitoring processes. This process, in Kuhn's opinion, is only likely to develop over time through experience, practice and support. Furthermore, Kuhn explains that the meta-level processes dictate strategy selection in a given occasion and also take feedback from the performance level, which leads to enhanced meta-level awareness of the goal and the extent to which it is being met by different strategies, as well as enhanced awareness and understanding of the strategies themselves, including their power and limitations. These enhancements at the meta-level lead to revised strategy selection which Kuhn says may be seen as an increase in meta-level awareness and control. Moreover, Kuhn argues that failure of a newly acquired strategy to transfer to new materials or contexts is due to lack of influence on the meta-level by strategy training. Thus, meta-level behaviour needs to be identified and measured in metacognition training programmes.

Borkowski, Chan and Muthukrishna (2000, p.7) propose a process-oriented model of metacognitive development. In the model, the development of metacognition occurs through seven hierarchical steps:

- (1) The student is initially taught to use a learning strategy and, with repetition, comes to learn about the attributes of that strategy (this is called *specific strategy knowledge*).
- (2) Next, the student learns other strategies and repeats them in multiple contexts. In this way, *specific strategy knowledge* is enlarged and enriched. The student comes to understand when, where, and how to deploy each strategy.
- (3) The student gradually develops the capacity to *select strategies* appropriate for some tasks (but not others), and to fill in knowledge gaps by *monitoring* performance, especially when essential strategy components have not been adequately taught. At this stage, higher-order *executive processes* emerge. This is the beginning of *self-regulation*, the basis for adaptive, planful learning and thinking. Initially, the function of the executive is to analyse the task at hand and to select an appropriate strategy; during the course of learning, its role extends to strategy monitoring and revision.
- (4) As strategic and executive processes become refined, the student comes to recognise the utility and importance of being strategic (*general strategy knowledge accumulates*), and beliefs about *self-efficacy* develop. In addition, as the child acquires domain-specific knowledge and skills, beliefs about efficacy become differentiated across domains. More specifically, students learn to *attribute* successful (and unsuccessful) learning outcomes to *effort expended in strategy deployment* rather than to luck or to task difficulty encountered in specific domains of study. Furthermore, some students come to understand that through self-directed actions, *mental competencies* can be enhanced. In these ways, the metacognitive model integrates cognitive acts (in the form of strategy use) with their motivational causes and consequences. Following most cognitive acts, the student is often provided with, or infers, feedback about the correctness of performance and its specific cause(s). This feedback is essential for shaping personal-motivational states (e.g., attributional beliefs, which in turn can energize the executive processes necessary for strategy selection and deployment in future situations).
- (5) A sense of self-efficacy as well as enjoyment of learning flows from individual strategic events and eventually returns to energize strategy selection and monitoring decisions (i.e. executive processes).

- (6) *General knowledge about the world* as well as *domain-specific knowledge* (e.g., math) accumulates. Such knowledge is often sufficient to solve problems, even without the aid of strategies. In these situations, metacognitive processes such as strategy selection are unnecessary, although some motivational components may remain functional and important.
- (7) Crystallized visions into the future help the student form a number of “*hoped-for* and *feared possible-selves*” providing the impetus for achieving important short-term as well as long-term goals, such as becoming a “competent student” in order to eventually become a “successful lawyer”. In this way these self-system visions take on a futuristic perspective, providing goals and incentives that stimulate the operation of the entire metacognitive system.

3.6 EFFECTS OF METACOGNITION ON LEARNING

Pintrich (2002, p.223) concurs with the need to explicitly teach metacognitive knowledge. Schraw (1998) argues that metacognitive knowledge can be taught and can be developed through four ways. These include promoting general awareness of the importance of metacognition, improving knowledge of cognition, improving regulation of cognition, and fostering environments that promote metacognitive awareness.

The effectiveness of collaborative group approach to problem solving over individual effort regarding improving metacognitive skills has been shown (Cooper, Cox, Nammouz, Case, & Stevens, 2008). Cooper et al. report that students were able to adopt new problem solving strategies within the context of collaborative groups. In a related study, Lazakidou and Retalis (2009) found that in collaborative learning groups, students can increase their problem-solving skills in a relatively short period of time, and at the same time improve their approach to the solution of a given mathematical problem, performing significant signs of autonomy.

Many researchers will agree that reflective thinking during tasks performance is the onset of metacognition in action. However, many students have not developed the habit to reflect on their performance. A technique that appears to be promising in triggering reflective thinking is metacognitive prompting. Georghiades (2006) demonstrated that using metacognitive prompts alongside normal teaching procedures enhanced cross-contextual use of taught electricity concepts. During classroom discussion students were expected to react to the researcher’s prompts and questions, such as: “What are you asked to do in this experiment?” “Can you explain to your partner the method you followed to solve this problem?” etc.

Kramarski, Mevarech, and Arami (2002) investigated the differential effects of cooperative-learning with and without metacognitive instruction on lower and higher achievers' solutions of authentic mathematical tasks. The students in this study were 91 seventh graders who studied in three classrooms. Data were analysed by using qualitative and quantitative methods. Results indicated that students who were exposed to the metacognitive instruction within cooperative learning (COOP+META) significantly outperformed their counterparts who were exposed to cooperative learning with no metacognitive instruction (COOP). The positive effects of COOP+META were observed on both authentic and standard tasks. In addition, the findings showed the positive effects of COOP+META method on lower and higher achievers. However, there were some issues that undermine the validity of the results. Firstly, the authors did not clarify the criteria used to distinguish between high achievers and low achievers. Secondly, although a significant difference in prior knowledge was found between the experimental and control groups, the effect of prior knowledge was not controlled. In the study by Mevarech and Kramarski (2003), two intact grade eight classes were randomly assigned Worked-out Example ($N = 52$) and Metacognitive Training ($N = 70$) conditions. In addition, eight teams ($N = 32$) were randomly selected from all participating classrooms, and the students' problem-solving behaviours were videotaped. Students in the Metacognitive training group were taught mathematics using the following procedure: the teacher introduced the new concepts to the whole class by using the questioning-answer technique. Then, students worked in small heterogeneous groups on problems using the metacognitive prompts. Finally, at the end of the period, the teacher reviewed the new concepts, solved the problems that were considered difficult by many groups, and addressed students' questions. During the group work, the teacher played the role of an additional group member who provided support when needed. For the worked-out example group, the following procedure was followed: in each class period, students were administered a worked-out example followed by four problems of the same kind for them to practise. The worked-out example specified each step in the solution process and provided written explanations as needed. Students were asked to study cooperatively the worked-out example and then to solve the practice problems accordingly. Each student in turn solved a problem reading it out loud, and explained the solution to the group by using the worked-out example. It was found that within cooperative settings, students who were exposed to metacognitive prompting outperformed students who were exposed to worked out examples, on both the immediate and delayed post-tests. In particular, the differences between the two conditions were observed on students' ability to explain their mathematical reasoning.

Kramarski (2004) investigated the effects of forum discussion embedded within metacognitive guidance on mathematical literacy. The study involved 43 seventh-grade students (N = 20 for the FORUM + META group and N = 23 for FORUM only group) who practised online problem solving. The students who were exposed to forum discussion practised problem solving of real-life tasks once a week in the computer lab (90 min). The teacher did not interfere in the discussion; she encouraged the students to participate in the discussion, to send assignments to one another, to reflect on the solutions, and to submit questions regarding the solution process. The students were also encouraged to ask their friends for help when they encountered difficulties in understanding and correcting the solution, if needed. In addition, the students were asked to send the final solution to the teacher, in the forum, or as an attachment file using word or excel. In addition to the forum discussion, students in the FORUM + META group were encouraged to use the metacognitive questions during their discussion in their written explanations when they solved the mathematical tasks, and in their reflection on their friends' solutions. It was found that students who were exposed to FORUM+META discussion outperformed students who were not exposed to metacognitive guidance (FORUM discussion) on mathematical literacy. The effects were observed on various aspects of solving real life tasks: (1) Understanding the task; (2) Using mathematical strategies; (3) Processing information; and (4) Using mathematical reasoning. Smith, Rook and Smith (2007) showed the effect of metacognitive and affective questions on ninth graders' History achievement. In their study, three classes were taught using a common lesson plan, but received different questions to respond to in their journals. One class was used as a control group and actually received no questions as they did not participate in the structured journal-writing activity. One experimental group was given only cognitive or text-related questions to which to respond in their journals. The other experimental group responded to cognitive or text-related questions, metacognitive, and affective questions in their journals. Results indicated that students who responded only to text-related questions had no advantage compared to students who did not participate in journal questions at all. Also students who responded to metacognitive and affective questions in addition to text-related questions demonstrated better retention of content material as evidenced by course grades at the end of the study. Jbeili (2012) found that metacognitive scaffolding embedded within cooperative learning on fifth-graders' significantly improved mathematics conceptual understanding and procedural fluency in learning and solving problems and tasks involving the addition and subtraction of fractions. The study compared three instructional methods: (1) cooperative learning with metacognitive scaffolding (CLMS), (2) cooperative learning with no metacognitive scaffolding

(CL), and (3) traditional instructional method (T). Analysis of covariance showed that students in group CLMS significantly outperformed students in groups CL and T in mathematics conceptual understanding and procedural fluency. The results also showed that students in group CL significantly outperformed their counterparts in group T in mathematics conceptual understanding and procedural fluency.

Kauffman, Ge, Xie and Chen (2008) investigated the independent and interaction effects of problem-solving prompts and reflection prompts on college students' problem solving and writing within a Web-based instructional module. The study employed a 2×2 factorial design. The three experimental groups received either problem solving and reflection prompts, or a problem solving prompt only or reflection prompt only while solving a problem. The prompts were automated and generated during the problem solving process. The control group received neither problem solving nor reflection prompts. They found that students who received problem-solving prompts solved problems and wrote with more clarity than did students who did not receive problem solving prompts. Reflection prompts also positively influenced problem solving and writing, but only when students also received the problem solving prompts. Özsoy and Ataman (2009) investigated the effect of using metacognitive strategy training on mathematical problem solving achievement of fifth grade students. Students in the experimental group ($n = 24$) were provided with metacognitive problem-solving prompts which specified the steps to follow to successfully solve a problem. In addition, problems were provided to students on worksheets which also included metacognitive strategy required to be used by the students in the form of check-lists. At the same time the students in the control group ($n = 23$) received no additional activities and continued their normal lessons. Students were pre- and post-tested with the Mathematical Problem Solving Achievement Test and Turkish version of Metacognitive Skills and Knowledge Assessment (MSA-TR). The results indicated that students in the metacognitive treatment group had significantly improved in both mathematical problem solving achievement and metacognitive skills.

Leopold and Leutner (2015) investigated the effect of metacognitive self-regulation on science text comprehension. In three experiments, students were trained to use strategies for learning from scientific texts: text highlighting (Experiment 1), knowledge mapping (Experiment 2), and visualising (Experiment 3). Each experiment compared a control condition, cognitive strategy training, and a combined cognitive strategy plus metacognitive self-regulation training with a specific focus on the quality of cognitive strategy application. After the training, students applied the learning strategies as they studied scientific texts. Across experiments, the results indicated that

the self-regulation component of the training helped the students to overcome the lack of efficacy of the cognitive strategy- only training when it was not effective by itself: the highlighting-only group was outperformed by the control group but the combined highlighting-plus-self-regulation training reduced this negative effect. The mapping-only group performed as well as the control group, but the combined mapping-plus-self-regulation group outperformed the control group. The visualising-only group outperformed the control group as did the combined visualising-plus-self-regulation group. According to the authors, the results suggest that cognitive learning strategies differ in their potential to induce deep versus surface processing of text contents. Specifically, these results show that the use of a concept map without self-regulation is no better a technique than ordinary reading in science text comprehension. In addition, the metacognitive self-regulation component of the training enhanced students' performance when the cognitive strategy training was not effective by itself. Also, visualization or mental model may compensate for lack of metacognitive self-regulation in science text comprehension.

Direct training in metacognition has been found to be effective in the development of metacognition. Another issue of concern is whether students will be motivated to use the metacognitive skills they have acquired when required. Rahman et al. (2011) surveyed students' preferences for metacognitive development activities based on their learning styles. The study sample consisted 161 science-stream students. Two instruments were used to collect the data on the student's learning style and their strategic preferences for promoting metacognitive skills development in their science classes. Results indicated that the most preferred metacognitive development activities, regardless of dominant learning style, were emotional support, teacher's encouragement and motivation, and student's voice (the feeling that student's own voice was being heard). Nett, Goetz, Hall, and Frenzel (2012) report that testing is one way to motivate students to use metacognitive strategies. The authors explored students' learning-related cognitions prior to an in-class achievement test, with a focus on metacognitive strategy use. A sample of 70 students in grade 11 completed a series of structured, state-based metacognitive questionnaires over a two-week period via the experience sampling method until the day before a class test. Results illustrated students' self-regulatory ability to preserve their motivational and cognitive resources, with test-related cognitions evidenced significantly more often in learning-related as opposed leisure settings. Metacognitive strategy use was also found to significantly increase as the test date approached, underscoring the goal-oriented nature of situated learning behaviours. Higher intercepts and increases in frequency of test-related cognitions over time corresponded positively to test

performance. Of the three metacognitive strategies assessed, monitoring was found to positively correspond with test performance.

Using path model, Sungur (2007) modelled the relationships among motivational beliefs, metacognitive strategy use, and effort regulation in science courses. The study involved 391 high-school students. The Motivated Strategies for Learning Questionnaire was used to measure students' motivational beliefs, metacognitive strategy use, and effort regulation. Results showed that intrinsic goal orientation, beliefs about value of a task, control of learning beliefs, and self-efficacy for learning and performance were predictors of students' metacognitive strategy use. Teng and Zhang (2017) hypothesised a mediation role of self-regulated learning strategy between motivation regulation and writing performance. They investigated the predictive effect of motivational regulation strategies on English-as-a-foreign-language students' writing performance. Results from structural equation modelling showed that motivation regulation directly predicted writing performance and indirectly through self-regulated learning strategies. The author of the above study suggested that the use of self-regulated learning strategy is preceded by the motivation to do so.

3.7 ASSESSMENT OF METACOGNITION

An analysis of existing research on metacognition reveals different conceptualisations of the construct from different theoretical perspectives on learning. From cognitive psychology perspective (e.g. Schraw & Dennison, 1994) metacognition is considered to have two components: knowledge of cognition and regulation of cognition. According to social-cognitive perspective, metacognition also involves motivational and social-emotional processes. Thus, while there is consistent acknowledgement of the importance of metacognition, conceptualisation of the construct differs among theoretical perspectives on learning. Consequently, different self-reported questionnaires for assessing metacognition have been developed.

An issue of disagreement among metacognition researchers from the cognitive psychology perspective has been the components of the construct. Schraw and Dennison (1994) hypothesize eight components of metacognition: declarative knowledge, procedural knowledge, conditional knowledge, planning, information management strategies, comprehension monitoring, debugging strategies and evaluation. Schraw and Dennison developed and tested the validity of a Metacognitive Awareness Inventory (MAI) for measuring metacognitive awareness of adults and adolescents. They conducted two experiments. The first experiment involved 197 university students enrolled in an introductory educational psychology course and was intended to explore the

latent variables underlying a 52-item inventory. Unrestricted factor analysis produced six-factor solutions which did not correspond precisely to the eight hypothesized subscales. However, a forced two-factor solution corresponded to knowledge of cognition and regulation of cognition. In the second experiment involving 112 university students, Schraw and Dennison tested the validity of the inventory. Again factor analysis supported a two factor model of metacognition. Correlation analyses revealed a significant relationship between knowledge of cognition and pre-test judgement of monitoring ability on one hand, and performance on a reading comprehension test on the other hand. No significant relationship manifested between regulation of cognition and any of the performance variables (pre-test judgement of monitoring ability, performance on reading comprehension test). These two factors were found again in a second instrument development study. Dennison, Krawchuk, Howard and Hill (1996) used the results from the Metacognitive Activity Inventory (MAI) study to develop two inventories for use with younger students, the Junior (Jr.) MAI, versions A and B. Their results indicated that both versions A and B revealed two distinct factors, accounting for 64% and 56% of the sample variance in metacognitive activities respectively. Rayne, Sperling, Howard, Miller and Murphy (2002) conducted two studies to investigate measures of children's metacognition. Experiment 1 presented two versions of a self-report inventory, the Jr. MAI, appropriate for assessing metacognition in children in grades 3–9. Factor analyses showed that neither a forced five-factor nor a two-factor solution was easy to interpret. Experiment 2 further addressed properties of the two versions, and compared the instruments to other inventories, teacher ratings of children's metacognition, and student achievement scores. Findings indicated high correlations between the Jr. MAI and an existing metacognitive problem-solving inventory. However, when the original 18 items of Jr. MAI were reduced to 17 and tested with 589 tenth grade students, two-factors – knowledge of cognition and regulation of cognition - were confirmed (Aydin & Ubuz, 2010). Scott and Levy (2013) showed that a two factor model of metacognition is more parsimonious than a five factor model. They extracted items from three existing questionnaires - MAI (Schraw and Dennison, 1994), Inventory of Metacognitive Self-Regulation (IMSR) (Howard, McGee, Shia & Hong, 2000) and Self-Assessment Questionnaire (SAQ) (O'Neil Jr. & Abedi, 1996) and then tested their questionnaire with 640 university students. Both exploratory and confirmatory factor analysis supported a two factor model which explained 40.2% of the total variance in metacognitive self-regulation.

O'Neil Jr. and Abedi (1996) argue that alternative assessments should result in more effort expended and less anxiety, and should engage students in higher level thinking or metacognitive skills. They

believe such assumed advantages should be measured directly and explicitly. They developed a State Metacognitive Inventory (SMI) and tested it iteratively with college and high school students. Factor analysis consistently confirmed a four factor model of metacognition with acceptable internal consistency coefficients as predicted. The factors were planning, self-checking, cognitive strategies and self-awareness. For Howard, McGee, Shia & Hong (2000) a metacognitive measurement should be valid for research and useful for assessment and intervention in classrooms. Accordingly, they developed the Inventory of Metacognitive Self-Regulation (IMSR) and tested it using 829 grade 6 – 9 students. Factor analysis indicated that there were five factors of metacognition relevant to problem solving. The factors had acceptable reliability ($\alpha = 0.720$ to $\alpha = 0.867$) and included knowledge of cognition, objectivity, problem representation, subtask monitoring and evaluation. Balcikanli (2011) reports that reducing the number of items in the original MAI from 52 to 24 yielded a parsimonious six factor solution. The factors corresponded to declarative knowledge, procedural knowledge, conditional knowledge, planning, monitoring and evaluation. Akin, Abaci and Cetin (2007) confirm the eight factors underlying the Metacognitive Activity Inventory (MAI) as predicted by Schraw and Dennison (1994). The study involved 607 university students. Respondents completed the English and Turkish versions of the MAI. Correlations between the two versions were high ($r = .93$) while internal consistency of the entire MAI was also high (.95). Exploratory factor analysis yielded eight factors as originally hypothesized. However, when MAI was applied to adolescents (15 – 16years), factor analysis showed that MAI had no underlying structure (Rahman & Masrur, 2011). The author concludes that lack of structure for MAI observed using this sample could be due to the age, arguing that at this age, children are much less accurate in self-awareness, often seeing themselves as what they would like to be rather than as they really are. Clearly, the lower level of accurate self-awareness of students made the data less precise. This has implications for measurement of metacognition among adolescents using self-reported questionnaire.

Although there is lack of agreement among researchers concerning the number of factors underlying the construct metacognition, one consistent finding is that metacognition is related to performance. Using the MAI (Schraw & Dennison, 1994), Şendurur, Şendurur, Mutlu and Baser (2011) investigated the metacognitive awareness of 49 first year university students in Turkey. The study also explored the relationship among metacognitive factors and academic success variables (GPA and course grade) and demographic variables (gender and graduated high school type). Results indicated that more than half of the students (57% of total scores) had low metacognitive awareness.

Paired *t*-test revealed that individuals' score on *knowledge of cognition* was significantly higher than the score on *regulation of cognition*. GPA weakly correlated with two variables of regulation of cognition (planning and monitoring), while course grade correlated with awareness of evaluation. Salari , Tarmizi, Hamzah, & Hambali (2013) investigated the reliability of MAI (Schraw & Dennison, 1994) and its correlation with nursing student achievement in Iran. The Persian version of the MAI was administered to 40 third year paediatric nursing students. In addition, paediatric nursing achievement was measured using multiple choice and open ended items. Results revealed that the MAI was reliable with a Cronbach's alpha coefficient of 0.74. In addition, there was high correlation between MAI factors and components of the achievement test, with the strongest correlation observed between higher order questions and overall MAI ($r = 0.831$). Correlation between lower order questions and overall MAI was weak ($r = 0.369$). These results emphasise the notion that level of difficulty of test item determines whether a metacognitive strategy will be used or not.

A few other questionnaires integrate concepts across the different learning theories. One of the early self-reported questionnaires of this category is the Motivated Strategy for Learning Questionnaire (MSLQ) (Pintrich & De Groot, 1990). The questionnaire was administered to 173 seventh-grade students. In addition, several indicators of academic performance (seatwork, tests/quizzes, essays/reports, and two semester grades) were measured. Factor analysis revealed an underlying structure with factors across different theoretical perspectives on learning: motivational components (intrinsic value, self-efficacy and test anxiety) and self-regulated learning components (strategy use and self-regulation). Regression analyses showed the predictive ability of MSLQ. Depending on the outcome measure, self-regulation, self-efficacy, and test anxiety emerged as the best predictors of performance. Tock and Moxley (2017) criticise the metacognitive self-regulation (MSR) scale of the MSLQ for lack of well-established psychometric properties and validity. In Study 1 they conducted both exploratory and confirmatory factor analysis to test the one-factor specification of the MSR scale. Time and study environment, total study time and cumulative grade point average were included as outcome variables in a structural equation model. Results of study one indicated poor one-factor model fit. In Study 2, a modified one-factor model was introduced that consisted of nine items and was named metacognitive self-regulation revised (MSR-R). A path analysis was performed to examine the relationship of the MSR-R to variables from Study 1. The results of Study 2 revealed that two and three-factor models of the MSR-R have improved psychometric properties and reliability.

Meijer et al. (2013) argue that several aspects of metacognition, in general, are not subsumed under the components metacognitive knowledge and metacognitive regulation. Meijer et al. use the term metacognitive responsiveness to refer to these aspects, which include students' sensitivity to metacognitive experiences; general awareness of metacognition and the importance thereof; and curiosity to learn about metacognition by information and feedback. The Motivated Strategies for Learning Questionnaire (MSLQ) and MAI questionnaires mainly focus on two of the most important components of metacognition: metacognitive knowledge and metacognitive regulation, without measuring metacognitive responsiveness, which Meijer et al. (2013) consider another important distinct component of metacognition. The authors developed an Independent Awareness of Learning Inventory (IALI) to address this limitation of the previous questionnaire. The 45-item questionnaire was administered to 1058 students in various types of Teacher Training Institutes in the Netherlands and Belgium. The abridged English version of the questionnaire was administered to another sample of 729 university students for validity study. Results showed that IALI had a satisfactory reliability. The validity study showed that there was a considerable level of congruity between parts of the AILI questionnaire and the relevant parts of the Motivated Strategies for Learning Questionnaire (MSLQ).

From the social constructivist perspective, metacognition can be improved by creating supportive learning environment. Thomas (2003) developed the Metacognitive Orientation Learning Environment Scale – Science (MOLES-S). MOLES-S gauges the students' perceptions of the extent to which the learning environment supports the development and enhancement of students' metacognition and consists of 35 items. The instrument was administered to 1026 science students aged between 14 and 17 years, and factor analysis revealed seven subscales with acceptable reliability coefficients ranging from 0.72 to 0.87. The subscales were: (1) Metacognitive Demands, (2) Student-Student Discourse, (3) Student-Teacher Discourse, (4) Student Voice, (5) Distributed Control, (6) Teacher Encouragement and Support, and (7) Emotional Support. Later, Thomas, Anderson and Nashon (2008) developed a questionnaire that integrated concepts from the motivation and social constructivism perspective of metacognition: Self-efficacy and Metacognitive Learning Inventory-Science questionnaire (SEMLI-S). The 72 item questionnaire was administered to 465 high school students. The final version of SEMLI-S was reduced to 30 items with five factors, following an iterative process of factor analysis and Rasch analysis. The five factors were: (1) Constructivist Connectivity (CC); (2) Monitoring, Evaluation and Planning (MEP); (3) Science

Learning Self-efficacy (SE); (4) Learning Risks Awareness (AW); and (5) Control of Concentration (CO). Reliability of the factors with this sample ranges from 0.68 to 0.85.

Cooper and Sandi-Urena (2009) believe that there are specific regulatory behaviours that are unique to chemistry problem solving. They developed a Metacognitive Activities Inventory (MCAI) for assessing metacognitive skillfulness in chemistry problem solving based on the regulation of cognition factors of metacognition, which comprise planning, monitoring and evaluation (Schraw & Dennison, 1994). For construction of the MCAI, they obtained an initial pool of items using a panel-of-experts technique. The experts were asked to list ten activities or skills they deemed related to successful problem solving. The study involved different samples of university students – 310 students in the main study and 609 students in the replication study. Reliability analysis showed that the MCAI was highly reliable across the different samples (alpha ranges from 0.85 - 0.91 for undergraduate students; and 0.74 - 0.92 for graduate students). However, factor analysis did not reveal the internal structure of the scale. Knowing the underlying structure of a metacognition questionnaire is important because it helps to determine the specific aspect of student metacognitive skills that is more important for solving a particular task. This will help in planning interventions that address this aspects directly. I believe that the theoretical model of metacognition that informed the construction of MCAI items (planning, monitoring and evaluation) is too simple to account for the behaviours that interplay to drive the problem solving process towards the goal. Thomas, Anderson and Nashon (2008) have shown that items for planning, monitoring and evaluation items cluster together when mixed with items measuring other components of metacognition. This suggests that these processes do not occur in isolation but alongside one another, with implications on operationalisation and measurement of the construct.

3.8 BACKGROUND TO CONSTRUCTION OF THE METACOGNITIVE SKILLS QUESTIONNAIRE

Zimmerman (1995) argues that self-regulation involves more than metacognitive knowledge and skills, explaining that views of self-regulated learning which do not include self-efficacy and personal agency and the motivational and behavioural processes to put these self-beliefs into effect, have difficulty explaining students' self-regulation failures and successes. According to Efklides (2006), metacognitive experiences can trigger either rapid, nonconscious control decisions or conscious analytic ones. These experiences also trigger attributions regarding the outcome of cognitive processing: for example, feeling of confidence leads to attribution of effort and ability,

whereas feeling of difficulty leads to attribution of task difficulty (Metallidou & Efklides, 2001). These attributions have implications for the expectancy of success and task value and may lead to the continuation of engagement or to the abandonment of the task at a next self-regulated learning cycle. Metacognitive feelings such as feeling of knowing may provide the intrinsic motivation needed to continue with a challenging task (Efklides, 2011). Thus, inferences from knowledge of a student's metacognitive experiences and performance can be used to gauge the student's control decisions and the motivation thereof. However, many self-report questionnaires for assessing self-regulation do not usually include the assessment of metacognitive experiences. The metacognitive skills questionnaire used in this study was adapted from Cooper and Sandi-Urena (2009). The adaptation involved writing more items, rephrasing some of the original items and deleting items that were not valid. Details about the adaptations and pilot testing of this questionnaire are given in sections 5.8.1.1 and 6.7 respectively.

3.9 THEORETICAL FRAMEWORK FOR THE CHEMICAL EQUILIBRIUM METACOGNITIVE SKILLS QUESTIONNAIRE

This study is underpinned by the process-oriented model of metacognition which posits that self-regulation develops gradually, with practice (Borkowski, Chan & Muthukrishna, 2000, p. 5). At the centre of the metacognitive model is strategy use – that is how well the student is able to select and use a particular learning strategy to achieve a goal. At the peripheral are the higher-order executive or meta-level processes which initially help to analyse the task, select an appropriate strategy and then monitor the performance at the later stages of problem-solving.

Figure 3.1 below suggests that, following most cognitive acts, the child is often provided with, or infers, feedback in the form of affect about the correctness of performance and its specific cause(s). This feedback is essential for shaping personal-motivational states (e.g., attributional beliefs), which in turn can energize the executive processes necessary for strategy selection and deployment in future situations. As strategic and executive processes become refined through more practice, the student comes to recognise the utility and importance of being strategic (general strategy knowledge accumulates), and beliefs about self-efficacy develop. In addition, as the child acquires domain-specific knowledge and skills, beliefs about efficacy become differentiated across domains. More specifically, students learn to attribute successful (and unsuccessful) learning outcomes to effort expended in strategy deployment rather than to luck or to task difficulty encountered in specific domains of study. Furthermore, some students come to understand that through self-directed

actions, mental competencies can be enhanced. As shown in this framework, executive processes relate to a specific task and should be assessed within the context of this task.

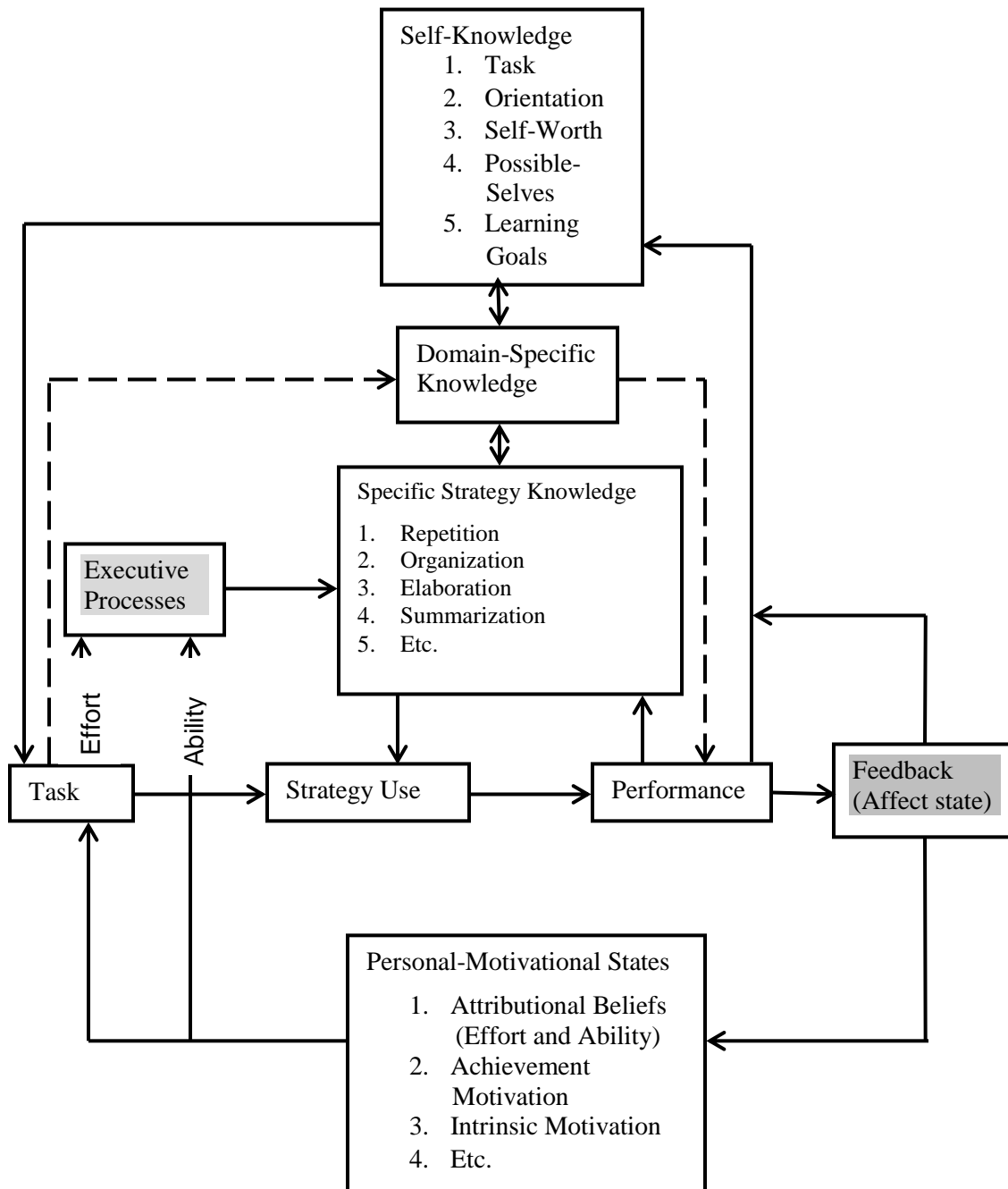


Figure 3.1: Cognitive, motivational, and self-system components of metacognition: The complete model. (source: Borkowski, Chan & Muthukrishna, 2000, p. 5).

3.10 SUMMARY

The review of various definitions of metacognition shows that the construct is multi-faceted and difficult to define. Various theoretical frameworks have attempted to describe the construct;

consequently, different self-report instruments have been developed to measure metacognition. Although there is consensus among different theoretical frameworks about the role of metacognition in learning, there are differences in what is assessed as metacognition. Within the same framework, past research has shown disagreements about the number of components of metacognition. The review further revealed a relationship between metacognition and other concepts. Strong links have been found between metacognition, critical thinking, approach to learning and executive function. The review has shown that metacognition is developmental, and can be enhanced through training. This can begin as early as the primary school with a variety of techniques such as metacognitive questions, teacher support and encouragement, allowing students' voice in the classroom and using visualisation. Most of the studies on training in metacognition have been done in mathematics education, and the evidence available supports the inclusion of metacognitive development activities in the school curriculum. However, the activities that promote metacognition developments in science learning are scanty. While a number of potential strategies such as inquiry, analogies, concept maps, and metacognitive questioning for metacognition development have been suggested, it is not clear how these strategies should be designed and implemented to foster conceptual change and metacognition development in science in order to make conceptual change learning more durable and transferable. The next chapter discusses research on conceptual change instruction in science with a focus on inquiry-based science instruction and its potential role in the development of metacognition.

CHAPTER FOUR: CONCEPTUAL CHANGE AND INQUIRY SCIENCE EDUCATION

4.1 INTRODUCTION

This chapter begins with a discussion on the links among conceptual change, inquiry learning and metacognition. The chapter continues by presenting an overview of the development of inquiry-based science education and the role that policy documents have played in shaping current conceptions of inquiry-based science instruction. The chapter continues with a review of challenges that impede the implementation of inquiry-based science teaching and learning. The chapter also discusses the teaching and learning strategies that align with inquiry-based science instruction and advances arguments for preference of argument-based strategies over strategies that focus on sequencing of instruction. Implementation barriers to inquiry science instruction are included in the discussion. The quality of students' arguments and conditions that tend to support good quality arguments are also discussed, as is the effect of argument-based science instruction on learning. Finally the chapter concludes with a summary of findings that emerged from the review.

4.2.1 CONCEPTUAL CHANGE, INQUIRY-BASED INSTRUCTION AND METACOGNITION

Science education researchers have been concerned with inquiry instructional strategies to achieve the goals of inquiry which includes conceptual change. In the 1950s expansion projects such as Nuffield project in the UK and the Physical Sciences Study Committee (PSSC) and the Biological Sciences Curriculum Study (BSCS) in the US created research interest in teaching science as inquiry (Harlen, 1999). In the 1990s, renewed research interest in inquiry learning in the US followed the publication of the National Science Education Standards (NRC, 1996;2000;2012). Along side the promotion of inquiry, research on learning as conceptual change and metacognition development were going on. The definition of conceptual change as “opening up of conceptual space through increased meta-conceptual awareness and epistemological sophistication, creating the possibility of entertaining different perspectives and different point of views” (Vosniadou, 2008, p.279) indicate that conceptual change and metacognition are linked. Indeed Saçkes and Trundle (2016) report that meta-conceptual awareness of change during conceptual change instruction enhanced the durability of the change. According to White, Frederiksen and Collins (2009) engaging in inquiry practices such as such as being able to use conceptual models to generate explanations and check for understanding facilitates both students' learning of inquiry and

metacognitive development. Suwono, Susanti and Lestari (2017) report that guided inquiry facilitated blended learning improves high school students' metacognitive skills and conceptual understanding of the circulatory system. Therefore inquiry-based instruction has the potential to promote conceptual change and metacognitive development.

4.2.2 THE DEVELOPMENT OF INQUIRY-BASED SCIENCE INSTRUCTION

The inclusion of inquiry into K–12 in the US (equivalent to kindergarten to grade 12 in South Africa) science curriculum was recommended by John Dewey (1910). Dewey considered that science had been taught too much as an accumulation of ready-made material with which students are to be made familiar with and not enough as a method of thinking, an attitude of mind, after the pattern according to which mental habits are to be transformed. Dewey argues that the worth of science knowledge that one possesses lies in method of acquisition of that knowledge:

Such knowledge never can be learned by itself; it is not information, but a mode of intelligent practice, a habitual disposition of mind. Only by taking a hand in the making of knowledge, by transferring guess and opinion into belief authorised by inquiry, does one ever get a knowledge of the method of knowing (p. 12).

Dewey encourages K-12 teachers of science to use inquiry as a teaching and learning strategy where the scientific method consists of the six steps: sensing perplexing situations, clarifying the problem, formulating a tentative hypothesis, testing the hypothesis, revising with rigorous tests, and acting on the solution. In Dewey's model, the student is actively involved, and the teacher has a role as facilitator and guide. Dewey (1944) modifies his earlier interpretation of the scientific method to accomplish his goal of reflective thinking: presentation of the problem, formation of a hypothesis, collecting data during the experiment, and formulation of a conclusion.

Schwab (1960) describes two types of inquiry: stable (growing body of knowledge) and fluid (invention of new conceptual structures that revolutionize science). Schwab opines that science should be taught in a manner consistent with the way modern science operates. He also encourages science teachers to use the laboratory to assist students in their study of science concepts. He recommends that science be taught in an inquiry format. Besides using laboratory investigation to study science concepts, students could use and read reports or books about research and have discussions about problems, data, the role of technology, the interpretation of data, and any conclusions reached by scientists. Rutherford (1964) considers inquiry as both content and concepts that are to be understood in the context of how they were discovered, so that future inquiries can

occur. He recommends that all science teachers should have a background in the history and philosophy of science. These recommendations motivated investigations into the status of science education

Project Synthesis was an effort to examine science education by reviewing a number of research studies funded by the National Science Foundation (Harms, 1980). The purpose of the project was to make policy-relevant interpretations of a large body of data which portrayed the state of science education in the late 1970s. The studies included “The Status of Pre-College Science, Mathematics and Social Science Education: 1955-1975,” Case Studies in Science Education,” and “1977 National Survey of Science, Mathematics and Social Education.” Project Synthesis also examined the third set of results of the National Assessment of Educational Progress. In addition to these reports, the staff of Project Synthesis also examined journal articles in science education, and analysed the most widely used textbooks because of their influence on the science education. Inquiry was one of the five areas of Project Synthesis (Harms, 1980). The Project Synthesis report divided student outcomes for inquiry into three categories (science process skills, nature of scientific inquiry, and general inquiry process). A finding reported by the inquiry group was that, although science teachers favoured the use of inquiry practices, there was very little inquiry in actual classrooms. This group pointed out that many teachers found inquiry methods difficult to manage, and that equipment and materials were not readily available. The inquiry group, after considering many alternatives, recommended a reformulation of the traditional views about teaching scientific inquiry. They recommended that all student outcomes with respect to inquiry should be responsive to individual differences, personal goals and community wishes.

Project 2061, the long-term efforts by the American Association for the Advancement of Science (AAAS) to reform K–12 science, identifies what all students should know and be able to do when they graduate at the end of 12th grade. Their first document, *Science for All Americans* (SFAA) (Rutherford & Ahlgren, 1989) defines scientific literacy rather broadly. Subsequently, *Benchmarks for Scientific Literacy* (AAAS, 1993) organises the topics into K–2, 3–4, 5–8, and 9–12 grade-level groupings. Project 2061 establishes goals for the teaching of inquiry in the SFAA chapter entitled “Habits of the Mind,” and inquiry is considered as a science content topic using the following recommendations: start with questions about nature; engage students actively; concentrate on the collection and use of evidence; provide historical perspective; insist on clear expression; use a team approach; do not separate knowledge from finding out, and de-emphasize the memorization of technical vocabulary. Later, the *Atlas of Scientific Literacy* (AAAS, 2001) included a series of

strand maps to illustrate several concepts of the Benchmarks (AAAS, 1993). They developed three strand maps on their interpretation of scientific inquiry. First, evidence and reasoning in inquiry includes two categories – lines of reasoning and observations and evidence. The second includes four categories of scientific investigations: control and condition, reliability of results, record keeping, and kinds of investigations. The third category states that scientific theories consist of six categories: making sense of evidence, alternative explanations, theory modifications, reliability of results, safeguards, and expectations and explanations. The overlapping categories illustrate how inquiry is treated as content. A second policy document, the *National Science Education Standards* (NSES) (National Research Council [NRC], 1996) considers inquiry as the overarching goal of scientific literacy. The NSES provides guidance on what science students are to know, how teachers are to teach science, and how teachers are to assess students. The NSES goes beyond Project 2061 in describing inquiry. In the first place, inquiry is the science content area that is viewed from two perspectives: what students should understand about scientific inquiry, and the abilities students develop based on their experiences with scientific inquiry. Secondly, inquiry also includes the teaching strategies associated with inquiry-based science activities.

Bybee (1997) argues that K–12 teachers of science should not separate science content from the processes of science. He encourages combining science processes with scientific knowledge, reasoning and critical thinking so that students can develop a richer, deeper understanding of science. Inquiry in this context has also been encouraged by the NSES (NRC, 1996), Howe (1997), Project 2061 (AAAS, 1993), and Rutherford and Ahlgren (1989). To provide clarification on inquiry, the NRC (2000) published *Inquiry and the National Science Education Standards* and identified five essential features of inquiry, regardless of grade level:

1. Scientifically oriented questions that will engage the students.
2. Evidence collected by students that allows them to develop and evaluate their explanations to the scientifically oriented questions.
3. Explanations developed by students from their evidence to address the scientifically oriented questions.
4. Evaluation of their explanations, which can include alternative explanations that reflect scientific understanding.
5. Communication and justification of their proposed explanations.

These essential features were expected to introduce students to many important aspects of science while helping them to develop a clearer and deeper knowledge of science concepts and processes.

According to the NRC (1996, 2000), K–12 teachers of science must know that inquiry involves (1) the cognitive abilities that their students must develop; (2) an understanding of methods used by scientists to search for answers for their research questions; and (3) a variety of teaching strategies that help students to learn about scientific inquiry, develop their abilities of inquiry, and understand science concepts (Bybee, 2000; NRC, 1996, 2000). The NRC (1996) includes a list of increased emphasis and decreased emphasis regarding inquiry. These statements allow teachers of science to see whether their perspectives about the three domains of inquiry are compatible with the reform movement in K– 12 science. Also, the NRC (1996, 2000) acknowledges that not all science concepts can or should be taught using inquiry. The following three paragraphs summarise interpretations about inquiry from the NRC in 1996, and each of these domains is clarified in the 2000 NRC document. The fundamental abilities of inquiry specified by the NRC (1996) are to:

1. identify questions and concepts that guide investigations (students formulate a testable hypothesis and an appropriate design to be used);
2. design and conduct scientific investigations (using major concepts, proper equipment, safety precautions, use of technologies, etc., where students must use evidence, apply logic, and construct an argument for their proposed explanations);
3. use appropriate technologies and mathematics to improve investigations and communications;
4. formulate and revise scientific explanations and models using logic and evidence (the students' inquiry should result in an explanation or a model);
5. recognise and analyse alternative explanations and models (reviewing current scientific understanding and evidence to determine which explanation of the model is best); and
6. communicate and defend a scientific argument (students should refine their skills by presenting written and oral presentations that involve responding appropriately to critical comments from peers).

Acquiring these six abilities requires K–12 teachers of science to provide multiple investigation opportunities for students. This type of investigation would not be a verification laboratory experience. When students practise inquiry, it helps them develop their critical thinking abilities and scientific reasoning, while developing a deeper understanding of science (NRC, 2000). The second domain of inquiry is the understanding of inquiry so that students will develop meaning about science and how scientists work. The six categories identified by the NRC (1996) are as follows:

1. Conceptual principles and knowledge that guide scientific inquiries.

2. Investigations undertaken for a wide variety of reasons – to discover new aspects, explain new phenomena, test conclusions of previous investigations, or test predictions of theories.
3. Use of technology to enhance the gathering and analysis of data to result in greater accuracy and precision of the data.
4. Use of mathematics and its tools and models for improving the questions, gathering data, constructing explanations, and communicating results.
5. Scientific explanations that follow accepted criteria of logically consistent explanation, follow rules of evidence, are open to question and modification, and are based upon historical and current science knowledge.
6. Different types of investigations and results involving public communication within the science community. (To defend their results, scientists use logical arguments that identify connections between phenomena, previous investigations, and historical scientific knowledge; these reports must include clearly described procedures so other scientists can replicate or lead to future research).

This domain of inquiry concentrates on *how* and *why* scientific knowledge changes when new evidence, methods, or explanations occur among members of the scientific community. Therefore, they will vary by grade level, but will be very similar, except for increasing complexity (NRC, 2000).

The third domain of inquiry of the NSES is found in the teaching standards. There are several teaching and learning strategies that facilitate students' developing a better understanding of science. Science teacher educators need to provide experiences and information so that future K–12 teachers of science can provide high-quality inquiry science lessons. Aspects of inquiry teaching include strategies to assess students' prior knowledge and ways to utilise this information in their teaching; effective questioning strategies, including open-ended questions; long-term investigations, rather than single-period verification-type investigations, and so forth. To accomplish high quality teaching, pre-service teachers need to participate in collaborative learning opportunities. By pairing similar observations in their field experiences with master teachers of science, the NSES expects that pre-service teachers will develop a better personal model of how inquiry teaching facilitates students' learning of science (NRC, 2000).

The NRC (2012) published a new policy document for USA – *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. The document proposes that K-12 science and engineering education should focus on a limited number of disciplinary core ideas and

crosscutting concepts, be designed so that students continually build on and revise their knowledge and abilities over multiple years, and support the integration of such knowledge and abilities with the practices needed to engage in scientific inquiry and engineering design. In the document, science, engineering and technology are to be integrated along eight practices considered essential for learning science and engineering in grades K-12:

1. Asking questions (for science) and defining problems (for engineering).
2. Developing and using models.
3. Planning and carrying out investigations.
4. Analysing and interpreting data.
5. Using mathematics and computational thinking.
6. Constructing explanations (for science) and designing solutions (for engineering).
7. Engaging in argument from evidence.
8. Obtaining, evaluating, and communicating information.

Inquiry, regarded in this document as *practices*, provides students with engaging opportunities to experience how scientists study the natural world. Thus, the meaning of inquiry as how scientists study the natural world, and the goal of inquiry in the science curriculum as developing knowledge and investigative skills, remain persistent attributes of inquiry in policy documents. It is also expected that by engaging in inquiry-based learning activities, students' conceptual understanding, critical thinking and problem solving abilities will be enhanced. Developing scientific inquiry skills has been advocated as a common curriculum goal in school science education throughout the world. Curriculum documents advocate that teachers use strategies that involve children "in asking scientifically valid questions, setting up investigations, collecting and analysing data, and coming to some conclusion based on the data collected" (Crawford, 2014, p. 515). In South Africa, this need is expressed in the new Curriculum and Assessment Policy Statement (CAPS) document for Physical Science where Specific Aim states that "the purpose of Physical Sciences is to make students aware of their environment and to equip students with investigating skills relating to physical and chemical phenomena" (DBE, 2011, p. 8). Despite attempts by policy documents to clarify the meaning of inquiry, the implementation of inquiry in science teaching has been a challenge.

4.2.3 BARRIERS TO THE IMPLEMENTATION OF INQUIRY-BASED INSTRUCTION.

Welch, Klopfer, Aikenhead and Robinson (1981) identify the reasons why USA teachers do not use inquiry; they identify limited teacher preparation, including school managers' lack of time, limited available materials; lack of support; emphasis on content only; and difficulty in using inquiry to teach. Subsequently, Eltinge and Roberts (1993) identify three reasons for avoiding inquiry: state documents emphasising content, easier to access content, and textbooks' emphasis of science as a body of knowledge. According to Anderson (2002), the last half of the 20th Century associates inquiry with "good science teaching and learning." His synthesis of the research about inquiry makes it clear that both teachers and students must be considered. Anderson opines that science teacher's beliefs and values about students, teaching, and the purpose of education, influence their adoption and implementation of inquiry. He specifically describes three barriers or dilemmas that influence the implementation of inquiry as envisioned by the NSES (NRC, 1996):

1. *Technical dilemmas* include the ability to teach constructively; the degree of commitment to the textbook; the challenges presented by state assessments; the difficulties of implementing group work; the challenge of the new teacher role as a facilitator; the challenge of the new student role as an active, rather than a passive, student; and inadequate professional development.
2. *Political dilemmas* include short-term or limited professional development programmes; parental resistance that science is taught differently than they experienced; unresolved conflicts among science teachers about what and how to teach; lack of available resources, and differing views about failures must be addressed at local and state levels because of funding ramifications.
3. *Cultural dilemmas* include quality of textbooks and support materials; views about purposes of assessment, and view of preparation for the next science class.

Further research on inquiry science teaching continues to confirm many of the factors that hinder the implementation of inquiry based approaches in schools as by Anderson (2002). These factors relate to curriculum, teacher, students, schools and entire context of implementation. Perhaps the most important of these factors is teacher beliefs about inquiry, since the teacher is at the centre of implementation. Teachers' misconceptions about inquiry science teaching can evoke negative attitudes towards inquiry, such as that inquiry science teaching wastes instructional time; inquiry does not matter as long as students are passing the national exam, and students do not have the capacity to do open-ended inquiry (Trautmann, MaKinster & Avery, 2004). Moore (2014) reports

that teaching beliefs, self-efficacy, experience, and possible misunderstandings of the concept of inquiry-based teaching may influence implementation. These factors may also influence fidelity of implementation. Penelope and Ji (2016) reveal that teachers often show limited understanding about inquiry-based teaching, often believing that inquiry means engaging in hands-on lab activities, and devote small amounts of time for implementing inquiry teaching. Gormally, Sullivan and Szeinbaum (2016) report the following as factors as impeding the implementation of inquiry based science teaching by teaching assistants (TAs): lack of sufficient facilitation skills; the problem of changing roles from transmitters of knowledge to facilitators of learning in inquiry based instruction; and pressure from students whose evaluation comments reinforce teacher-centred behaviours, pushing TA to adopt transmissive roles.

Abd-El-Khalick et al. (2004) integrate perspectives across countries on factors that impede the implementation of inquiry- based science education in schools. Their report states that state documents and related professional development activities in the US all omit attention to understandings about inquiry and Nature of Science (NOS). In Venezuela, there is lack of a clear framework for inquiry and NOS in the science curriculum, resulting in contradictory messages in curricular materials to teachers. In Australia, although primary teachers have initial teacher education in science, not all primary teachers have the confidence to teach science in an effective, inquiry-based manner. Examination-related anxieties, accountability pressures, lack of instructional time, and efficiency beliefs directly influence the way teachers approach science teaching in Taiwanese classrooms. In South Africa a lack of professional science knowledge (content knowledge, pedagogical content knowledge, and pedagogical knowledge) contributes toward teachers' uncertainty in inquiry-based teaching in township schools. Also, extrinsic factors such as school ethos, professional support, resource adequacy, and time, serve as significant barriers in the implementation of inquiry-based education at the school (Ramnarain, 2016). Furthermore, teachers lack the skills to support students' critical thinking and development of scientific concepts in inquiry-based activities (Ramnarain, 2015). Capps, Shemwell and Young (2016) report that most teachers they surveyed (approximately 60%) had vague knowledge of inquiry and misinterpreted inquiry enactment statements when asked about them in an interview. Dimensions in which teachers misinterpreted inquiry included asking scientifically oriented questions, constructing explanations and constructing and using models.

The Dr Stirling McDowell Foundation (2005) identifies time constraints, lack of materials, large class sizes, students' beliefs about teaching, examination pressure, students' abilities and social-cultural issues as factors that influence the implementation of inquiry based science teaching.

Dorier and Garcia (2013) traced the way conditions and constraints are operative in affecting the implementation of inquiry based Mathematics and Science education (IBMSE), and report that the persistence of dominant teaching practices – traditional teacher centred approaches – act as a definite barrier for the implementation of IBMSE, which challenges teachers' self-perceived roles in the classroom and forces them to adopt a different position. “Even when teachers are aware of what their role should be, overcoming their current practices is a major challenge for any action that foresees a wider use of IBMSE.” (p. 842). Another barrier to the implementation of IBMSE is lack of a sustained and systematic strategy aimed at supporting teachers in their professional development towards IBMSE. “In-service training is very loosely controlled and the training mainly consists of one- or two-day sessions mostly organised by volunteer teachers who do not have a specific qualification as trainers” (p. 843). Barriers to the implementation of IBMSE are also operative as the resistance to change offered by teachers, students and parents, and assessment policies which continue to reflect traditional perspectives on assessment, discouraging teachers from implementing IBMSE. The above studies suggest that barriers to the implementation of inquiry-based science teaching could range from limitations imposed by science teachers, the science curriculum, ethos of the school up to availability of materials. The above barriers suggest that, even where inquiry-based science teaching has been implemented, the ultimate goal of knowledge and skills integration through inquiry practice (NRC, 2012) is far from being reached, especially as teachers lack understanding of scientific inquiry. However, Fang et al. (2016) report that inquiry curriculum based on different instructional designs is supportive in developing students' conceptual knowledge and integration of science content knowledge with inquiry abilities. In the next section research advances in supporting knowledge integration through inquiry-based science teaching will be discussed further.

4.3 MODELS OF INQUIRY AS A CONCEPTUAL CHANGE INSTRUCTIONAL STRATEGY

Prior to the NSES frameworks of inquiry, a number of attempts have been made at developing conceptual change teaching and learning models that align with inquiry. For example, the Nuffield projects in junior and secondary schools in the UK; and the PSSC and BSCS in the US (Harlen,

1999). One of the inquiry-aligned instructional models that gained popularity in the US in the 1980s was the BSCS 5E instructional model (Bybee et al, 2006). The BSCS 5E instructional model assumes that learning of science occurs in five phases: Engagement, Exploration, Explanation, Elaboration and Evaluation. Bybee et al (2006) describe the activities in each of the phases of the 5E instructional model as follows:

Engagement

In the engagement phase the teacher or a curriculum task assesses the students' prior knowledge and helps them become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should make connections between past and present learning experiences, expose prior conceptions, and organise students' thinking toward the learning outcomes of current activities. .

Exploration

Exploration experiences provide students with a common base of activities within which current concepts (i.e. misconceptions), processes, and skills are identified and conceptual change is facilitated. Students may complete lab activities that help them use prior knowledge to generate new ideas, explore questions and possibilities, and design and conduct a preliminary investigation.

Explanation

The explanation phase focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills, or behaviours. This phase also provides opportunities for teachers to directly introduce a concept, process, or skill. Students explain their understanding of the concept. An explanation from the teacher or the curriculum may guide them toward a deeper understanding, which is a critical part of this phase.

Elaboration

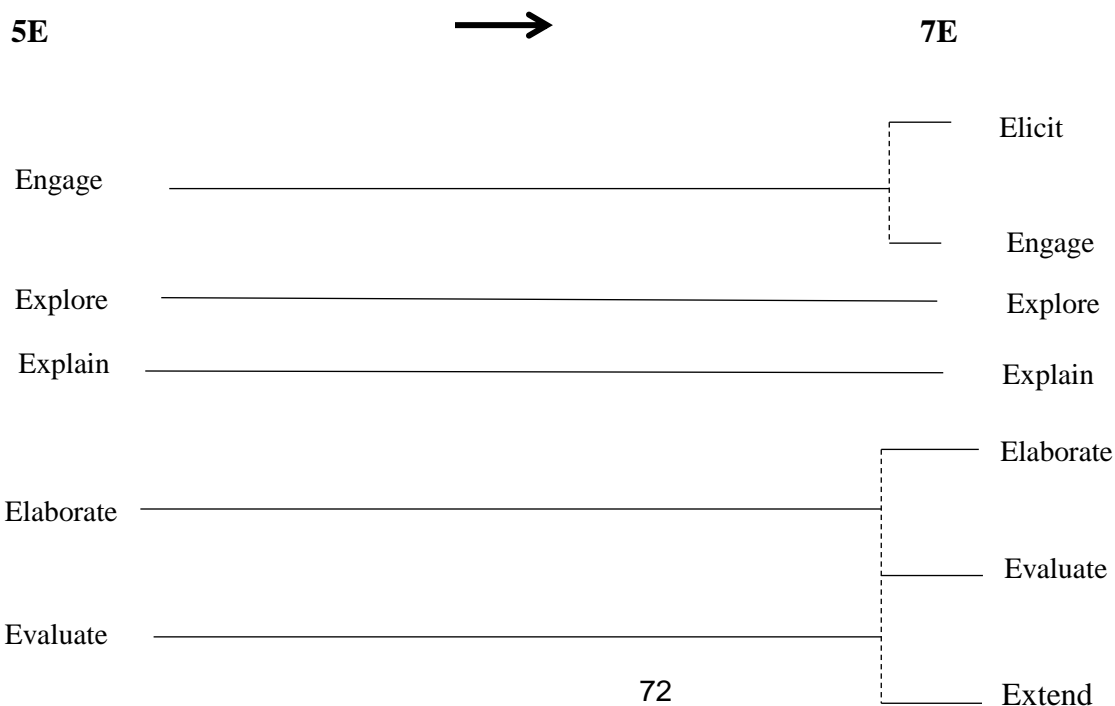
Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. Students apply their understanding of the concept by conducting additional activities.

Evaluation

The evaluation phase encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the educational objectives.

Since its inception in the late 1980s, a survey on the utilisation of the 5E Instructional Model (Bybee et al, 2006) has revealed that: (1) more than 235,000 lesson plans were developed and implemented using the 5E Instructional Model; (2) more than 97,000 posted and discrete examples of universities using the 5E model in their course syllabi were available; (3) more than 73,000 examples of curriculum materials were developed using the 5E model; (4) more than 131,000 posted and discrete examples of teacher education programmes or resources that use the 5Es were available. Moreover, at least three states strongly endorse the 5E model, including Texas, Connecticut, and Maryland. In addition there is some research based evidence in favour of the use of the 5E Instructional Model over the traditional teaching approach with respect to mastery of subject matter of science (Demircioğlu & Çağatay, 2014; Fazelian, Ebrahim, & Soraghi, 2010; Wilson et al., 2010; Yadigaroglu, & Demircioglu, 2012) and scientific reasoning (Wilson et al., 2010). However, these studies are very few (Bybee et al, 2006) and evidence available is not enough to make a comprehensive evaluation of the impact of the 5E Instructional Model with respect to development of integrated scientific knowledge.

Eisenkraft (2003) argues that elicitation of prior understandings and the practice of transfer of learning are important components of a constructivist learning model which the 5E instructional model does not take into account. He proposed an expansion of the 5E instructional model to a 7E instructional model involving a separation of the engagement phase to elicitation and engagement and the introduction of an extend phase. Thus, the 7E instructional model consists of seven phases; the five phases of the 5E model plus two phases: elicitation and extension.



In the 7E instructional model, the elicitation phase is solely devoted to assessing prior knowledge, while the engagement phase focuses on generating enthusiasm for the subject matter. The extension phase activities are geared towards rehearsal of newly learnt concepts and skills in different contexts to promote transfer of learning. The exploration, explanation, elaboration and evaluation phases of the 7E instructional model are the same as in the 5E instructional model. The relationship between the 5E instructional model and 7E instructional model is given in the schematic diagram above adopted from Eisenkraft (2003, p. 57).

The 7E instructional model has been shown to improve critical thinking skills in students (Mecit, 2006). Further evidence on the effect of the 7E instructional model comes from Kanli and Yagbasan (2007) who report that the laboratory approach based on 7E instructional model applications was more effective than the traditional verification laboratory approach applications in the development of students' science process skills and remediating student's misconceptions about force and motion. Research, however, shows that Computer Assisted Instruction is more effective than the 7E instructional model with regard to cognitive learning outcomes at the knowledge and comprehension levels, while at the applications level, there is no significant difference (Gönen, Kocakaya, Inan, 2006).

Both the 5E and the 7E instructional models have been shown to be more effective than the traditional teacher-centred approach in promoting students' understanding of science. One issue that seems worth investigating is whether the number of E's in the instructional model matters in terms of effectiveness. Theoretically, it makes sense to suggest that the 7E will be more effective than the 5E in promoting conceptual understanding. If we have to compare the effectiveness of 7E with that of 5E, then we should make sure that the time variable is controlled for a valid conclusion to be made. However, it may not be theoretically sound to compare the two instructional models for the following reasons: (1) If subjects in the 5E treatment group must spend the same time as those in the 7E treatment group, then more students' needs, particularly those of slow students, are likely to be met, as students will have opportunity to ask more questions, answer more questions, and discuss in more detail, leading to a better overall effect when compared to students in the 7E treatments group. (2) The phases in both instructional models have similar content; if both models are implemented meticulously, and the conditions cited in (1) are met, both approaches will most likely yield similar results. (3) Meta-analysis of the 5E instructional model (Anil & Batdi, 2015) and the 7E

instructional model (Balta & Sarac, 2016) suggests that both inquiry approaches are more effective than the traditional teacher-centred approach and that in each case the effects varied across studies. In some cases however, the 7E model was ineffective. More recently the 9E instructional model has been proposed as an enhancement to the 7E model (Kaur & Gakhar, 2014), complicating matters regarding the choice of the E inquiry model. The argument for extending the number of phases of the E inquiry model is consistent with the belief that there is a hidden condition for development of integrated scientific knowledge and skills that will be satisfied by extending the number of E's. This condition refers to the metacognitive knowledge which takes time to develop and which has been regarded as responsible for a more durable and transferable learning (Georghiades, 2000). Metacognitive knowledge develops gradually over time through experience and practice (Kuhn, 2000) and can be promoted by investing teaching time in certain learning activities such as discussions, writing, and reading (Chin & Osborne, 2010; Hand, Nam & Choi, 2012)). Wilson et al. (2010) report that the 5E instructional model is more effective in promoting students' understanding, reasoning and argumentation skills compared to traditional teacher-centred approach. Details of the implementation of the 5E instructional Model reveal that more time was spent by the experimental group than the control group on some learning activities: lecture with discussions: 15 minutes for control group and 25 minutes for inquiry group; class discussions: none for control group and ten minutes for inquiry group; writing work: 160 minutes for control group and 275 minutes for inquiry group; reading sit work: 30 for control and 50 minutes for inquiry group; small group discussions: 70 minutes for control group and 245 minutes for inquiry group; and teacher-student interactions: five minutes for control group and 100 minutes for inquiry group. Furthermore, most of the time on written work was spent on constructing explanations – 235 out of 275 minutes. It should also be noted that the control group spent more time on other activities such as lecturing and problem modelling than the inquiry group, making the total time for both groups the same. It is clear from Wilson's (2010) study that the amount of time spent in constructing explanations, reading and discussions was what actually influenced students' knowledge, reasoning and argumentation and this should be the focus of research rather than the number of Es.

Another framework on inquiry as a conceptual change instructional approach is argumentation. Argumentation has been regarded as a prominent feature of the language of scientific inquiry (Duschl & Osborne, 2002). Argumentation studies focus on the analysis of students' classroom discourse to determine its quality and factors that promote good students' arguments. According to Duschl and Osborne, learning argumentation requires students to engage in practising and using its

discourse in a range of structured activities, and only such tasks will support the social construction of knowledge.

4.3.1 ARGUMENTATION PRACTICE IN SCIENCE EDUCATION

Contrary to the lay perception of argumentation as war that seeks to establish a winner, argumentation in a professional sense is viewed as a social and collaborative process necessary to solve problems and advance knowledge (Duschl & Osborne, 2002). The US National Science Education Standards (NRC, 1996) indicate the importance of engaging students in describing and in using observational evidence and current scientific knowledge to construct and evaluate alternative explanations “based on evidence and logical argument” (p. 145). In Hofstein and Lunetta’s (2004, p.34) opinion, engaging in scientific argumentation assists students in constructing meaningful science concepts and in understanding how scientists develop knowledge of the natural world. In South Africa, the Physical Sciences curriculum encourages the practice of argumentation in the classroom through its Specific Aim Two which states: “Physical Sciences promotes knowledge and skills in scientific inquiry and problem solving; the construction and application of scientific and technological knowledge; an understanding of the nature of science and its relationships to technology, society and the environment” (DBE, 2011, p.8). Nevertheless, like many other science curricula worldwide, the Physical Sciences curriculum document (CAPS) does not provide a framework for implementing argumentation in the classroom.

4.3.2 QUALITY OF STUDENTS’ ARGUMENTS IN SCIENCE

Watson, Swain and McRobbie (2004) explore the quantity and quality of argumentation used during the open inquiry process. The study explores the extent to which small group argumentation and discussion was used as part of a series of three practical inquiry-based science lessons in each of two Year 8 (age 12–13) classes. The actions and talk of the teacher and two target groups of students in each class were recorded using video- recorders and audio-recorders. Students and teachers were interviewed and all the students completed a questionnaire. Results showed that the quantity and as well as the quality of discussion of the inquiry was low. Most students failed to explicitly link their claims to data but treated data as proofs of their claim. Further when students were interviewed, it was revealed that students’ explanations of their claims were based on personal opinions rather than the data. Teacher – student interaction was low. Watson et al. (2004) argue that the socio-cultural context in which the lessons take place leads students to view inquiry as a set of routine procedures which are used to produce a written product, rather than as a process of

discussion and decision-making. Kim and Song (2006) examined the features of peer argumentation in middle school students' scientific inquiry. The sample comprised two boys and six girls in grade 8. Students engaged in open inquiry activities in small groups. Each group prepared the report for peer review and then, during the peer discussion, presented their inquiry results while another group acted as critics, in a way similar to conference presentations by scientists. This study's data sources included audio- and video-tapes of discussions, copies of student reports, questionnaires completed by the students and transcripts of interviews with the students. Results showed that the critical peer discussion in general proceeded through the following four stages: Focusing, Exchanging, Debating and Closing. In addition, 75.6% of evidence used in students' arguments was personal evidence and students used various cognitive and social strategies in the critical discussion. Kim and Song (2006) suggest that for an effective critical discussion, making good use of the Focusing Stage has been found to be important factor. Students improve their interpretation and methods of experiment during the argumentation process and this feedback makes the inquiry circular. Thus peer critiquing can be a valuable tool in enhancing the quality of students' inquiry skills and arguments in learning science. From the analysis of data, the authors propose a framework for students' peer review discussion following open inquiry, which consists of four elements: Focusing, Exchanging, Debating and Closing. In the focusing stage, students try to focus their arguments on a point and to construct common ground for debating. Exchanging Stage is the stage where students exchange information about the details of the experiment, such as the method and techniques of experiments. In the debating stage, students debate the results and procedures of the experiment. The debate phase is categorized into Confrontation, Coexistence and Consensus, according to the response to an opponent's argument. Confrontation refers to rejecting another's arguments and Coexistence refers to preserving one's own argument while accepting another's argument as valid. Consensus is not found very often. The three types of closing stages are: Explicit Closing, Implicit Closing and Circumstantial Closing.

Heng, Surif and Seng (2015) report low quality of scientific argumentation among Malaysian secondary-level science students. A total of 120 students were randomly assigned to answer a Scientific Argumentation Test (SAT) based on acids and bases, either individually or in a group. Based on the answers, two groups of students (one who had answered with valid scientific concepts and another who had answered with invalid concepts) were identified and interviewed. The results showed that students were weak in the construction of scientific arguments with valid concepts. Moreover, most of the constructed arguments consisted of misconceptions. The results also showed

that students who were involved in group argumentation tended to have a more complex argumentation scheme, compared to individual students. Heng et al. (2015) explain that as a group, students were able to argue with more scientific elements and showed their understanding of the links between macro and sub-microscopic levels of chemical phenomenon. Furthermore Heng et al. (2015) argue that the problem of misconception, the lack of understanding of the triplet relationship between the levels of representation of chemical phenomena, and the lack of theoretical understanding of argumentation structure have contributed to the students' poor performance. Sampson, Grooms and Walker (2011) also report from their study that although the implementation of argument-driven laboratory inquiry improved students' disciplinary engagement and written arguments, students' arguments were characterised by conceptual inaccuracies indicating lack of understanding of scientific concepts.

Kulatunga, Moog and Lewis (2013) report high quality arguments among undergraduate university students involved in Peer-Led Guided Inquiry sessions involving problem solving in general chemistry. Students were mostly engaged in co-construction of arguments, with more than one student providing evidence and reasoning during group activities. Students often supported their claims with data and warrants, but rarely offered backings. However, the percentage of arguments containing backings increased when arguments contained contributions from more than one student rather than being presented by one individual. Another significant finding reported was that students were able to resolve incorrect claims through argumentation without peer leader intervention, which indicates independent learning.

Ozdem, Ertepinar, Cakiroglu and Erduran (2013) investigated the kinds of argumentation schemes generated by preservice elementary science teachers as they perform inquiry-oriented laboratory tasks. The study explored how argumentation schemes vary by task as well as by experimentation and discussion sessions similar to Kim and Song's (2006) design framework. The sample of the study comprised 35 pre-service teachers who taught middle school science to sixth through eighth grade students. The data were collected through video- and audio-recordings of the discussions made by the pre-service teachers in six inquiry-oriented laboratory sessions. The results illustrated that pre-service teachers constructed high quality arguments during their discussions. The teachers applied varied premises rather than only observations or reliable sources to ground their claims or to argue for a case or an action. It is also worth noting that the construction and evaluation of scientific knowledge claims resulted in different numbers and kinds of arguments. In the author's opinion, the critical discussion stage provided an effective context where students were required not to consider

singular explanations of phenomena, but only plural accounts, thus designing inquiry-oriented laboratory environments, which are enriched with critical discussion and provide discourse opportunities that can support argumentation. Although pre-service teachers are able to construct high quality scientific arguments, their understanding of scientific argumentation is limited – teachers could not differentiate between scientific explanation and scientific argumentation (Aydeniz & Ozdilek, 2015).

4.3.3 CONDITIONS FOR HIGH QUALITY STUDENTS' ARGUMENTS

Zohar and Nemet (2002) report that when students are given explicit coaching/instruction in argumentation, coupled with the opportunity to practise with science content, they are more likely to cite specific scientific knowledge as evidence in their arguments and perform better on tests of content knowledge than peers in a control group. More concretely, a study by Zohar and Nemet (2002) focuses on explicit teaching of reasoning patterns integrated into the teaching of scientific content in genetics. Their results show that explicit teaching of reasoning patterns contributed to improving students' scores in the argumentation tests. Moreover, as the authors claim, students' scores improved not only in the genetic argumentation tests but also in the transfer tests, indicating that they were able to transfer reasoning abilities taught in the context of dilemmas in genetics to dilemmas taken from everyday life. Subsequently, when engaging in argumentation, students draw on their prior experiences and knowledge; such activity enables students to consolidate their existing knowledge and elaborate on their science understanding at relatively high levels of abstraction (Von Aufschnaiter, Erduran, Osborne & Simon, 2008). Moreover, students can show a higher quality of argumentation that consists of well-grounded knowledge of a relatively low level of abstraction. The main indicator of whether or not a high quality of argument is likely to be attained is students' familiarity with and understanding of the content of the task (Von Aufschnaiter et. al, 2008). When students are familiar with and understand the content of the task, they are more likely to engage in high quality arguments. Developing argumentation in the classroom therefore requires a consideration of the nature and extent of students' content specific experiences and knowledge. The results of this study also suggest that, prior to argumentation practice, students must have accurate facts about the subject matter which must be given through direct teaching.

Garcia-Mila, Gilabert, Erduran and Felton (2013) show that student argument involving consensus building among dyads resulted in significantly higher quality of students' argument than arguments involving persuasion of the other party. Two dialogue groups specifically, consensus building group

and persuasion group, were asked to argue about a dilemma according to their experimental condition (persuasion goal versus consensus goal). It was found that students in the consensus condition engaged more in arguments involving rebuttals than the students arguing within the persuasion condition. There was also a deeper analysis of the mutual arguments among the consensus group to co-construct a solution to the dilemma.

Berland and Lee (2012) demonstrate that peer legitimization of disparate or incorrect ideas is one vehicle that can enable students whose arguments rely on incorrect ideas to feel that they are heard by the rest of their group and have value. The authors claim that this legitimization is important because it can help students “save face”, which enables students to move away from the competitive and persuasive aspects of argumentation and towards interactions that align more closely with sense making and consensus building. When students know they have to reach consensus, they tend to explore one another’s claims more fully and look for ways to integrate knowledge rather than disregard opposing claims and evidence out of hand (Garcia-Mila et al., 2013). Through this behaviour students tend to be more critical both in evaluation of evidence and reflection on own ideas leading to high quality arguments. According to Larrain, Howe and Ceda (2014), the aspects of student argument that significantly predicted gained scores on a delayed posttest were justification utterances and counter arguments. Teachers’ counter-questions and counterfactual elicitations, according to Larrain et al. (2014), were probably a key aspect of the potential of those episodes (teacher-students justification interactions) for knowledge construction. They argue that the justificatory interactions are equivalent to rebuttals and counter-arguments and that they are constructions in which teachers play a central role to scaffold students’ reasoning. Moreover, they were collaborations put forward by a virtual field of possible alternative and opposite ideas, which, although not formulated clearly, were operating through teachers’ interventions.

The complexity of the argumentation task also influences the quality of students’ argument. Katchevich, Mamlok-Naaman and Hofstein (2014) report that more complex experiments in open-ended inquiry laboratory experiments serve as a better platform for developing arguments as well as for the number of arguments. Moreover, the authors identify the characteristics that serve as a catalyst for raising arguments during the discourse. These include asking questions and experiments that yield unexpected results. They identify three distinct types of questions: questions that stimulate discussions, questions aimed at clarification and understanding the issues related to the experiments, and questions posed for the purpose of obtaining information. Katchevich et al. (2014) claim that understanding the task requirements and the reason for assessing the task determine the existence

and extent of argumentative discourse. They argue that the strict instructions of the work for the students and indicators for assessment stimulated students' awareness of task requirements, and that this directed the conduct of the inquiry activity in the laboratory. Chin and Osborne (2010) argue that developing the skills of questioning – both those of framing an appropriate question and the cognitive demands required to respond to such a question – offer a potential heuristic to facilitate argumentation of a better quality. The authors developed question prompts and “our arguments sheet” and “theory sheet” for scaffolding students' arguments during a collaborative problem solving session involving deciding the best heating graph for water among alternatives. The authors put forward three claims accounting for the role of students' questions in the collaborative group discussions: in the first place, that students' questions acted as psychological tools or scaffolds helping the students to articulate their puzzlement through think-aloud verbalisation, and to structure the process and content of their thinking. Secondly, the questions acted as springboards to further inquiry and dialogic talk by spawning further subordinate questions which activated critical cognitive engagement and the development of elaborated arguments. Finally, questions served a metacognitive function, forcing students to think about their own thinking.

4.3.4 EFFECTS OF ARGUMENTATION PRACTICE ON STUDENTS' LEARNING

Studies have shown that scientific argumentation can be explicitly taught as early as fifth grade level (McNeill, 2011). A number of approaches for supporting and facilitating argumentation in the science classroom have been described (Osborne, Erduran & Simon, 2004). They include a table of statements, a concept map of student ideas, a report of a science experiment undertaken by students and competing theories. Others are constructing an argument, predict-observe-explain, and designing an experiment. Acara and Patton (2012) contend that counter-argument and rebuttal skills develop when using competing theory approach to teach argumentation.

Sağır and Kılıç (2012) report that argument-based instruction is significantly more effective in developing students' conceptual understanding and retention of learning of acid-base concepts than the traditional lecture/demonstration approach. In a study, Aydeniz, Pabuccu, Cetin and Kaya (2012) found that college chemistry students' conceptual understanding of properties and behaviours of gases improved significantly when they were instructed by the arguments-based approach compared to the control teacher-centred approach with at least 80% of students in the experimental group abandoning all their misconceptions while less than 50% of students in the control group abandoned all their misconceptions. Çelik and Kılıç (2014) investigated the impact of

classroom-based argumentation on high school students' conceptual understanding of chemistry concepts, their attitude towards chemistry, and argumentativeness using quasi-experimental design. Results showed that the argument approach was significantly more effective in promoting conceptual understanding, attitude toward chemistry, and argumentativeness, compared to the traditional teacher-centred approach. Cetin (2014) also found that pre-service science teachers who were instructed using the argument-based approach showed significantly better understanding of reaction rate concepts, were able to construct high quality of arguments and were more able to use reaction rate concepts in constructing an argument.

4.3.5 THE SCIENCE WRITING HEURISTICS

Research in constructivism has also revealed that negotiation of meaning as students engage a learning activity can occur both at the social and the individual levels. According to Keys, Hand, Prain and Collins (1999) students' negotiation of meaning should not be seen as limited to discussion, but through reading and writing texts. They argue that students' attempts either to read text or construct text involves them in processes in which they have to engage their own understanding to construct meaning for the science topics they are studying. Therefore encouraging students to read text and write is a way to encourage the negotiation of meaning and construction of knowledge. Keys et al. (1999) developed a new tool for learning science – the Science Writing Heuristics (SWH). The goal for using the SWH was to foster generation of meaning for laboratory activities, reasoning from evidence to claim, metacognition, conceptual change and more sophisticated understandings of the nature of science through classroom activities. Keys et al. (1999) developed the SWH template for students to support construction of written arguments and presentation of written laboratory report. The science SWH template consists of seven steps: (1) beginning ideas; (2) tests; (3) observation; (4) claims; (5) evidence; (6) reading; and (7) reflection. The use of SWH in promoting conceptual understanding, quality of students' writing and metacognitive skills development is reported in the science education literature.

A study by Hohenshell and Hand (2006) found that ninth and tenth grade students using the SWH approach performed significantly better on conceptual questions than the students from a control group. In another study, Rudd, Greenbowe, and Hand (2007) report that SWH students' understanding of Le Chatelier's principle improved and these students did better on lecture examinations and laboratory practical tasks than students using the traditional laboratory investigation approach. Erkola, Kişoğlu and Büyükkasap (2010) observed that students who used

the SWH format for presenting their laboratory report on mechanics investigation performed significantly better on both multiple-choice and conceptual problems than students who presented their reports using the traditional laboratory report writing format. Hand, Nam and Choi (2012) also state that students who followed the SWH approach performed significantly better on conceptual understanding and summary writing in chemistry than students who followed traditional laboratory approach to investigation.

Several studies have indicated the importance of high-quality teaching and learning in implementing the SWH approach. Akkus, Gunel Hand (2007) suggest that high quality implementation of the SWH approach plays an important role in decreasing the achievement gap within science classrooms between low and high-achieving students. Nam, Choi & Hand (2011) also emphasize higher level of teacher implementation of the SWH approach for better student achievement. Recently, Kingir, Geban and Gunel (2012) also found that low academic level students performed better after the intervention of the SWH approach so that the gap between high and low levels decreased in high school chemistry. They indicate that the SWH approach provides opportunities for students to think critically, reason about the meaning of laboratory data, and develop scientific concepts. Park and Chung (2012) report that SWH had a positive effect on logical thinking for high-achieving and low-achieving students but with scientific inquiry skills and metacognition, the effect was limited to high-achieving students. The authors hypothesized that an increased amount of writing on each step was counter-effective for low-achieving students with regard to the development of scientific inquiry skill. Pertaining to lack of effect of SWH on low-achieving students' metacognition, low-achieving students might need external reflection prompts (Barkley, 2012) from more capable persons.

Indeed, several studies have suggested that additional teaching and learning techniques with the SWH approach are more effective than those with the SWH only. Demirbag and Gunel (2014) report that students who were given additional multi-modal awareness and integration instruction besides the SWH approach, scored significantly higher than students who were instructed by the SWH approach only on science achievement and report writing. Hand, Wallace and Yang (2004) report that in addition to using Science Writing Heuristics (SWH) to accomplish a laboratory investigation, students who were involved in writing-reviewing-rewriting in the process of completing a write-up performed better as a group on post conceptual test questions than those who completed a more traditional write-up format without adult or peer-review. Similarly Avci (2014) reports that students who used the SWH approach with peer assessment used the SWH template

more effectively than the group without peer assessment as indicated by the evaluation scores. The awareness of claim, evidence and reasoning explicitly prompted by the SWH template, and the social cohesion that occurs during the process of knowledge negotiation in the form of talking and writing, creates a learning environment that encourages practice of metacognitive strategies (Van Opstal & Daubenmire, 2015). In addition, peer assessors' comments during the review process prompt elaboration of ideas, use of appropriate language, and also draw attention to inconsistency in arguments, which the students on their own might not be conscious of, or may consider trivial or obvious to the reader (Hand, Wallace & Yang, 2004). In summary, the peer assessors' comments act as metacognitive scaffolds that promoted reflection and critical thinking, leading high to quality learning.

Other strategies have been suggested for making the SWH approach more effective. Burke, Greenbowe and Hand (2006) contend that teachers in the SWH approach should assist students in negotiating meaning from experimental data and making decisions with responsibility and ownership. Choi, Klein, and Hershberger (2015) report that instructional strategies employed by teachers while implementing SWH included class discussions, scaffolding and modelling argumentation for students. According to the teachers, the difficulties faced by students while using the SWH approach were lack of decision making ability and difficulty to write their thoughts. The studies reviewed here suggest that for the SWH to be used effectively to support students to write their arguments effectively, the following modifications should be made: (1) the number of steps should be reduced so that low achievers especially may be able to cope (2) the SWH template should be used together with other teaching techniques such as modelling (3) peer review of students' written work.

4.3.6 MODELLING BASED TEACHING (MBT)

4.3.6.1 The meaning of model and modelling

According to Gilbert and Justi (2016), modelling is understood as “a process of producing or building models, or a more detailed process that also includes the use or manipulation of models” (p. 24). Harrison and Treagust (2000) define a scientific model as “an abstract, simplified, representation of a system of phenomena that makes its central features explicit and visible and can be used to generate explanations and predictions” (p. 633).). Knuuttila (2005) criticizes the representationalist notion of models for their positivistic orientation which limits their epistemic value. She proposes a view of models as human made artefacts materialized in some way, which

results in them having “many other epistemic functions besides that of representing the world” (p. 18). Gilbert and Justi (2016) view models as external artefacts whose function is to support thinking, whilst their construction and manipulation support their performance of several epistemic functions. For Knuuttila (2005) and Gilbert and Justi (2016), examples of models include verbal (oral or written), 2D (drawings, schemes, graphics, etc.), 3D (from the use of any available concrete material), gestural, virtual, and mathematical representation.

Science education researchers such as Acher, Arcà, & Sanmartí, 2007 ; Campbell, Oh, & Neilson, 2012; Gilbert, 2004 ; Gobert & Buckley, 2000 ; Halloun, 2007 ; Justi & Gilbert, 2002; Lehrer & Schauble, 2012 ; Schwarz et al., 2009 ; Svoboda & Passmore, 2013 have emphasised the importance of including modelling in the school Science curriculum. In addition, the *Framework for K-12 Science Education* (National Research Council, 2012) considers the construction and use of models as one of the eight scientific and engineering practices that engage students in scientific inquiry and engineering designs.

The use of modelling activities in teaching characterizes what has been named *modelling-based teaching* (MBT). In a broader sense, it is defined as any implementation that brings together information resources, learning activities, and instructional strategies intended to facilitate mental model-building, both in individuals and among groups of students (Gobert & Buckley, 2000, p. 892). MBT provides an opportunity to introduce students to the use of analogies as tools for creativity, i.e. generation of knowledge, and to enhance students’ analogical reasoning ability (Gilbert & Justi, 2016, p. 200). Modelling helps students to clarify their thinking, develop group consensus, and share their ideas with others to try to persuade or help them understand phenomena (Schwarz et al. 2009). Engaging students in modelling activities will lead to the gradual development of argumentation skills and an understanding of the nature of science (Gilbert & Justi, 2016 p.200), as well as to the development of a flexible and critical knowledge about scientific concepts. Students’ meta-modelling knowledge (a series of higher order cognitive skills that can be used in different situations and problems) can be enhanced through participating in modelling activities. According to Gilbert and Justi (2016) students tend to support their argumentation with non-verbal modes of representations such as drawings, formulae, concrete models or gestures and this occurs when students are not able to verbally express their ideas about a given subject or when defending their ideas or questioning another person about an aspect of an idea that is unclear for them.

4.3.6.2. Basic principles for conducting modelling based teaching

To be able to participate meaningfully in MBT, Gilbert and Justi (2016 p. 66) suggest that the following conditions must be met:

- Students must have at least a simple view of models in the scientific context. By this they mean students must understand that (1) models are not copies of the entity being modelled, patterns to be followed, or distinct types of a given class of objects; (2) models can be used for many functions, mainly to simplify complex entities, to represent such an entity, to support explanations and predictions, etc.; (3) models can be changed, and (4) it is possible to have more than one model for a given entity.
- Students must be motivated to participate MBT activities. Gilbert and Justi (2016) argue that students' motivation may be encouraged by making students understand the aims for producing the model, valuing and respecting students' ideas and doubts during the activities.
- Students should work in small groups in order to help each other, to discuss doubts, to try to produce a group consensus model to be communicated to and discussed with the whole class.

4.3.6.3 Teaching sequences for model-based-teaching

Schwarz et al. (2009) developed a seven-step modelling-based teaching sequence for elementary curriculum materials. These are: (1) Anchor phenomena, e.g. use a phenomenon that may necessitate using a model to figure it out. (2) Construct a model; i.e. create an initial model expressing an idea or hypothesis and discussing the purpose and nature of models. (3) Empirically test the model; i.e. investigate the phenomena predicted and explained by the model. (4) Evaluate the model: return to the model and compare with empirical findings. (5) Test the model against other ideas, theories, and laws. (6) Revise the model, i.e. change the model to fit new evidence, compare competing models, and construct a consensus model. (7) Use the model to predict or explain other phenomena. Using the above teaching sequence, Schwarz et al. (2009) noted that some students were able to reach level three of the four-level learning progression proposed.

Gilbert and Justi (2016 p.68) propose a four-stage teaching sequence for MBT. The first stage involves *creation of a proto-model*. The introductory activity in this stage involves understanding the aims of the model to be produced by assisting students understand the question(s) they will seek to answer. After this, the teacher ought to involve students in experiences with the entity to be modelled. This may require students: (1) to remember previous ideas (either acquired in school situations or in ordinary, everyday, ones); (2) to acquire information from external sources

(textbooks, the internet, etc.); and (3) to gather information by performing practical work and/or simulations.

The second stage involves the *expression of the proto-model* by students in order to communicate and/or discuss their ideas. Students may be guided to express their proto-model by using one or more of the most common modes of representation: verbal (oral or written), 2D (drawings, schemes, graphics, etc.), 3D (from the use of any available concrete material), gestural, virtual, and/or mathematical. During the expression of model stage, teachers' actions may include requesting students to explain why a given mode of representation is being used and the meaning of codes of representation in each expressed model. When students are novices in modelling, the teacher may identify a model and explain that: (1) the given mode of representation was chosen due to some facility which it has in relation to the aim of the model, not because it is the "right" way to represent it; and (2) other modes could be used to provide distinct representations for the same model, which would be more, or less, useful in diverse contexts. During the expression stage, Gilbert and Justi (2016) suggest that students be encouraged to generate codes of representation of their models and explain the meaning of those codes. However, Mulder, Bollen, de Jong Lazonder (2016) find that modelling environment with a partial model that comprised the main components of the model students had to develop resulted in building better models of insulin-glucose system than the control modelling environment where model components were not provided.

The third stage of the MBT involves *testing of expressed models* by students. This stage aims at checking whether the current model fulfils its purposes and, if necessary, modify the model or reject it and restart the process. This may be done by conducting thought experiments, initiated by the teacher, based on students' difficulties and misconceptions of the science ideas being leaned. Multiple tests may be considered as different groups of students may develop different models. During this stage groups of students may be required to present their models and defend them against the teacher's and peers' questions in front of before the wholes class. The outcome of this test leads to rejection or modification of students' models. The activities in this stage should lead to one or more class-consensus model(s).

The fourth stage of the MBT sequence is *evaluation*. After reaching an agreement around one or more class-consensus model(s), the final activities of each sequence are to provide opportunities for using it (them) in different and distinct contexts. Evaluation may be done by questioning students, supporting the establishment of additional relationships, or providing additional information. In this study the evaluation of students' graphical model of changes in concentration of substances

following the disturbance of a chemical equilibrium system was done by requesting students to construct written arguments in support of their graphs. The scope and limitations of the model(s) have to be identified and discussed. It is important to note that the sequence given here is not linear but cyclical.

4.4 SUMMARY

Teaching science as inquiry is not a new idea but an old one that has undergone transformations. This transformation has been influenced by policy documents which attempt to clarify issues on inquiry science education. These documents articulate the specifications on teaching science as inquiry, and view inquiry science teaching from two perspectives: in the first place what students should understand about scientific inquiry, and the abilities students develop based on their experiences with scientific inquiry. The second perspective is the teaching strategies associated with inquiry-oriented science activities. This chapter has also shown that implementation of inquiry science education has, however, been impeded by several factors including those related to teachers, students, schools, curriculum and educational policies.

This chapter has shown that students' argument are characterised by conceptual inaccuracies and misconceptions, use of personal evidence, low quality of students' argument. The quality of students' arguments is better if students' educational level is high and if students are given explicit instruction in argumentation. The quality of students' arguments also improves if arguments involve consensus building and if students are familiar with and understand the content of the task. Encouraging justification utterances and teacher counter questions, as well as awareness of task requirement and skills in questioning, can improve students' arguments. Argumentation approaches have been found to improve argumentation skills, conceptual understanding, retention of learning and attitudes towards science.

This chapter also pointed to SWH as another perspective on argumentation which uses writing templates to scaffold students' arguments. Use of SWH has been shown to improve report writing, science process skills and metacognition, higher order cognitive skills and conceptual change in general, particularly when adult or peer review processes are integrated. Furthermore this chapter pointed to a relationship between MBT and argumentation with models as tools in argumentation. Most importantly, this review has revealed links among conceptual change inquiry instruction and development of metacognition. In the next chapter, the methods used to investigate the effect of

conceptual change instruction based on metacognition development on students' metacognitive skills and achievement in chemical equilibrium will be described.

CHAPTER FIVE: RESEARCH METHODOLOGY

5.1 INTRODUCTION

This research was designed to answer the overarching question: To what extent does the implementation of conceptual change teaching based on metacognition development promote knowledge integration and metacognition of grade 12 Physical Science students? This chapter describes the research methodology, design and methods of data generation and analysis and discusses the justification of the choices and decisions made. The chapter begins with a description of the literature review process, followed by a framework for implementing conceptual change teaching to promote knowledge integration and metacognition, and continues with the research questions or hypotheses, aims and objectives, design, qualitative approach and quantitative approach. The chapter ends with a discussion on ethical issues and summary.

5.2 THE LITERATURE STUDY

Extensive literature study was needed to construct a general conceptual framework for the implementation of conceptual change teaching to promote knowledge integration and metacognition in chemical equilibrium. Most of the sources cited in this study were retrieved from the internet through the free online databases and the North-West University portal. To facilitate retrieval of relevant journal articles, alerts were set up in Google Scholar, so as to remain informed about the most recent research in education. In addition, the researcher further traced prominent scholars in science education and their citations through Google Scholar. The *International Journal of Science Education* and *Metacognition and Learning* were identified as prominent journals in conceptual change teaching and metacognition. When a relevant article is retrieved, the references were checked to determine if they contained other relevant citations. Once relevant citations had been identified, Google Scholar and A-Z publication finder were used to search for the article. Other computerised data bases such as JSTOR, providing the full text of these articles, and EBSCOHost were also included. Articles were managed by assigning them to conceptual categories that emerged after reading through the abstract. Figure 5.1 below depicts the main literature map within this study. The bottom cell indicates the path that leads to the general framework for implementing conceptual change teaching to promote knowledge integration and metacognition in chemical equilibrium.

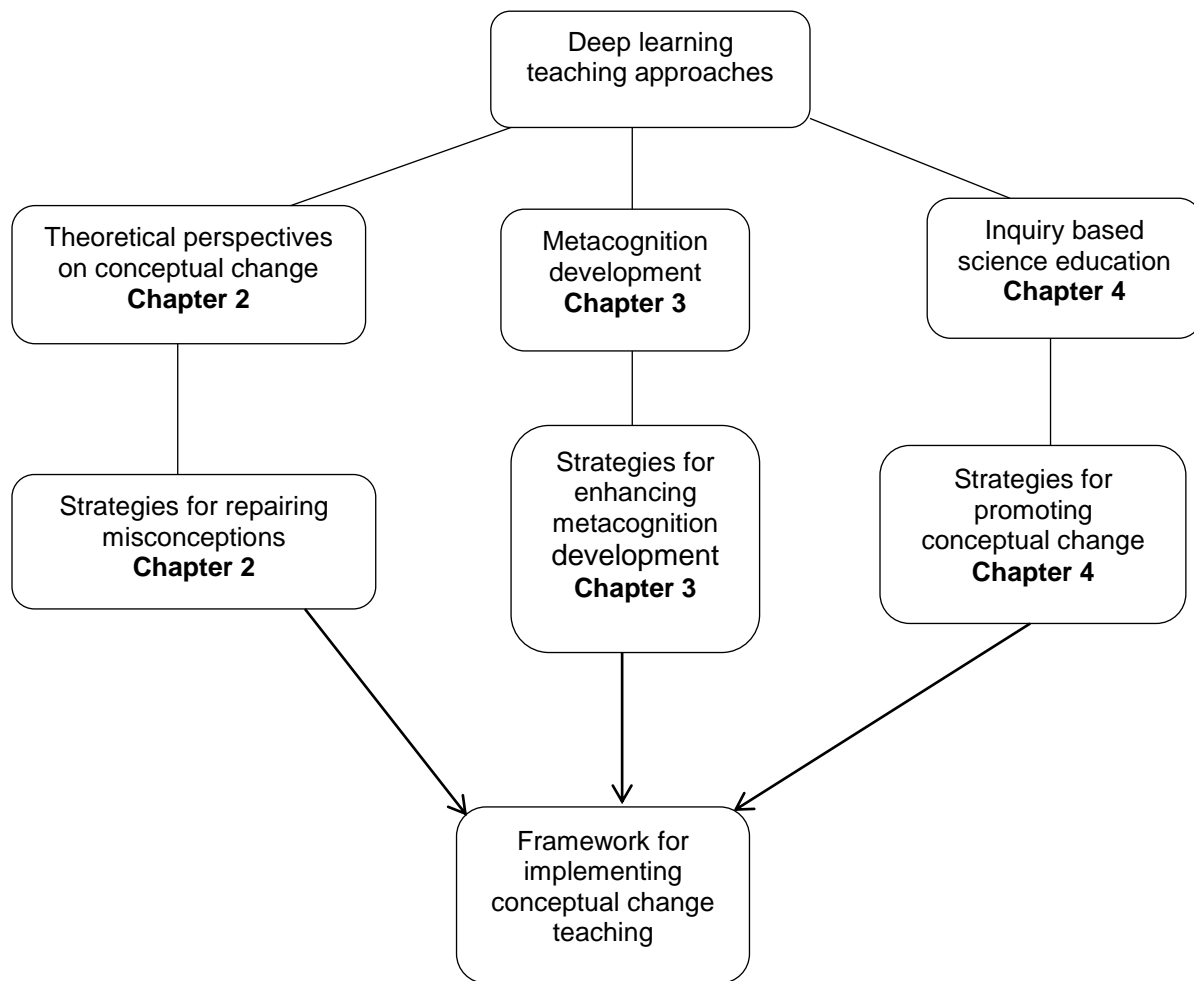


Figure 5.1: Literature review map

5.3 CONCEPTUAL FRAMEWORK

The depth of conceptual change is determined by the type of knowledge processing activities employed, that is, whether deep processing or surface processing strategies were employed (Chan, Burtis & Bereiter, 1997). Engaging in deep processing requires high levels of metacognitive reflection and control of the one's learning (Rickey & Stacy, 2000) and maturity in epistemology (Windschitl, 1997). Such reflection may cause recognition of discrepancy in the knowledge building process. The revision of cognitive operations may lead to rectification of the discrepancy, resulting in the building of more coherent and integrated knowledge system (diSessa, 2002). Inquiry based practices such as constructions of scientific arguments to support one's claim, have the potential to engage students in deep processing and metacognitive control of one's own learning. However, one's epistemological beliefs may undermine the knowledge construction process. Epistemological beliefs are individually held theory-like structures (Stathopoulou & Vosniadou, 2007), not available

to conscious awareness and hypothesis testing (Vosniadou & Ioannides, 1998). These epistemological beliefs underlie the knowledge building process and influence the depth of knowledge construction (Windschitl, 1997).

Cho, Lankford and Wescott (2011) report that students’ epistemological beliefs significantly correlate with their views on NOS and conceptual change. However, there is no significant relationship between NOS views and conceptual change. This suggests that the relationship between NOS and conceptual change is mediated by epistemological beliefs. Nevertheless, there is a direct link between epistemological beliefs and metacognitive awareness, with maturity in epistemology associated with high metacognitive awareness (Güven & Belet, 2011; Jena & Ahmad, 2013). Moreover, there is evidence that training in metacognitive awareness has a positive influence on students’ NOS views (Abd-El-Khalick & Akerson, 2009; Çetinkaya & Çakıroğlu, 2013) as well as students’ understanding of science concepts (Georghiades, 2006). Personal motivation also plays a role in metacognitive strategy use (Borkowski, Chan & Muthukrishna, 2000; Sungur, 2007). Thus, metacognition is key to improving students’ epistemological beliefs, NOS views as well as conceptual understanding. Since metacognition is trainable (Georghiades, 2006; Kramarski, 2004; Mevarech & Kramarski, 2003; Özsoy & Ataman, 2009) a conceptual change model should consider as its main agenda the development of metacognitive awareness.

Figure 5.2 below indicates that, as students’ metacognition improves, they are more likely to hold mature epistemological beliefs. For instance, they will tend to believe that knowledge is not simple and learning is gradual and requires effort.

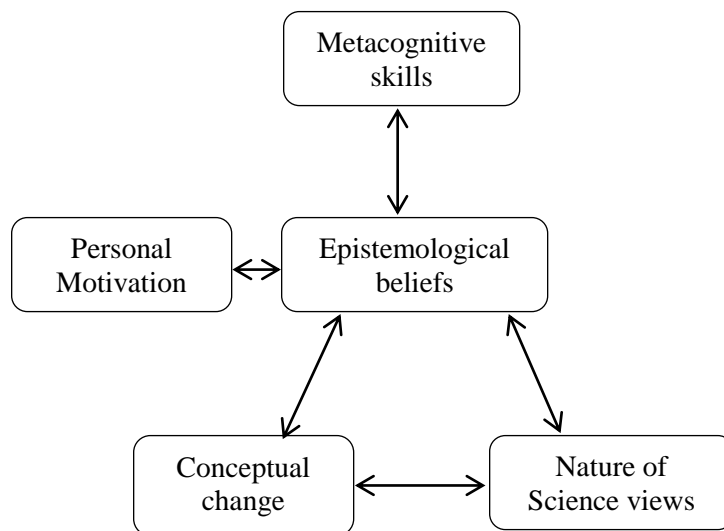


Figure 5.2: A metacognition model of conceptual change

With improved epistemological beliefs, the student driven by personal motivational states, such as achievement motivation or self-efficacy, is likely to put in more effort in acquiring useful learning strategies which could translate into building a more coherent and complex conceptual system. The reverse paths may also be true; if the student already has acquired a more coherent and integrated knowledge system, then s/he will likely hold mature views about knowledge and will be able to develop those higher order cognitive skills needed for self-direction in conceptual change learning. Also through mature epistemological beliefs, the student will more likely hold mature views about the nature of science, such as scientific knowledge is tentative rather than absolute.

This framework suggest that conceptual change is not only a change in ideas or conceptions, but also a change in epistemology and learning and thinking strategies. Therefore, in order to give a comprehensive account of a teaching intervention purported to promote conceptual change, a change in ideas as well as learning strategies should be measured. The conceptual models in Figure 5.2 also suggests that learning activities should be carefully selected, i.e. activities involving routine or simple algorithmic problems should be avoided as much as possible as they have the tendency to reinforce simple knowledge beliefs, thus discouraging students from learning useful strategies. Instead, learning activities should be moderately challenging but have variations so that the use of ready-to-use or routine procedures cannot be applied. In this way, students' critical thinking skills will likely be developed. Learning or thinking strategies should not be left to chance; students must be explicitly taught useful learning and reasoning strategies. Furthermore, since acquiring and adoption of useful strategies are influenced by achievement motivation, testing and prompt feedback should form part of conceptual change learning.

5.4 RESEARCH QUESTIONS/HYPOTHESIS, AIM AND OBJECTIVES

5.4.1 Research questions

This study proposes a framework for the implementation of conceptual change teaching in Physical Science within the Further Education and Training (i.e. grade 10-12) phase. In order to do so, the study was guided by the following overarching research question: To what extent does conceptual change instruction in chemical equilibrium based on metacognition development promote students' achievement and metacognitive skills of grade 12 Physical Sciences students in Mpumalanga? To answer the primary question, three secondary questions had to be addressed:

1. What is the level of metacognitive skillfulness of grade 12 Physical Science students in solving chemical equilibrium problems?

2. What factors influence students' use of cognitive strategies in solving chemical equilibrium problems?
3. How well do the two measures of learning strategy (learning approach and metacognitive skills) predict achievement in chemical equilibrium based on CEAT scores? How much variance in chemical equilibrium achievement can be explained by scores on these two scales?"
4. How can conceptual change instruction be effectively implemented in Physical Science to foster deep learning and the development of metacognitive skills.

5.4.2 Research hypotheses

In addition to the research questions, the following hypotheses were tested:

1. Students taught chemical equilibrium through the conceptual change instruction based on metacognition development will:
 - a) achieve significantly better in chemical equilibrium than students taught through the traditional lecture approach, and;
 - b) develop significantly better metacognitive skills in chemical equilibrium than students taught through the traditional lecture approach.
2. Conceptual change instruction based on metacognition development will narrow the achievement gap between high and low achievers in chemical equilibrium.
3. Conceptual change instruction based on metacognition development strategy will not narrow the metacognitive skills gap between high and low achievers in chemical equilibrium.

5.4.3 Aims and objectives

The central aim of this study was to determine the extent to which conceptual change instruction based on metacognition development can promote deep conceptual change learning in chemical equilibrium. The objectives of this study were to:

1. determine the level of Physical Science students' metacognitive skilfulness in solving chemical equilibrium problems.
2. identify the factors that influence students' use of cognitive strategies in answering high order questions in chemical equilibrium.
3. determine how well chemical equilibrium achievement can be explained by the chemical equilibrium metacognitive skills questionnaire (MCAI-CE) and the revised two-factor study process question (R-SPQ-2F)

4. determine the effect of conceptual change instruction modelled on metacognition development on students' achievement in chemical equilibrium and the development of metacognitive skills in learning chemical equilibrium.
5. develop a framework for the effective implementation of conceptual change instruction in Physical Science to foster deep learning and develop metacognition.

5.5 RESEARCH PARADIGM

In order to choose a paradigm for the research topic, the researcher considered the problem of persistent poor performance of students in chemical equilibrium as a complex phenomenon. The researcher made the following assumptions about the problem: first, the extant literature says learning of chemical equilibrium is hindered by students' current conceptions (commonly known as misconceptions) on this topic (see Chapter 2). However, given the recent developments in conceptual research where a new perspective for viewing naïve knowledge is offered (see Chapter 2), the researcher found it necessary to explore further by asking new questions concerning the causes of students' poor performance. The researcher decided that, since the purpose is to generate new hypotheses about the factors of poor performance in chemical equilibrium, these could best be achieved through inductive research approaches. The researcher also assumed that having proposed the factors responsible for students' poor performance, it is necessary to confirm these factors through deductive investigative approach. This leads to adoption of a mixed method approach which aligns with pragmatism. The link between mixed method research and pragmatism is given in Table 5.1.

Table 5.1: Philosophical bases for mixed method research (Creswell, 2014, p.10)

-
- Pragmatism is not committed to any one system of philosophy and reality. This applies to mixed method research in that inquirers draw liberally from both quantitative and qualitative assumptions when they engage in their research.
 - Individual researchers have a freedom of choice. In this way, researchers are free to choose the methods, techniques, and procedures of research that best meet their needs and purposes.
 - Pragmatists do not see the world as an absolute unity. In a similar way, mixed method researchers look to many approaches for collecting and analysing data rather than subscribing to only one way (i.e. quantitative or qualitative).

- Truth is what works at the time. It is not based in a duality between reality independent of the mind or within the mind. Thus, in mixed method research, investigators use both quantitative and qualitative data because they work to provide the best understanding of a research problem.
 - The pragmatist researchers look to the *what* and *how* for research based on the intended consequences—where they want to go with it. Mixed method researchers need to establish a purpose for their mixing, a rationale for the reasons why quantitative and qualitative data need to be mixed in the first place.
 - Pragmatists agree that research always occurs in social, historical, political, and other contexts. In this way, mixed method studies may include a postmodern turn, a theoretical lens that is reflective of social justice and political aims.
 - Pragmatists have believed in an external world, independent of the mind as well as that lodged in the mind, but they also believe that we need to stop asking questions about reality and the laws of nature. They would simply like to change the subject.
 - Thus, for the mixed method researcher, pragmatism opens the door to multiple methods, different worldviews, and different assumptions, as well as different forms of data collection and analysis.
-

Through a pragmatic stance, the researcher was positioned to gain maximum insight when addressing the research questions without being distracted by paradigmatic tension (Creswell, 2014). The researcher experienced his pragmatist stance as problem-faced, pluralistic and a real-world orientated practice, enhancing the answering of research questions, rather than focusing on methods (Creswell, 2014). Because the focus of pragmatism is towards “what works” whilst answering the research questions, this paradigm offers an epistemological justification and logic for mixing approaches and methods in order to address the problem in this study (Onwuegbuzie, Johnson & Collins, 2009). Furthermore, the researcher found that pragmatism enhanced flexibility while viewing this study holistically, using qualitative research to inform the interpretation of quantitative data and vice versa. For example, quantitative data compensate for the fact that qualitative data cannot be statistically generalised; qualitative data help to explain relationships discovered through quantitative data (Onwuegbuzie & Leech, 2005). As a result of choosing this paradigm, this research developed a framework for implementing conceptual change instruction by qualitative means and tested this framework by quantitative means. Four purposes of employing mixed method research included: (1) triangulation (i.e. seeking convergence and corroboration of

results from different methods studying the same phenomenon); (2) complementarity (i.e. seeking elaboration, enhancement, illustration and clarification of the results from one method with results from the other method); (3) development (i.e. using the results from one method to help inform the other method); and (4) expansion (i.e. seeking to expand the breadth and range of inquiry by using different methods for different inquiry components) (Onwuegbuzie & Leech, 2005).

5.6 RESEARCH DESIGN

This study employed the mixed method design. Mixed method research is defined as “the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study” (Johnson & Onwuegbuzie, 2004, p. 17).

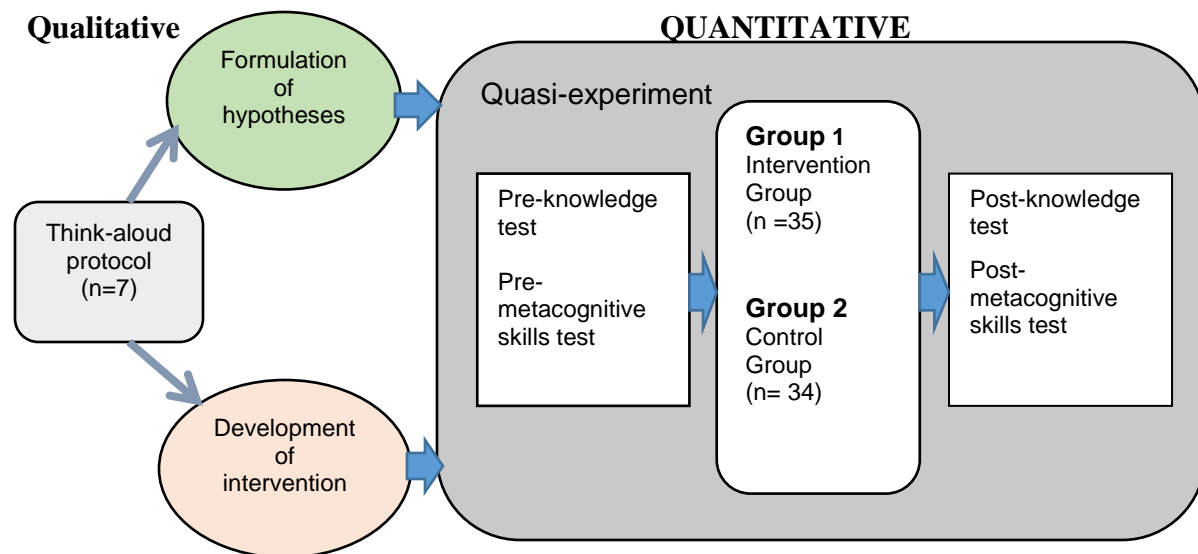


Figure 5.3: The visual model of the exploratory sequential mixed method design

To best address the research problem, an exploratory sequential mixed research design was chosen (Creswell, 2012). The intent for choosing this design is for the quantitative data results to refine and extend the qualitative findings by testing out the hypotheses that developed from the qualitative of phase of the study. In this way, the initial qualitative exploration leads to detailed, generalisable results through the second quantitative phase (Creswell, 2012). Also, triangulation provided opportunities for convergence, correspondence and confirmation of results from different methods while studying the same phenomenon, enhancing the credibility/trustworthiness and quality of the study (Flick, 2009). The visual model of the research design is shown in Figure 5.3. The diagram shown above describes only the activities that occurred during the main study on the field. They

indicate the procedure of data collection for addressing research questions and hypotheses, except research question 3 which was addressed in the pilot study. The qualitative phase of the study addressed research questions 1 and 2 while the quantitative phase addressed the research hypotheses. As shown in Figure 5.3 above, the mixed method design used in this study consists of two phases, an initial qualitative phase and a second quantitative phase. Lower and upper case labels of the phases denote priority while the arrows indicate the sequence of activities in the study (Creswell, 2012). In the qualitative phase students solved four chemical equilibrium problems while thinking aloud. Analysis of think-aloud protocols resulted in the generation of hypotheses and also informed the development of an intervention for the second phase. The hypotheses were tested in the second phase using a pre-test/post-test quasi-experiment.

5.7 QUALITATIVE RESEARCH

5.7.1 Method

The qualitative think-aloud inquiry approach was used to investigate the causes of students' difficulties in solving chemical equilibrium problems while performing the tasks (Charters, 2003). In think-aloud method "the subject is asked to talk aloud, while solving a problem and this request is repeated if necessary during the problem-solving process, thus encouraging the subject to tell what he or she is thinking" (Van Someren, Barnard & Barnard, 1994, p. 26). In think-aloud inquiry, analysis of the data commences from a point where the referents are unknown, rather than confirmed or contrast known entities (Chi 1997; Payne, 1994). Hence, the think-aloud approach is particularly useful in uncovering new or emerging phenomena, rather than testing or confirming what is already known (Young, 2005). Wade (1990) suggests that, as the student is engaged in a real activity, thinking aloud produces more reliable results than if asked to report on a hypothetical situation. According to Young (2005), the addition of student voice in think aloud observational data is more reliable than the observational data only.

Despite the advantages of the think-aloud method, the researcher is aware of the limitations which can make the data from think-aloud less valid. Young (2005) discusses the limitations to think-aloud. *Reactivity* refers to three main effects of asking a participant to think-aloud. The first relates to the ability of a participant to think and attend to a task at the same time. The second considers the effects of talking aloud during an activity which would normally be undertaken in silence. The third refers to the effect of drawing a participant's attention to the cognitive processes underlying the task being undertaken. In this study, reactivity effect was reduced by (1) carefully selecting tasks that

were appropriate for eliciting verbal data; (2) maximising comfort of the participant by informing them of the purpose of the study and assuring them of confidentiality (3) giving students some time to practise think-aloud before the think-aloud task was performed (Young, 2005).

Branch, as cited in Young (2005), note that verbal abilities of participants may limit the usefulness of the think-aloud data. In this study, this problem was reduced by recruiting participants with best verbal abilities. Further, as suggested by Wilson (1994), think-aloud is held to tap into the content of consciousness and therefore cannot tap into cognitive processes that never reach consciousness. To address this shortcoming, post-activity interviews were conducted to gain further insight into what appeared to be critical moments during the think-aloud session (Young, 2005)

5.7.2 Research context and participants

This qualitative study was conducted at the Lehukwe circuit of the Bohlabela district of the Mpumalanga Province of South Africa. The participants of this study were seven (7) grade 12 high school students from Lehukwe in the Bohlabela district of Mpumalanga province. There are eight high schools in the Lehukwe circuit out of which two high schools (one high performing and one low performing school according to the Mpumalanga department of basic education categorisation) were conveniently selected. The reason for using samples from high and low achieving schools was to determine if there were differences in how students from different schools were taught chemical equilibrium and also if those differences could influence students' metacognitive skillfulness about using strategies to solve chemical equilibrium problems. Four students, Angela, Brenda, Eliot and Morena (pseudonym names) were purposively selected from the low performing school while three students, Mashile, Chrestina and Percy (pseudonym names) were purposively selected from the high performing school. The four students from the low performing school and three participants from the high performing school were selected on the bases that they were more likely to verbalise their thoughts while solving problems better than others in their classes according to their teachers' judgements. Therefore they were not necessarily low achievers or high achievers in their respective classes. However, for the sake of simplicity in data analysis and reporting, they will be referred to as low achievers and high achievers respectively.

5.7.3 Selection of tasks for think-aloud

Four chemical equilibrium tasks similar to the ones on the chemical equilibrium achievement test were selected for think-aloud performance. An issue that requires careful thought is the level of

difficulty of the think-aloud task. While too difficult tasks may prevent participants from verbalising their thoughts, simple tasks may be performed almost automatically making it difficult for these automatic responses to be described (Charters, 2003; Young, 2005). The tasks selected for the think-aloud were therefore familiar to the students but at the same time not lending themselves to ready-to-use strategies so that metacognitive activities could be provoked (Meijera, Veenman & Van Hout-Wolters, 2006). To achieve the desired level of difficulty, each task was selected such that it contained a constraint that interferes with the “usual” procedures for solving chemical equilibrium tasks. The think-aloud task is attached as Appendix 5.1.

5.7.4 Procedure for conducting the think-aloud interview

The seven interviews were conducted in a closed classroom at each school’s premises after normal lessons when all other students had left the school’s premises. This was to ensure that noise and disturbances coming from outside were eliminated. The participants were seated comfortably in a chair with a glass of water at hand. Before each interview started, the student was informed of the purpose of the interview. It was emphasised to the student that the purpose for the interview was to understand the way people solve problems, and not their unconscious emotions and hidden thoughts. They were also assured that the data generated would be dealt with strictly confidentially (Van Someren, Barnard & Barnard, 1994). Prior to each think-aloud session, each student was given an opportunity to practise verbalisation of a similar task in order to familiarise her/himself with thinking aloud. The practice phase also gave the researcher an opportunity to train the subject to stick to verbalising his/her thoughts and not to interpret the thoughts (Van Someren, Barnard & Barnard, 1994). The practice phase was done until the researcher was confident that the participant was comfortable with the task of thinking aloud. During the sessions, the researcher encouraged the student to report his or her thoughts without offering any help with respect to the content of the task. The researcher used four prompts to stimulate participants: “Keep on thinking aloud”, “Will you think aloud?”, “Keep on talking, please”, and “What are you doing now?” (Charters, 2003; Meijera, Veenman & Van Hout-Wolters, 2006; Van Someren, Barnard & Barnard, 1994). Each session took place in the classroom with the researcher sitting opposite the student. According to Wilson (1994), while think-aloud is held to tap into the content of consciousness, it can never tap into cognitive processes that have not reached consciousness. As such, post-activity was conducted on critical moments noted in the protocols in order to gain further insight into students’ cognitive process (Young, 2005).

5.7.5 Data analysis

All think-aloud sessions were video recorded on a Secure Digital Memory card using a digital video camera. Protocols were transcribed by the researcher according to the guidelines given by Van Someren, Barnard and Barnard (1994). Recognisable pauses and unusual silence between two words were noted by three dots. A long silence was transcribed as “silence” and punctuations were not used. Also actions and gestures, such as underlining a word or taking notes while thinking aloud, were transcribed by noting them down in brackets. The resulting protocols and the accompanying written calculations on the answer sheets as well as the video recordings served as the source of data for this study. The protocols were then segmented into episodes (see Appendix 5.2 for transcripts). A think-aloud episode in this study refers to a problem solving step in the RICEE table procedure for solving chemical equilibrium problem Table 5.2 shows the number of think-aloud episodes for each participant on each of the tasks. A total of 171 episodes were obtained from the protocols. Fifty-nine (59) for task one, nineteen (19) for task two, forty-four (44) for task three and forty-nine (49) for task four.

Table 5.2: Number of episodes per participant and task from the think-aloud protocols

Number of episodes								
Task	Angela	Eliot	Morena	Brenda	Percy	Carren	Phindile	Total
1	3	9	9	9	11	9	9	59
2	2	1	2	2	4	4	4	19
3	7	5	4	4	7	9	8	44
4	2	5	9	3	12	9	9	49
Total	14	20	24	18	34	31	30	171

As expected, the metacognitive activities observed in the think-aloud protocols were mostly execution of action plans. According to Meijera, Veenman and Van Hout-Wolters (2006), some subordinate categories of execution activities are mostly overt cognitive activities from which covert metacognitive activities are inferred. For example, to study a graph while solving a problem is a cognitive activity in itself, but the decision to study the graph is of a metacognitive nature. On the basis of this and the purpose of the analysis, it was decided to analyse cognitive processes of subjects so that the metacognitive activities that occurred could be inferred.

The next step of the analysis was the preparation of a coding scheme for coding the transcribed protocols. First, the think-aloud tasks were analysed to determine cognitive processes required to successfully solve the tasks. This was done by the researcher and two other expert Physical Science

teachers solving the tasks (Van Someren, Barnard & Barnard, 1994). When the solutions of these three experts were compared, they were found to follow similar procedure in arriving at the solution in each task. A single model of the problem solving process for each task was constructed through discussion among the researcher and the two Physical Science teachers. The abstractions from the cognitive processes of the experts' problem solving served as initial coding scheme for the protocols. Furthermore, the protocols were examined for new categories that could not be categorised using the initial scheme. The new categories identified were added to the initial scheme to form a final coding scheme for coding the protocols. In this way the final coding scheme was a mixture of top-down (i.e., theoretically driven) and bottom-up (i.e., empirically driven) strategies (Van Someren, Barnard & Barnard, 1994; Meijera, Veenman & Van Hout-Wolters, 2006). The final coding scheme given in Table 5.3 was used to code the protocols of students by the researcher and one expert Physical Science teacher. Before doing independent coding, we used the coding scheme to code the protocols of one of the participants. During this trial phase, a number of misunderstandings were clarified by the researcher.

Table 5.3: Coding scheme for coding think-aloud protocols

Code	Descriptors
Interpretation of graph (IG)	<p>“from the graph I have the initial mol and the equilibrium mol”</p> <p>“Initially for A₂ is 2,4mol, and for B₂ is 2,0mol, then for AB₂ is 0mol.</p> <p>“initial moles of A₂ is 2,4mol and 2,0 mol for B₂ ...initial mole of our product is 0mol.</p>
Justifying choice of strategy (J)	“our aim for using a table is to find the equilibrium concentration of reactants and products in order to calculate the value of K _c ”.
Determination of equilibrium moles from graph (EM)	“at equilibrium for the A ₂ , we have 2,0mol; and for B ₂ we have 1,2mol; and for AB ₂ we have 0,8mol”
Calculating equilibrium concentration (EC)	“then c which is n over v which is, we take the moles that are in equilibrium and divide by 0,2”
Setting up K _c expression (Kc)	“K _c is always the product which is [AB ₂] square over concentration of [A ₂] multiply by concentration of [B ₂] square”
Substitution of values into K _c expressions (S)	“then the concentration for the product is 4 square over 10 times 6 square” “24 square divided by 7 multiplied by 7,5 square”
Calculating K _c value (C)	“then I will punch the calculator: $4^2 \div 10 \times 6^2 = 0,04$ ”
TASK 2	
Studying available	“when reading from graph, AB ₂ is increasing and the temperature

evidence (SE)	was increased”
Activating prior knowledge (PK)	“increase in temperature favours endothermic reaction”
Connecting previous knowledge to evidence(CPE)	“which in this case is the forward reaction because products are increasing”
Drawing conclusion(DC)	“that means the production of AB ₂ is endothermic”
TASK 3	
Justifying choice of strategy (J)	“for this one there is no need to draw a table because everything that we need is there.
Determination of initial moles (IM)	Initially from the statement I have 0,1mol.dm ⁻³ of Fe ³⁺ ...I also have 0,2mol.dm ⁻³ of this...and initially I have 0mol.dm ⁻³ of the product.
Determination of equilibrium concentration of product (ECP)	“and then I was given the equilibrium concentration of the product...which is 0,05mol.dm ⁻³ ...
Determining equilibrium moles (EMP)	This step was absent from the protocol
Using mole ratios to deduce change moles of reactants (CMR)	“we compare the mole ratio, it’s 1 is to 1 is to 1 that means here will be 0,05mol per cubic decimeter, and then here is 0,05mol per cubic decimeter”.
Determination of equilibrium moles of reactant (EMR)	“So to get the equilibrium mole we say 0,1 – 0,05 and it is 0,05 mol.dm ⁻³ ”
Calculating equilibrium concentration of reactants (ECR)	we subtract this and that and then we get the equilibrium concentration”
Setting up Kc expression (Kc)	“Kc is equal to the product, which is [Fe(SCN) ²⁺] divided by the reactant which is [Fe ³⁺] times concentration of [SCN ⁻]”
Substitution of values into Kc expressions (S)	“it will be equal to 0,05 divided by 0,05 time 0,15”
Calculating Kc value (C)	“I’m using a calculator, 0.05 ÷ 0.05 × 0.15 = 6,67”
TASK 4	
Justifying choice of strategy (J)	“I will draw my table first”
Determination of initial moles (IM)	“I was given the initial moles of sulphur dioxide which is 1.59mol”
Determination of	“to get the equilibrium mole of Sulphur trioxide, I will say 94,3

equilibrium moles of product (EMP)	divided by 100 times 1,59”
Using mole ratios to deduce change moles (MR)	“because the ratio is 2 is to 1 to get the used moles of this, I can simple say 1,5 times 1 divided by 2”
Determining equilibrium moles of reactant (EMR)	“equilibrium moles we subtract produced moles from the start mole...”
Calculating equilibrium concentration (EC)	“we calculate the concentration of O ₂ at equilibrium, is 0,105 divided by 30”
Setting up Kc expression (Kc)	“Kc equal to the concentration of the product, SO ₃ square over the concentration of SO ₂ square multiply by the concentration of O ₂ ”
Substitution of values into Kc expressions (S)	“which will be equal to 5×10^{-2} square divided by 3×10^{-3} square times $3,5 \times 10^{-3}$ ”
Calculating Kc value (C)	“ $(5 \times 10^{-2})^2 \div (3 \times 10^{-3})^2 \times (3,5 \times 10^{-3}) = 79365,78$ ”

The coders then individually assigned protocol episodes to categories on the coding scheme for each task. The intercoder agreement was 93% for task one, 100% for task two, 95% for task three and 89% for task four. In cases where there was lack of intercoder agreement, we discussed and reach a consensus on the category to ascribe such episodes.

In analysing think-aloud data, the number of certain types of thoughts are usually counted and that gives indication of level of metacognitive activities of the think-aloud subject. However, Meijera, Veenman and Van Hout-Wolters (2006) warn of the errors associated with such criteria for determining the quality of metacognitive activities. They claim that the think-aloud protocols of participants may contain some statements (in our case episodes) which are irrelevant to the cognitive operations required to solve the task and therefore merely counting such statements may result in unwarranted operationalisation of cognitive and metacognitive activity. Instead, they recommend a qualitative scoring method where every categorised statement (or episode) is scored on a scale from say 1 to 4, depending on the apparent depth of processing of the activity. In this study the quality of metacognitive activity was determined by this approach. The relevant episodes of the problem solving process were identified and a scoring rubric was prepared to evaluate each thinking episode for each participant. The rubric is based on a three-point scale on which 1 represents unacceptable or absent of activity, 2 represents low or present but developing and 3 refers to high or acceptable activity(see Appendix 5.3 for the rubric).

5.8 QUANTITATIVE RESEARCH

5.8.1 Development of research instruments

5.8.1.1 The Chemical Equilibrium Metacognitive Activity Inventory (MCAI-CE)

Each of the 28 items in the original MCAI for assessing metacognitive skills in chemistry problem solving was modified to reflect the specific content topic that the student should consider when providing a response to an item. For example, the item “I try to relate unfamiliar problems with previous situations or problems solved” was changed to “when solving chemical equilibrium problems, I try to relate unfamiliar problems with previous situations or problems solved”. This additions to the original items served as recall cues that limited respondents’ memory search of responses to metacognitive behaviours closely related to chemical equilibrium (Schwarz & Oyserman, 2001). The 28 items were increased to 34 by writing more items to reflect other metacognitive skills in the literature which were not captured in the original MCAI. These skills include four items, which represent predicting possible errors or misconceptions, thinking about alternative solutions (Yildiz, Baltaci & Güven, 2011) identifying key words and reading the problem statements several times. Two other items represent socially shared metacognition (Iiskala, Vauras, Lehtinen & Salonen, 2011). In addition, six (6) items representing the metacognitive experience dimension of metacognition were included, bringing the total number of items to 40. Four of the items were adapted from Efklides (2006) and the remaining two were written by the researcher. The response scale was based on a 5-point Likert scale with responses coded as follows: 1 – never or rarely; 2 – sometimes; 3 – about half of the time; 4 – frequently; and 5 – always or almost always. The new questionnaire (Appendix 5.4) was pilot tested with a sample of 37 grade 12 Physical Science students to determine if there were issues with understanding some vocabulary of the items. It emerged from the pilot testing that some of items from the original MCAI were not understood by the students. Upon discussion with students it was agreed that these items should be rephrased. For example, the item “When I solve chemical equilibrium problems, I omit thinking of concepts before attempting a solution” was rephrased as “When I solve chemical equilibrium problems, I do not think of concepts before attempting a solution.”

5.8.1.2 The Chemical Equilibrium Achievement Test (CEAT)

The CEAT is a task developed for assessing chemical equilibrium achievement for students by the researcher. It consists of 21 two-tier multiple choice questions adapted from literature (e.g. Özmen, 2008) and six essay type questions adopted from past Physical Science Paper 2 (Chemistry)

questions. Before the CEAT was developed, the Physical Sciences assessment taxonomy (DBE, 2011) was consulted to know the types of cognitive level learning outcomes that should be assessed. Table 5.4 below shows the description of four cognitive levels, the explanation of each cognitive level, the cognitive skills the student is expected to demonstrate at each level, and the action verbs that might be used in framing a learning objective pertaining each cognitive level.

Table 5.4: Physical Sciences assessment taxonomy (DBE, 2011)

DESCRIPTION OF COGNITIVE	LEVEL	EXPLANATION	SKILLS DEMONSTRATED	ACTION VERBS
CREATING	4	The student creates new ideas and information using the knowledge previously learned or at hand. At the extended abstract level, the student makes connections not only within the given subject area but also beyond it and generalises and transfers the principles and ideas underlying the specific instance. The student works with relationships and abstract ideas.	<ul style="list-style-type: none"> • Generating • Planning • Producing • Designing • Inventing • Devising • Making 	Devise, predict, invent, propose, construct, generate, make, develop, formulate, improve, plan, design, produce, forecast, compile, originate, imagine
		The student makes decisions based on in-depth reflection,	<ul style="list-style-type: none"> • Checking • Hypothesising • Critiquing 	Combine, integrate, modify, rearrange,

<p>EVALUATING</p>		<p>criticism and assessment. The student works at the extended abstract level.</p>	<ul style="list-style-type: none"> • Experimenting • Judging • Testing • Detecting • Monitoring 	<p>substitute, compare, prepare, generalise, rewrite, categorise, combine, compile, reconstruct, organise, justify, argue, prioritise, judge, rate, validate, reject, appraise, judge, rank, decide, criticise</p>
<p>ANALYSING</p>	<p>3</p>	<p>The student appreciates the significance of the parts in relation to the whole. Various aspects of the knowledge become integrated, the student shows a deeper understanding and the ability to break down a whole into its component parts. Elements embedded in a whole are identified and the relations among the</p>	<ul style="list-style-type: none"> • Organising • Comparing • Deconstructing • Attributing • Outlining • Finding • Structuring • Integrating 	<p>Analyse, separate, order, explain, connect, classify, arrange, divide, compare, select, infer, break down, contrast, distinguish, draw, illustrate, identify, outline, point out, relate, question, appraise, argue, defend, debate, criticise, probe, examine,</p>

		elements are recognised.		investigate, experiment
APPLYING		The student has the ability to use (or apply) knowledge and skills in other familiar situations and new situations.	<ul style="list-style-type: none"> • Implementing • Carrying out • Using • Executing 	Apply, demonstrate, calculate, complete, illustrate, show, solve, examine, modify, relate, change, classify, experiment, discover, construct, manipulate, prepare, produce, draw, make, compile, compute, sequence, interpret
UNDERSTANDING	2	The student grasps the meaning of information by interpreting and translating what has been learned.	<ul style="list-style-type: none"> • Interpreting • Exemplifying • Comparing • Explaining • Inferring • Classifying 	Summarise, describe, interpret, contrast, associate, distinguish, estimate, differentiate, discuss, extend, comprehend, convert,

				explain, give example, rewrite, infer, review, observe, give main idea
REMEMBERING	1	The student is able to recall, remember and restate facts and other learned information.	<ul style="list-style-type: none"> • Recognising • Listing • Describing • Identifying • Retrieving • Recalling • Naming 	List, define, tell, describe, identify, show, know, label, collect, select, reproduce, match, recognise, examine, quote, name

A test specification table based on the cognitive levels is given in Table 5.5. The knowledge areas under chemical equilibrium (DBE, 2011) is also given in Table 5.6. Table 5.5 below indicates that most of the items (29) on CEAT (see Appendix 5.5) are in the level 3 category i.e. applying and analysing. This makes the test valid for assessing higher order cognitive learning outcomes, and is consistent with the aim of this study which sought to determine the effect of implementation of conceptual change instruction based on metacognition development on higher order cognitive or metacognitive skills.

Table 5.5: Chemical equilibrium achievement test specification table

ITEM	MARKS	COGNITIVE LEVELS				KNOWLEDGE AREA
		1	2	3	4	
1.1	2			✓		Effect of concentration on K_c
1.2	2		✓			Effect of solid reactant on heterogeneous equilibrium
1.3	2			✓		Effect of concentration
1.4	2			✓		Effect of temperature on K_c value
1.5	2			✓		Effect of catalyst
1.6	2			✓		Dynamic equilibrium

1.7	2			✓		Effect of solid reactant on heterogeneous equilibrium
1.8	2			✓		Effect of catalyst
1.9	2			✓		Effect of concentration on K_c value
1.10	2				✓	Effect of concentration
1.11	2			✓		Effect of temperature
1.12	2			✓		Effect of temperature
1.13	2			✓		Effect of temperature
1.14	2			✓		Effect of solid reactant on heterogeneous equilibrium
1.15	2			✓		Effect of inert gas
1.16	2					Effect of pressure
1.17	2			✓		Effect of concentration
1.18	2			✓		Effect of concentration
1.19	2			✓		Calculation of equilibrium moles
1.20	2			✓		Calculation of equilibrium moles
1.21	2			✓		Calculation of equilibrium moles
2.1	2	✓				Graph interpretation
2.2	3			✓		Graph interpretation
3.1.1	2	✓				Graph interpretation
3.1.2	7			✓		Calculation involving of K_c
3.1.3	2		✓			Interpretation of K_c value
3.2	4			✓		Effect of temperature
4.1.1	2			✓		Graph interpretation
4.1.2	2			✓		Graph interpretation
4.1.3	2			✓		Graph interpretation
4.2	2			✓		Graph interpretation
5.1	2		✓			Endothermic/Exothermic reactions
5.2	9			✓		Calculation involving K_c
5.3	2		✓			Interpretation of K_c value
6.1	8			✓		Calculation involving K_c
6.2	2		✓			Effect of temperature on K_c value
7.1	2		✓			Endothermic/Exothermic reactions
7.2.1	2		✓			Graph interpretation
7.2.2	2		✓			Graph interpretation
7.2.3	8			✓		Calculation involving K_c
7.3	4			✓		Effect of temperature on K_c value

According to the National Senior Certificate examination diagnostic report of 2014, (DBE, 2014, p. 159) about 50% of marks (7-10 marks out of a maximum of 17 marks) in chemical equilibrium

topic are awarded in the knowledge area involving the calculation of equilibrium constant. As indicated in Table 5.6, most of the marks are allocated to calculations involving K_c .

Table 5.6: Distributions of marks across knowledge areas in the CEAT

Knowledge Area	Items	Marks	Weight (%)
Dynamic equilibrium	1.6	2	1.8
Effect of concentration on K_c	1.1, 1.9	4	3.5
Effect of solid reactant on Heterogeneous equilibrium	1.2, 1.7, 1.14	6	5.3
Effect of concentration	1.3, 1.10, 1.17, 1.18	8	7.1
Effect of catalyst	1.5, 1.8	4	3.5
Effect of inert gas	1.15	2	1.8
Effect of temperature	1.11, 1.12, 1.13, 3.2	10	8.8
Effect of temperature on K_c	1.4, 6.2, 7.3	10	8.8
Effect of pressure	1.16	2	1.8
Calculation of equilibrium moles	1.19, 1.20, 1.21	6	5.3
Calculation involving K_c	3.1.2, 5.2, 6.1, 7.2.3	32	28.3
Interpretation of equilibriums graphs	2.1, 2.2, 3.1.1, 3.2, 4.1.1, 4.1.2, 4.1.3, 4.2, 7.2.1, 7.2.2	19	17.0
Interpretation of K_c value	3.1.3, 5.3,	4	3.5
Endothermic/exothermic reaction	5.1, 7.1	4	3.5
Total		113	100

CEAT is scored by using a marking scheme (see Appendix 5.6). For the two-tier items, one mark is awarded for a correct response to the first tier and another one mark is awarded for a correct response to the second tier. For the open ended questions, awarding of marks is indicated on the marking scheme.

5.8.1.3 The Revised Study Process Questionnaire (R-SPQ-2F)

The R-SPQ-2F was developed by Biggs et al. (2001) and consists of 20 items measuring learning approach in general. It was originally validated using a sample of university students so some of the items contain words such as lectures, lecturers, course outline readings which are applicable at the university but can confuse high school students. These words were replaced with more appropriate ones. For instance, lecturers was replaced by teachers; lectures by lessons; course outline by work schedule; and readings by textbooks/study guides. R-SPQ-2F was modified to be topic-specific because it has been shown that learning approach is discipline-specific (Jones, Reichard, & Mokhtari, 2003) and could probably be topic-specific. For example, the sentence in the original

instrument “I find that studying academic topics can at times be as exciting as a good novel or movie” was adapted to read “I find that studying chemical equilibrium can at times be as exciting as a good novel or movie”. Each of the 20 items was rewritten to reflect the topic the student is thinking about while responding to the items. This questionnaire is attached as appendix 5.7.

5.8.1.4 Testing of research instruments

The pilot testing of research instruments was a survey of 207 grade 12 Physical Science students from the Bohlabela district of the Mpumalanga province. The 207 students were selected conveniently from five FET schools designated as the Mathematics, Science and Technology category by the Mpumalanga Department of Education. The average age of the students was approximately 18 years.

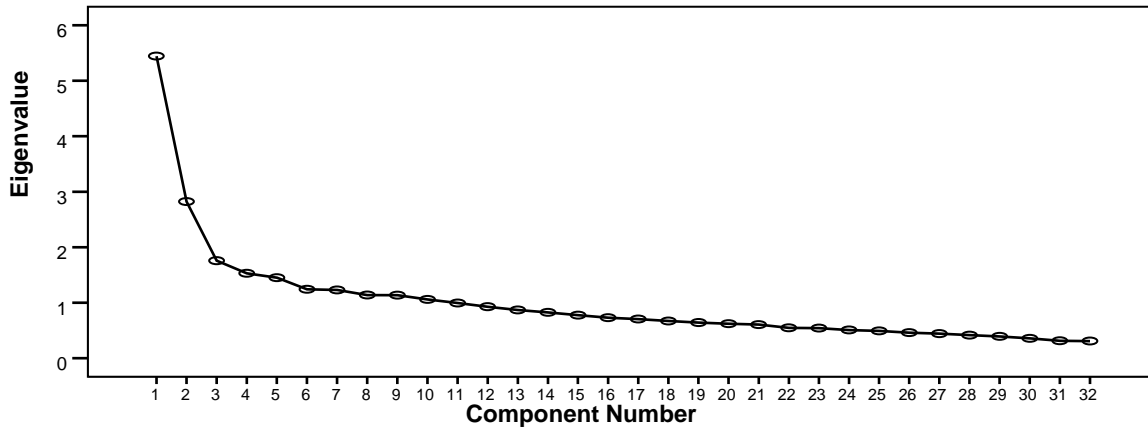
Following permission from the Mpumalanga department of basic education (see Appendix 5.8) and the principals of the sampled school (see Appendix 5.9), appointments for administration of the instruments were booked. Students’ consent forms and parental informed consent forms (see Appendix 5.10) were distributed on the day of making appointment for the research visit. In each school, the administration of CEAT took two hours while the administration of the MCAI–CE and R-SPQ-2F questionnaires took 15 minutes each. Students filled out the questionnaires on paper in class immediately after administering the Chemical Equilibrium Achievement Test (CEAT). The reason for administering the questionnaires immediately after the CEAT was to mitigate the memory reconstruction problem that characterizes retrospective self-reports by cutting back the delay between task performance and retrospective questioning to a minimum (Veenman, 2011). Teachers were present during administration to assist in the distribution and collection of tests and questionnaires. An important aspect of the procedure was that students were told that there was no reason to offer socially desirable answers as there were no rewards for students who gain high scores on the questionnaires. Students were instructed to read the introduction to the questionnaire very carefully, before they started to fill it out. The completed questionnaires were collected from students and checked to ensure that there were no missing data.

5.8.1.5 Results of the pilot test of research instruments

To test for construct validity, factorability of the 40 MCAI-CE items was examined. The data were screened for univariate outliers using box plot, but no univariate outlier was found. The minimum amount of data for factor analysis was satisfied, with a final sample size of 207 with over five cases

per variable. Several well-recognized criteria for the factorability of a correlation were used. Firstly, an inspection of correlation matrix revealed a considerable number of correlations in excess of 0.3, suggesting reasonable factorability (Pallant, 2011). Secondly, the Kaiser-Meyer-Olkin

Figure 5.4: Scree Plot



measure of sampling adequacy was 0.75, which is above the recommended value of 0.6, and Bartlett's test of sphericity was significant ($\chi^2(820) = 2174.94, p < 0.05$). The diagonals of the anti-image correlation matrix were all over 0.5, supporting the inclusion of each item in the factor analysis. Finally, the communalities were almost all above 0.3 (Pallant, 2011), further confirming that each item shared some common variance with other items. Given these overall indicators, factor analysis was conducted with all 40 items. Principal component analysis was used because the primary purpose was to identify and compute composite scores for the factors underlying the MCAI-CE. The initial eigenvalues showed that the first factor explained 15% of the variance, the second factor 8% of the variance, and a third factor 5% of the variance. Eigenvalue of a factor represents the proportion of variance accounted for by that factor. The fourth, fifth and sixth factors had eigenvalues of just over one, each factor explaining 4%. Three, four, five and six factor solutions were examined, using oblimin rotations of the factor loading matrix. The five factor solution was preferred because of, the levelling off of eigenvalues on the scree plot (Figure 5.4) after five factors, and the insufficient number of primary loadings and difficulty of interpreting four and six factors. Direct oblimin rotations were used because the factors correlated with each other. Oblimin removes overlapping variances so that only the unique contribution of each factor to the

variance of each variable is shown. This makes it easy to see the set of variables which compose a factor, and hence also easier to interpret (Tabachnick & Fidell, 2013). During several runs of factor analysis, a total of eight items were eliminated because they did not contribute to a simple factor structure, or loaded well on more than one factor, or failed to load on any factor. The item “I try to double-check everything, my understanding of the problem, calculations and units” loaded approximately 0.3 on both Factor 2 and Factor 3. Similarly the item “I spend little time on problems I am not sure I can solve” loaded between 0.40 and 0.46 on Factor 2 and Factor 3. The item “I experience a feeling of confidence with my solution” did not load on any factor. Finally the item “I experience a feeling of knowing the problem” loaded below 0.4 on Factor 3 which made interpretation of the factor difficult. These items were therefore deleted.

A principal-component factor analysis using oblimin rotations of the remaining 32 items was conducted, with the five factors explaining 40,65% of the variance. All items had primary loadings over 0.32 which is considered as the minimum (Tabachnick & Fidell, 2013), and only five items had a cross-loading above 0.32; however, these items had a strong primary loading on the main factors. Factor 1 was labelled Executive Function 1 (EF1) because items on this factor describe behaviours that occur at the initial stage of problem solving which includes task analysis or orientation and planning (see Table 5.7). EF1 constitutes the largest proportion of the total variance with a unique variance of 17%. The second factor derived consists of four items and was labelled Affect (A) because of high loadings of the following variables: “I experience a feeling of anxiety” and “I experience feeling of not being sure” which represent metacognitive experiences (Efklides, 2009). This factor constitutes the second largest proportion of the total variance explained with a unique variance of 9%. Factor 3 explained 5% of the total variance and it is labelled Execution Function 2 (EF2). Items on this factor represent behaviours which are technical in nature but are used to facilitate task analysis aimed at making the representation of the problem space clear (Efklides, 2009). The fourth factor explained 5% of the total variance and it is labelled Executive Function 3 (EF3). This factor describes error detection behaviours or performance monitoring which is another role of the Executive Function. The fifth factor makes up 5% of the total variance and it is labelled Negative Problem solving Behaviour or Negative Behaviour in short (NB). This label was chosen because all the items on this factor are negative.

Table 5.7: Factor loadings and communalities based on a principal components analysis with oblimin rotation for 32 items from the Metacognitive Activity Inventory (MCAI-CE)

FACTOR	Loading			NB COMMUNALITIES
	EF1	AFFECT	EF2	
Item 4	.686			.459
Item14	.685			.463
Item26	.548			.483
Item16	.540			.348
Item1	.510			.404
Item7	.504		.351	.442
Item2	.474			.390
Item8	.461		.400	.426
Item13	.421		-.317	.328
Item10	.352			.185
Item11	.353			.299
Item32		.812		.659
Item31		.699		.514
Item29		.681		.457
Item30		.673		.514
Item9			.573	.336
Item25			.530	.394
Item28			.500	-.315
Item24			.484	.258
Item22	.352		.395	.322
item15			.331	.354
Item6				-.681
Item3				-.635
Item5				-.623
Item12				-.441
Item20				.674
Item19				.648
Item18				.552

Item17					.509	.375
Item23					.469	.306
Item27					.415	.295
Item21			-0.358		.380	.483
Eigenvalue	5.444	2.824	1.759	1.531	1.45	
% of variance	17.011	8.824	5.497	4.784	4.54	
Total variance					40.65%	

Table 5.8 indicates statistical means, standard deviation and reliability of the scales. The Cronbach's alphas for the scales were moderate - 0.79 for EF1 (11 items), 0.73 for Affect (4 items), 0.58 for EF2 (6 items), 0.60 for EF3 (4 items) and 0.66 for Negative Behaviour (7 items). No substantial increases in alpha for any of the scales could have been achieved by eliminating more items. However the Cronbach's alpha for the total scale was 0.84. As shown in Table 5.13, EF2 metacognitive skills were the least used, i.e. less than half of the time, suggesting the students were not familiar with using such strategies as diagrams and/or tables to understand the problem better. Meanwhile NB was the metacognitive skills reportedly used most, i.e. almost frequently, meaning the students attempted to engage critically with learning materials.

Table 5.8: Descriptive statistics and reliability of the five MCAI-CE factors (N = 207)

Factor	No. of items	Mean	SD	Cronbach's α
Factor 1 (EF1)	11	3.36	.716	.79
Factor 2 (A)	4	3.22	.994	.73
Factor 3 (EF2)	6	2.71	.756	.58
Factor 4 (EF3)	4	3.02	.911	.60
Factor 5 (NB)	7	3.78	.745	.66

The relationship between chemical equilibrium metacognitive skills and chemical equilibrium achievement was investigated using Pearson's product-moment correlation coefficient. As shown in Table 5.9, there was a strong, positive correlation between the two variables, $r = 0.58$, $n = 207$, $p < .001$, with high levels of chemical equilibrium achievement associated with higher levels of metacognitive skills.

Table 5.9: Correlations matrix for MCAI-CE factors and CEAT scores (N = 207).

Metacognitive Factor	CEAT (DV)	EF1	A	EF2	EF3
EF1	.53**				
A	.31**	.15*			
EF2	.35**	.43**	.14*		
EF3	.26**	.45**	.14*	.34**	
NB	.31**	.23**	.41**	.16*	.14*
MCAI-CE	.58**				

**p < .001, *p < .05

This relationship provides evidence of predictive validity of the MCAI-CE. Also there were significant correlations between each of the MCAI-CE factors and CEAT scores.

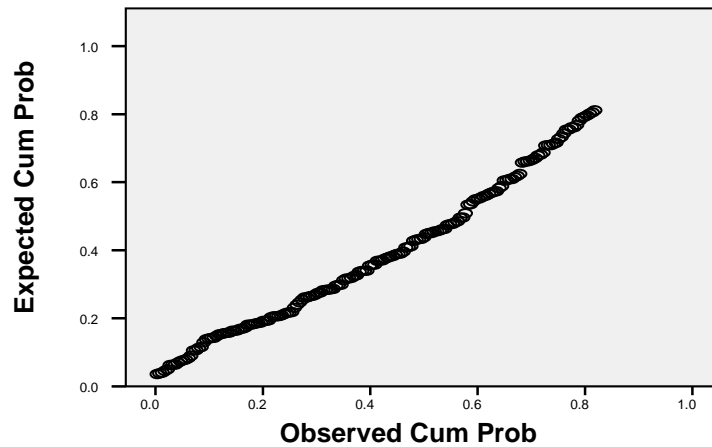
Available literature suggests that learning approach as measured by the R-SPQ-2F is a weaker predictor of achievement (Choy, O’Grady & Rotgans, 2012). The hierarchical multiple linear regression was appropriate because it would help to determine the unique contribution made by the learning approach R-SPQ-2F after controlling for metacognitive skills measured by MCAI-CE. All statistical assumptions underlying the use of multiple linear regression were tested. Inspection correlation matrix (see Table 5.10) showed reasonable correlations (above 0.3) between CEAT and the independent variables. Also correlation between the two independent variables was 0.55 which is less than 0.7, suggesting that multicollinearity was not an issue. Tolerance was greater than .10 (.699) and the variance inflation factor was less than 10 (1.431) suggesting further that multicollinearity was not a problem.

Table 5.10: Correlations matrix for CEAT, MCAI-CE and R-SPQ-2F with means and standard deviations

	1	2	3	<i>M</i>	<i>SD</i>
1. CEAT	-	.41**	.58**	30.83	16.10
2. Study approach (R-SPQ-2F)		-	.55**	3.14	0.44
3. Metacognitive Skills (MCAI-CE)			-	3.27	0.51

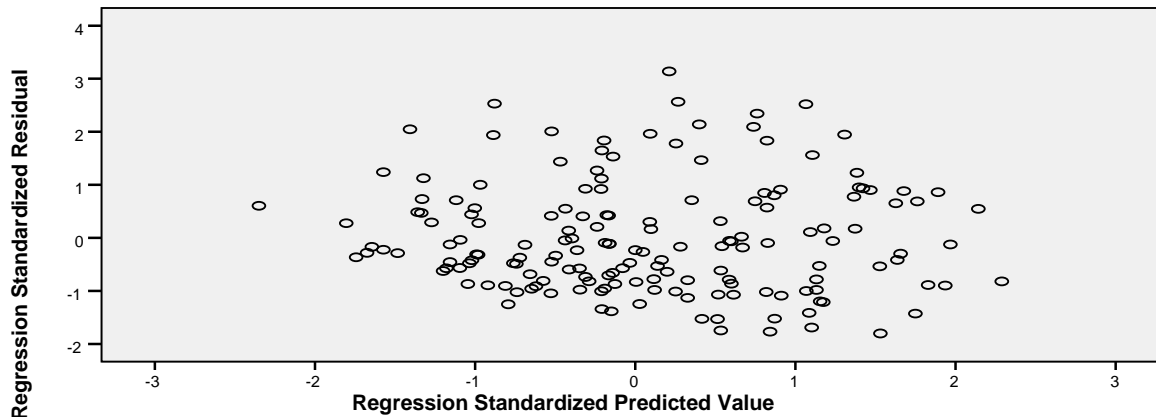
**p < .001

The Normal Probability Plot of regression standardized residuals showed points lying in a reasonably straight diagonal line from bottom left to top right suggesting no major deviations from normality (see Figure 5.5).



The scatter plot of standardized residuals showed a roughly rectangular distribution with most of the scores concentrated in the centre indicating that linearity, normality and homoscedasticity assumptions have been met. Inspection scatter plot of standardized residuals did not show any case with standard residual of more than 3.3 or less than -3.3 (see Figure 5.6). This indicate the absence of outliers from the scores. A relatively random display standardized residuals showed points lying in a reasonably straight diagonal line from bottom left to top right, suggesting no major deviations from normality. The scatter plot of standardized residuals showed a roughly rectangular distribution with most of the scores concentrated in the centre, indicating that linearity, normality and homoscedasticity assumptions have been met. Inspection of the scatter plot of standardized residuals did not show any case with standard residual of more than 3.3 or less than -3.3. This indicates the absence of outliers from the scores. A relatively random display of points in the scatter plot of standardized residuals provides evidence of independence of residuals. The Durbin –Watson statistic was 1.806, which is very close to 2, suggesting independence of residuals.

Figure 5.6: Scatter plot of standard residuals



The mean Study Approach based on a 5-point Likert Scale was 3.14 with a standard deviation of 0.44, and the mean Metacognitive Skills was 3.27 with a standard deviation of 0.51.

A two-step hierarchical multiple linear regression was performed to determine how much additional variance in CEAT scores could be explained by study approach based on the Revised Two Factor Study Process Questionnaire (R-SPQ-2F) after controlling for the effect of metacognitive skills (MCAI-CE). Scores on MCAI-CE were entered first as Block 1, because the correlation between CEAT and MCAI-CE is stronger than the correlation between CEAT and R-SPQ-2F. The hierarchical multiple regression revealed that at Step 1, Metacognitive Skills contributed significantly to the regression model, $F(1) = 102.5, p < .001$ and accounted for 33.3% of the variation in achievement in chemical equilibrium (see Table 5.11). Introducing Learning Approach in Step 2 explained an additional 1.2% of variation in chemical equilibrium Achievement and this change in R^2 change was not significant, $F \text{ change}(1) = 3.71, p > .05$. In the final model, only Metacognitive Skills was significant with a beta weight of .506, $p < .05$. This pilot testing of research instruments was intended to develop valid and reliable instruments for the main study. The Cronbach Alpha value for the chemical equilibrium achievement test using was 0.87, while that of the chemical equilibrium metacognitive skills was 0.84. However, the Cronbach Alpha value for the revised two-factor study process question was 0.61 which is similar to the alpha values of the

original instrument when tested with 495 university students, i.e. 0.73 for the deep approach subscale and 0.64 for the surface approach subscale.

Table 5.11: Summary of hierarchical regression analysis for variables predicting achievement in chemical equilibrium (N = 207). 95% Confidence intervals reported in parentheses.

	<i>B</i>	<i>SEB</i>	β	<i>p</i>
Step 1				
Constant	-28.247 (-39.89, -16.59)	5.908		
Metacognitive skills	18.069 (14.55, 21.58)	1.785	.577	.0001
Step 2				
Constant	-35.779 (-49.68, -21.87)	7.053		
Metacognitive skills	15.826 (11.64, 20.01)	2.121	.506	.0001
Study approach	4.723 (-0.11, 9.56)	2.452	.131	.056

$R^2 = .333$ for Step 1: ΔR^2 for Step 2 = .012

This suggests that the revised two-factor study process questionnaire is not a reliable measure of deep learning. The correlation between learning approach and metacognitive skills was significant, suggesting that the two measures of learning strategy are related. Also each of the two measures significantly correlated with chemical equilibrium achievement, but multiple linear regression analysis revealed that Study Approach did not make any significant contribution to the regression models after controlling for the effect of metacognitive skills. This suggests that the relationship between learning approach as measured by the revised two-factor study process questionnaire is mediated by metacognitive skills. In other words a student can be oriented towards deep learning, but if the student does not actually engage his/her learning resources in authentic learning activities, the student is most likely not to perform well on tests. This finding supports Choy, O'Grady and Rotgans (2012) who report that the relationship between learning approach as measured by the revised two-factor study process questionnaire and academic achievement was significantly mediated by achievement-related classroom behaviour. Similarly, Loyens, Gijbels, Coertjens and Cote' (2013) report that students' professional behaviour and self-study time significantly mediated the relationship between academic achievement and learning approach measured with the revised two-factor study process questionnaire. The authors viewed professional behaviour along three

dimensions, i.e. how well the student was prepared for lessons, how well the student participated in lessons and how well the student assumed roles as chair and scribe during group discussions.

The findings of this pilot test have implications for establishing cause and effect relationship between teaching approach and learning approach. As shown in this study, the revised two-factor study process questionnaire is not a reliable measure of learning approach, so using it to measure the effect of a teaching approach on learning approach may lead to misleading conclusions. This might explain why previous studies investigating the effect of teaching approach on learning strategy have yielded unexpected results (Dinsmore and Alexander, 2012). Therefore other more reliable measures of learning approach, such as the metacognitive skills questionnaire developed in this study, should be used in evaluating the effect of teaching approach on learning approach.

5.8.2 Development of materials

Eight lessons were developed based on the scope of content of chemical equilibrium prescribed in the curriculum and assessment policy statement (CAPS) for Physical Science. The first lesson was on the nature of chemical equilibrium. This activity was intended to demonstrate to students the sub-concepts that define chemical equilibrium, namely dynamism, incomplete reactions and reversibility. It was also intended to help students acquire a richer declarative knowledge in order to construct accurate mental models of chemical equilibrium as suggested by the qualitative phase of his study. The instructional strategy used was modelling, and the activities involved simulating of dynamic chemical equilibrium (adopted from Saricayir, Sahin and Üce, 2006), plotting equilibrium graphs, questions and discussions, worksheets

As part of the researcher's usual teaching, the researcher tested the simulation activity with eight students and observed the following: (1) Students could not follow the instructions to perform the calculations and the other operations involved in the generating data on how a chemical system proceeds towards equilibrium easily. As a result the researcher had to explain the procedure for performing the analogy several times, and this took much teaching time (about 30 minutes).

(2) Even when students finally got the procedure, they had to be guided through the analogy.
(3) Although students managed to perform the calculations and tabulated the results they did not refer to the analogy when answering questions, instead, they were looking for answers in the textbook which they could not find. However, when prompted to reflect on the analogy, some students realised what the analogy was explaining and started referring to it. So the researcher took the following decisions: in the first place, the analogy should be presented and the presenter should

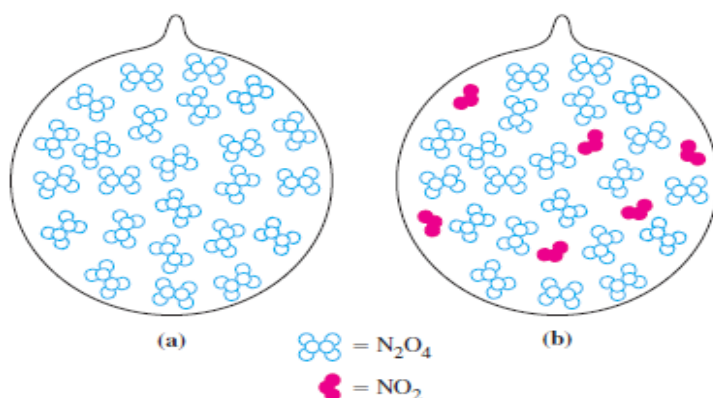
explicitly point out to students the correspondence between chemical equilibrium idea aspects of the analogy. Secondly, questions should be used after the presentation to check if students could match the features of chemical equilibrium to aspects of the analogy. Specific questions were asked to draw students' attention to closed system, equality of rates at equilibrium and constancy of concentration, and most importantly make students see the difference between initial state and equilibrium state. Question prompts were added on students' worksheets. Another feature of this analogy was that students were asked to draw the graph of the data obtained from the analogy. This was expected to draw students' attention to the differences in rate-time graphs and concentration-time graph and to help students see the intermediate changes that occurred between the initial state and the equilibrium state in a different mode of representation. It was also expected to help students build coherence between symbolic representation, graphical and tabular representation and microscopic (marble models of atoms) representation in order to promote the development of conceptual knowledge. This activity would also introduce students to equilibrium constant expressions and calculations based on the data obtained.

Lesson two involved calculation of equilibrium constant. The instructional strategy used was using a model to illustrate initial and equilibrium states and guiding students to use RICEE (Reaction, Initial moles, Change moles, Equilibrium mole and Equilibrium concentration) table in solving chemical equilibrium problems. The instructional activities included solving problems involving the equilibrium constant in different contexts, using metacognitive supports and interpreting equilibrium constant values. These activities were intended to help students understand how to use the RICEE table. The first problem in this activity was based on the decomposition of N_2O_4 gas in a closed system. Figure 5.7 gives a microscopic representation of the reaction: (a) shows the initial condition where only reactants are present while (b) indicates the equilibrium condition after some time. The equation for the reaction is $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$. The following assumptions were made: firstly, the number of molecules was the same as the number of moles, and secondly the volume of the vessel was equal to one cubic decimetre. Students were required to calculate the equilibrium constant for the $\text{N}_2\text{O}_4 - \text{NO}_2$ equilibrium system. The outline of the corresponding RICEE table for Figure 5.7 is given in Table 5.12. Students would then be guided to complete the remaining cells and calculate the equilibrium constant. The other problems that were solved contained only numbers, text and equilibrium reactions. One insight from the qualitative phase of the study was that students who were unsuccessful in solving equilibrium problems failed to detect errors that could have been avoided if they had reflected on their progress.

Table 5.12: RICEE table

Reaction	N_2O_4	2NO_2
Initial	24mol	0mol
Change		
Equilibrium	18mol	6mol
Equilibrium concentration $c = \frac{n}{v}$, $v = 1\text{dm}^3$		

Therefore a regulatory checklist that contained step by step reflection prompts was added on students' worksheets in order help them detect and correct errors (Schraw, 1998).

**Figure 5.7:**

Lesson three was about the effect of concentration on the equilibrium constant K_c , and was intended to show students that using different initial concentrations does not affect the value of the equilibrium constant. The inquiry based instruction involving analysis and interpretation of data was used. In this lesson data demonstrating three different approaches to chemical equilibrium were given with different initial and equilibrium moles. Question prompts on students' worksheets were used to direct students to calculate the equilibrium constant in each case, explain their results and draw conclusions. The instructional activity was adapted from Petrucci, Harwood, Herring, and Madura (2007, p. 625-626). In this activity, students were expected to realise that even though the initial concentration could change, as long as temperature does not change, the equilibrium constant will not change.

Lesson four involved the effect of concentration on chemical equilibrium at constant volume and temperature. The instructional strategies used in this lesson were modelling and argumentation. The instructional activities were constructing graphical models of changes in concentration, constructing written arguments in support of direction of shift in equilibrium position, and discussions. In the

first example, the diagram in Figure 5.8 below adopted from Petrucci et al. (2007) was used to illustrate the meaning of changing equilibrium conditions by adding a reactant or product to a chemical equilibrium system at constant volume and temperature for the reaction: $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$, $K_c = 2.8 \times 10^2$ at 1000 K. Figure 5,8 (a) indicates the composition of the system at the first equilibrium state; (b) indicates when some SO_3 was injected into the system, and (c) indicates the composition of the system when equilibrium was reached again. Questions were used to draw students' attention to the changes that occurred in the system following the disturbance. Since the diagram in Figure 5.8 does not show the intermediate state between the first and the second equilibrium, the information in Figure 5.8 was to be expressed by students using a graphical representation so that they could track the change of each substance in the systems until the new equilibrium state. Based on the graphical information and Figure 5.8, facts about how a change in concentration affected the equilibrium position could be constructed.

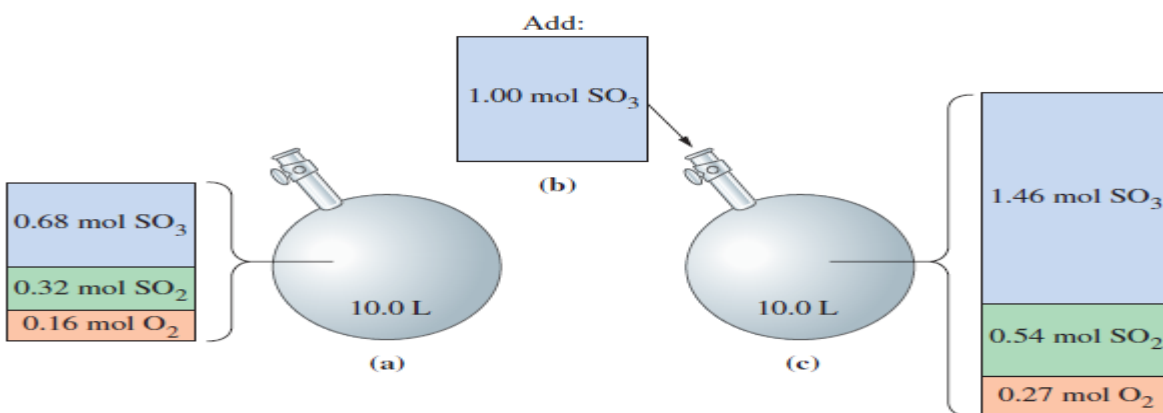


Figure 5.8: Effect of concentration on equilibrium position

The second example involved the removal of amounts of substance from the equilibrium mixture at constant volume. The remaining problems in this activity were to be done in small group argumentative discussions supported by our argument template.

Lesson five involved the effect of change in pressure on chemical equilibrium at constant temperature. The instructional strategies used in lesson five were modelling and argumentation, The effect of pressure was illustrated with the N_2 , H_2 and NH_3 equilibrium system, $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$, shown in Figure 5.9. The enclosed container in Figure 5.9 indicates the microscopic representation of the equilibrium system; (a) indicates the change in the size and the number of molecules in the container after pressure was decreased and (b) indicates the change in the size and the number of molecules in the container after pressure was increased. Question prompts were used

to draw students' attention to the change in the size and number of molecules in each case. Also, since the intermediate state between the first equilibrium and final equilibrium is not shown on the diagram, a graphical representation of change in Figure 5.9 was to be sketched by the students to help visualise the intermediate states between the initial and final equilibrium state and also track the changes concentration of each substance in each case. With the diagram in Figure 5.9 and the graph, a class discussion led to the construction of facts about the effect pressure on the equilibrium systems. The other problems in this lesson were attended to in small groups based on the argumentative discussions supported by our argument template.

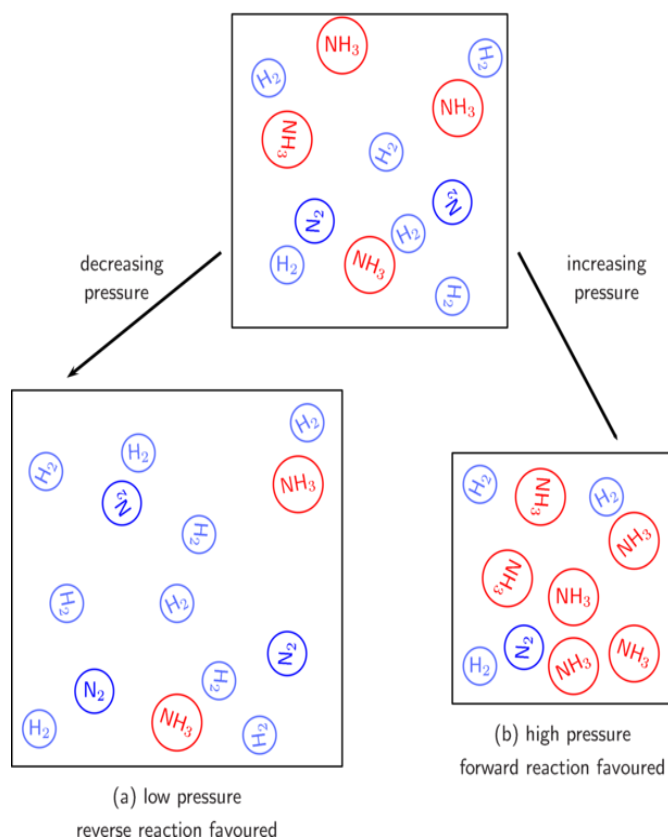


Figure 5.9: Effect of pressure on equilibrium

Lesson six involved the effect of temperature on chemical equilibrium. The instructional strategies used in this lesson were modelling and argumentation and the instructional activities were constructing graphical models of changes in temperature, constructing written arguments, and discussions. In this lesson, the basic knowledge to be learned included exothermic and endothermic reactions and the effect of temperature on the rate of exothermic and endothermic reactions was introduced in grade 11. The first part of this lesson involved revision exercises on these ideas. These basic ideas were reconstructed and given to students as evidence statements on students' worksheets which also contained the argument template. Through argumentative discussions on problems in

small groups, students were expected to explain the effect of change in temperature on the chemical equilibrium. Students were also to be guided to construct a graphical representation of the changes of concentration of substances to support their claims.

Lesson seven involved heterogeneous equilibrium for the thermal decomposition of CaCO_3 : $\text{CaCO}_3(\text{s}) \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$. The intention was to demonstrate that adding or removing the amount of a pure solid in an equilibrium mixture has no effect on the equilibrium system since the concentrations of pure substances do not change.

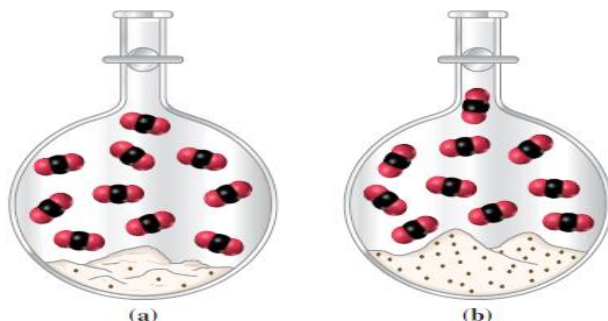
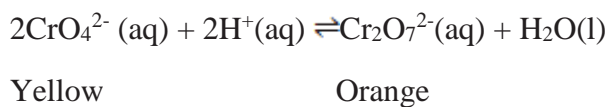


Figure 5.10: Heterogeneous equilibrium (Source: Petrucci et al., 2007).

The instructional strategies for this lesson were modelling and argumentation. Figure 5.10 (a) shows the decomposition of solid limestone $\text{CaCO}_3(\text{s})$ upon heating in a closed vessel, yielding a few granules of lime, $\text{CaO}(\text{s})$, together with Carbon dioxide $\text{CO}_2(\text{g})$ which soon exerts its equilibrium partial pressure. Figure 5.10 (b) indicates that the introduction of additional $\text{CaCO}_3(\text{s})$ and/or more $\text{CaO}(\text{s})$ has no effect on the partial pressure or concentration of the $\text{CO}_2(\text{g})$, which remains the same as in (a). Questions were used to draw students' attention to the differences and similarities between the two diagrams and suggest possible explanations. Students were expected to argue in support of whether introduction or removal of more solid substances could shift the equilibrium position.

Lesson eight was intended to illustrate the common-ion effect. A demonstration involving chromate – dichromate equilibrium system was used.



The outcome of the demonstration was used as evidence during argumentation writing activities. Further reflection questions were to be posed to stimulate critical thinking and promote construction of explanation. The students' worksheets for these lessons are attached as Appendix 5.11. These worksheets were bound into a booklet and were used as the support material for the experimental group. The control group used their prescribed textbook for Physical Science as their support

material but the same chemical equilibrium practice problems for the experimental group were given as leaflets to the control group. Therefore both groups solved the same type of chemical equilibrium problems during lessons but used different support materials and different teaching and learning strategies. The outline of instructional strategies for each lesson and the corresponding students' activities for the experimental and control groups are shown in Table 5.13 and Table 5.14 respectively.

Table 5.13: Instructional strategies and instructional activities used for teaching chemical equilibrium to experimental group

Lesson	Chemical equilibrium content item	Instructional strategy	Students' activities
One	Nature of dynamic equilibrium	Inquiry (Modelling)	(1) listening and observing (2) representing chemical equilibrium using graphical model (3) answering questions (4) discussing
Two	Calculations involving the equilibrium constant value	Modelling the use of cognitive strategy, encouraging the use of metacognitive strategy, using multi-modal representation	(1) listening and observing (2) solving problems involving the equilibrium constant (3) using metacognitive supports (4) interpreting equilibrium constant values
Three	Effect of concentration on equilibrium constant	Inquiry (Analysing and Interpreting data)	(1) calculating equilibrium constant values from data (2) comparing equilibrium constant values (3) group discussions
Four	Effect of temperature on equilibrium	Inquiry (Modelling and argumentation)	(1) constructing graphical models of changes in temperature (2) constructing written

			arguments (3) group discussions
Five	Effect of concentration on equilibrium	Inquiry (Modelling and argumentation)	(1) constructing graphical models of changes in concentration (2) constructing written arguments (3) group discussions
Six	Effect of pressure on equilibrium	Inquiry (Modelling and argumentation)	(1) constructing graphical models of changes in pressure (2) constructing written arguments (3) group discussions
Seven	Effect of adding a solid reactant on	Inquiry (Modelling and argumentation)	(1) constructing writing arguments (2) using models (3) discussions
Eight	Common-ion effect	Predict-Observe-Explain demonstration and argumentation	(1) practical demonstration (2) constructing arguments (3) construction graphical models (4) discussions

Table 5.14: Instructional strategies and students' activities used for teaching chemical equilibrium to control group

Lesson	Chemical equilibrium content item	Instructional strategy	Students activities
One	Nature of dynamic equilibrium	Direct teaching with chalkboard illustrations	(1) listening and observing (2) asking questions and discussions (3) taking notes
Two	Calculations involving equilibrium constant value	Modelling the use of cognitive strategy, working out examples	(1) listening and observing (2) following worked examples to solve problems

			(3) taking notes
Three	Effect of concentration on equilibrium	Direct teaching, working out examples	(1) taking notes (2) listening and observing (3) answering questions (4) following worked examples solve problems
Four	Effect of temperature on equilibrium	Direct teaching, working out examples, Teacher-lead discussions	(1) taking notes (2) listening and observing (1) answering questions (2) discussions (3) following worked examples to solve problems
Five	Effect of pressure on equilibrium	Direct teaching, Teacher-lead discussions	(1) taking notes (2) listening and observing (3) discussions
Six	Effect of adding a solid reactant on equilibrium	Direct teaching	(1) taking notes (2) listening and observing
Seven	Common-ion effect	Teacher demonstration, direct teaching	(1) taking notes (2) listening and observing
Eight	Interpretation of chemical equilibrium graphs	Direct teaching Working out examples	(1) taking notes (2) listening and observing

5.8.3 Sample

Guided by the pragmatist principle of practicality, one of the eight Further Education and Training (FET) schools in the Bohlabela district of Mpumalanga province of South Africa was conveniently selected for this quantitative phase of the study. The school had two grade 12 classes offering Physical Science with a total of 70 students. The researcher was also the Physical Science teacher of the two classes. The school was classified by the Mpumalanga department of education as a high achieving school with a record of at least 85% overall pass rate in grade 12 exit examinations for the

past three years. As one of its school improvement strategies, the school had in place a student support programme in the form of extra lessons given to students in the mornings, afternoons and on Saturdays. This programme was monitored by the school management team with support from teachers. As a result, student absenteeism was minimal, especially in grade 12. The placement of the 70 students in the two classes was done by the school management team such that high achievers and low achievers were roughly evenly distributed across the two classes. Although there are various criteria for identifying high and low achievers, for the sake of this study a high achiever was considered as a student who obtained a minimum pass mark of 30% in Physical Science in the previous grade's (i.e. grade 11) end of year examination. A low achiever on the other hand was a student who failed to obtain the minimum pass mark of 30% in Physical Science in the previous grade's (i.e. grade 11) end of year examination although he/she might have obtained the minimum pass requirement in other subjects. The 30% minimum mark is the pass requirement in Physical Science according to the DBE (DBE, 2011). One of the two classes was randomly assigned the experimental group and the other one to the control group by tossing a coin. The two classes were labelled Head and Tail and it was decided that the one that wins the toss becomes the experimental group and the other one the control group. Each of the classes consisted of 35 students, however during the analysis of data, one student from the control group was excluded because his score was an outlier. This reduced the number of students in the control group to 34 and the total sample size to 69. Of the 35 students in the experimental group, 23 were low achievers and nine 12 were high achievers. Twenty-five students in the control group were low achievers and nine (9) were high achievers.

5.8.4 Procedure for experimental group

The day before the implementation of the lessons, the pre-knowledge test (Chemical Equilibrium Achievement Test [CEAT]) and the pre-metacognitive skills (Physical Science Metacognitive Skills [PSMS]) questionnaire developed by the researcher for this study were administered to both experimental and control groups.

Lesson one which was to promote students' understanding of the nature of chemical equilibrium was implemented on the following day after the administration of the pre-tests. At the beginning of the lesson, the researcher distributed worksheets to students and explained the purpose of the modelling activities on students' worksheets. The worksheet for lesson one contains a diagram of microscopic representation of the $A(g)_{blue\ discs} \rightleftharpoons B(g)_{red\ discs}$ equilibrium, indicating the concentrations of reactants and products molecules at the end of each minute from the start of

reaction to equilibrium. Beside each diagram is a tabular recording of the reaction rates and the concentrations of the system. Then the researcher used the coloured discs to model how a reversible reaction proceeds from the start to equilibrium by performing the calculations and then turned the actual discs on the other side to indicate chemical reaction. Students asked questions for clarifications and the researcher addressed these questions. Metacognitive questions expected to direct student's attention to salient characteristics of target concepts of chemical equilibrium (which the analogues were intended to highlight) were asked on students' worksheets for students to respond to in their group discussion. The group discussions were followed by class discussions led by the researcher, during which feedback was given to students on their responses to metacognitive questions. After this, the effect of catalyst while the reaction was at equilibrium was simulated using the discs: while the reaction was at equilibrium (the blue and the red discs were exchanging sides at the same rate), powdered chalk (assumed to be the catalyst) was sprinkled on the system. The effect was that the discs exchanged sides faster, so students concluded that the catalyst increased the rate of forward and reverse reactions in the same way, so the net change in rate would be zero. This activity lasted one hour and 30 minutes. It is worth noting that during the class discussion, five students confirmed that the simulation challenged their understanding of chemical equilibrium. The students said they thought at equilibrium, concentration of reactants was equal to the concentration of products. The next question on students' worksheets required students to graph their data using the concentration versus time and rate versus time grids provided, and then to indicate the initial and equilibrium concentrations, the initial and equilibrium rates as well as the times when equilibrium was reached. After the lesson, students were given similar data to those generated from the analogy to plot into a graph and then answer metacognitive questions, some of which students had not been explicitly taught. The researcher observed that students were able to answer questions about the graph correctly but they were not able to answer questions involving calculations of the equilibrium constant. The researcher later provided the solutions to students. After that, one female student asked for clarification on the procedure involved in calculating the equilibrium constant, K_c , and these were the researcher's words:

We have to write the K_c expression, products over reactants, just as we saw in the analogy while keeping the following in mind: in K_c expressions, stoichiometric coefficients are exponents; there is no plus sign in the K_c expression; when substituting into K_c expressions, concentrations must be in moles per decimetre cube; reactants are what is on the left hand side of the equation while products are on the right hand side of the equation. The

equilibrium concentrations given in the problem were in mole so they have to be converted to moles per decimetre cube before substitution into the K_c expression using the concentration formula.

In the question that was discussed earlier, nitrogen and hydrogen were reactants in equilibrium with ammonia as the product. However, in order to check whether students understood how to write K_c expressions correctly, the equation was reversed with ammonia as a reactant, and nitrogen and hydrogen as products, and students were asked to set up the K_c expression. Some students thought that ammonia was always a product and made it the numerator even though it was on the reactant side. At this point the researcher intervened and emphasised that it did not matter which substance they were dealing with; once it was on the left hand side of the reversible reaction, it was the reactants and should be placed as a denominator in the K_c expression. In this same lesson the significance of the K_c value was introduced and discussed, supported by the analogy in the previous lesson. Although students had learnt in the analogy that K_c values less than one means more reactants compared to products when the reaction is at equilibrium and values greater than one mean more products are there at equilibrium compared to reactants, students seemed not to easily make these connections. To enhance students' understanding, the researcher explained to the students by putting K_c value in a real world context:

Synthetic chemists are more concerned about K_c values because they are interested in products not reactants. It is therefore worrying if K_c values are lower than one because that will mean their equilibrium mixture has a greater proportion of reactants than products. However, they will be happy if their K_c values are greater than one because that will mean their equilibrium mixture will have a greater proportion of the product compared to the reactant.

At this point students were given problems similar to those discussed in class to perform. After some time students were asked to stop writing to allow for a class discussion, and feedback was given to students. The lesson lasted for one hour and 30 minutes.

Lesson two was about calculations involving K_c . In this activity, a diagram showing the microscopic representation of N_2O_4 (g) and NO_2 (g) was used to simulate the initial state and the equilibrium state of N_2O_4 / NO_2 equilibrium. The question in the activity requested students to calculate the equilibrium concentration of N_2O_4 and K_c for the reaction. The researcher presented the outline of the RICCE table and then demonstrated step by step how information from the

diagram of microscopic representation is placed inside the appropriate cells on the table and how to fill the remaining cells on the table. The researcher presented the common errors that students usually make while using the RICEE table to the students, and then directed them to use a checklist on their worksheets to always check for those errors. The researcher then allowed students to solve a second problem with a different constraint on Kc calculations in the groups using the RICEE table and the check list. Although groups were told to use the checklist, they did not refer to it. Rather, when they got stuck, they asked the researcher for help. To some of the groups the researcher gave a hint on how they could overcome the constraints, but they still could not proceed. To other groups, the researcher gave a hint and also gave them the correct answer to work towards, and they succeeded in beating the obstacle rendered by the constraint in the problem. Knowledge of the correct answer appeared to have served two purposes: (1) it stimulated critical thinking, reflection, and self-correction, and that was seen in students working back and forth until they arrive at the correct answer; (2) it motivated students to stay on the task despite the difficulty. It was decided that giving students the problem and providing the correct answer could be a way of encouraging students to use metacognitive strategies. Therefore in the second problem, the correct answer was given. Some groups managed to overcome the constraint and solved the problem very quickly, while other groups took longer to solve the problem. In the third problem where the constraint was more familiar, students were seen working more as individuals and were able to solve the problem quickly. Some sought assistance from other group members and the researcher. As students were working in groups, the researcher was an additional group member moving round the groups and scaffolding students' thinking by asking questions. As the researcher was going round, the following observations were made: (1) students were not referring to the question prompts to check for their mistakes; (2) students generally tried to solve the problem as individuals first; (3) after trying for some time, some students checked what other students in the group were doing; (4) when there was a difference in procedure, they begun to negotiate for common procedure; (5) this process got some of the groups to get the correct answer; (6) when the group could not agree on a common procedure, they called the researcher to come and assist; (7) most of the negotiation was in the form of asking question for clarification or explanation from peers; and (8) when group members were satisfied with the solution, they asked for another question. The lesson lasted for two hours.

Lesson three aimed at illustrating to students that for a particular reversible reaction, equilibrium could be approached from either side and once the temperature remains the same, the amount of reactants used at the beginning does not matter; once equilibrium is reached at the same

temperature, the equilibrium constant will be the same. Students were asked to calculate equilibrium constants from three hypothetical experimental data obtained from the synthesis of methanol from carbon monoxide and hydrogen and draw a conclusion. Students concluded that the K_c value was the same in all three experiments, even though initial and equilibrium concentrations were different, but they could not explain why the answers were the same. The researcher drew students' attention to the fact that it was only a change in temperature that could change the equilibrium constant value, and in that case temperature was the same in the three experiments. This lesson lasted 30 minutes.

Lesson four was on the effect of temperature on equilibrium and Le Chatelier's principle. The lesson used a modelling and argumentation approach in which students were given our argument worksheet. Students had previously been trained on the structure of an argument and how to write an argument. The researcher asked students to list the factors that affect reaction rate, and then introduced Le Chatelier's principle to students by stating and explaining it, and making students aware that the way Le Chatelier's principle was applied differed for each of the factors. The researcher then used a problem to explain how claim, evidence, reason, counter-argument and rebuttals were used to formulate an argument that provided a solution to the problem. Then the researcher used another problem to model argumentative writing, using the argument template, evidence statements, and evidence diagrams provided. Students were told that evidence could be information from an authority such as theory, law, facts or principle. It could also come from observation, data on a table or graph, or a model. Evidence statements in the form of facts and evidence diagrams like graphs were supplied on students' worksheets. Students were also informed that some evidence could be located in the problem statement itself and therefore they needed to cast their nets wide while looking for evidence to support their claims. Students were made aware that evidence for a single claim could be more than one and the more the evidence, the stronger the claim. Students were then given another problem on the effect of temperature. It became clear that the students, particularly the low achievers, were reluctant to use the argument template. When students' work was inspected, the researcher realised they were using only the evidence from the evidence statements correctly, and either not using evidence provided by the enthalpy of reaction (ΔH sign) correctly, or misinterpreting, or ignoring it, although the two pieces of evidence had to be combined to develop a full argument that provided a solution to the problem. At this point the researcher decided that students needed to be motivated to use the argumentation strategy correctly. According to Sungur (2007), if students believed in the value of a task they would be more likely to

use metacognitive strategy that would guarantee success. For students, one of the motivations for learning is to pass the exam and get a higher grade. To make the task valuable, the researcher decided to make students aware of examiners' feedback related to a similar problem. The comments pointed out common errors and misconceptions of students, failure to use the enthalpy of reaction information in the problem statement correctly, or to misinterpret it, and the consequence of choosing a wrong alternative that looked plausible. Students were told they could not ignore that aspect of the problem. After that the researcher revised the relevant forms of representation of endothermic and exothermic reactions (i.e.

$\Delta H < 0$ or $\Delta H = -ve$ for exothermic reaction and $\Delta H > 0$ or $\Delta H = +ve$ for exothermic reaction

with students in order to improve declarative knowledge. Students were then asked to revise the previous problem they had failed to do. As they were working in groups, the researcher went round to offer support to groups. Students were then given a second problem as homework to solve and submit to the researcher for review the following day. The following difficulties were identified during the review: first, there were inconsistencies in reasoning. Specifically where questions were asked about the effect of an increase in temperature, students explained the effect of a decrease in temperature. Also, students did not refer to the ΔH information to decide which of the two reactions was exothermic and which was endothermic. Furthermore, their arguments were not complete. Remarks drawing students' attention to these difficulties were written on each student's script and they were asked to make corrections and resubmit. In addressing these challenges, graphs showing the concentration of reactants and products change were introduced to assist in constructing explanation. When students resubmitted, there was improvement in their written arguments. This session lasted one hour and 30 minutes, excluding the time for review of students' homework.

Lesson five was about the effect of concentration on equilibrium system position. The lesson was introduced by using diagram to demonstrate to students how a disturbed equilibrium proceeds to establish a new equilibrium. The researcher used questions to draw students' attention to the initial amounts of reactants and products in the $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$ equilibrium, when some $\text{SO}_3(\text{g})$ was injected into the mixture, and the amount of each reactant and product when in the final equilibrium. Then the researcher represented how the system transformed from the initial equilibrium to the final equilibrium on a concentration versus time graph. That graph was to serve as evidence for the change that occurred in the diagram. The researcher then drew students'

attention to evidence statements on their worksheets that helped to predict the effect of concentration on equilibrium. After that the researcher asked students to solve another problem. The researcher observed that students were able to predict the direction of shift of equilibrium, but they were not able to account for how the amount of other substances in the mixture changed. Students were encouraged to sketch a concentration versus time graph and use it to explain how all the substances in the mixture changed. Students in groups were then asked to construct their own explanation using the arguments template, and to discuss their answers. As the researcher went round to check groups' performance, he realised that students' explanations were improving. This lesson lasted for one hour.

Lesson six was about the effect of pressure on the equilibrium system using the $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$ as example. First, the researcher used a diagram showing the microscopic representation of how the number of molecules and the volume change when pressure is increased or decreased. Then the researcher drew students' attention to the fact that increase in pressure caused a decrease in volume and therefore a systematic increase in concentration of all substances as illustrated by the closeness of molecules in the diagram after pressure was increased. The second diagram showed what happened to equilibrium system following a decrease in pressure, i.e. larger volume and larger spaces between molecules. Students were asked to compare the initial number of molecules to the final number of molecules in the system when pressure was increased and when pressure was decreased. They counted the number of molecules and responded correctly that there were more molecules when pressure was decreased and fewer molecules when pressure was increased. At this point the researcher explained to students that equilibrium position would shift to the side with a smaller number of gas molecules when volume decreased and to the side with more gas molecules when volume increased. The researcher asked students to illustrate this symbolically using the chemical equation. After that the researcher asked students to sketch a graph to represent the change that occurred in each case, and then explained how each of the substances changed. Students in groups were then asked to solve a problem on their worksheet using the argument template. The lesson lasted for one hour and 30 minutes.

Lesson seven was about the effect of adding a solid to a heterogeneous equilibrium. This lesson used the modelling and argumentation approach. A diagram of two sealed vessels showing the microscopic representation of $\text{CaCO}_3(\text{s}) \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$ equilibrium was shown to students. At the start of the lesson the researcher used questions to draw students' attention to the fact that the two vessels contained different amounts of solid CaCO_3 but the same amount of $\text{CO}_2(\text{g})$, and then

explained that adding more solid CaCO_3 to the first equilibrium increased the amount, but the amount per unit volume which was concentration did not change, hence equilibrium would not be disturbed and none of the reactions would be favoured. However, most students asked for further explanation and the researcher explained that when the concentration of one of the substances changed, equilibrium would be disturbed and the system had to react to restore equilibrium. In this case where you added more solid CaCO_3 its amount (n) as well as its volume (v) increased, so its concentration n/v would remain the same and equilibrium would not be disturbed. This lesson lasted for 1 hour 30 minutes

Lesson eighth was about common ion effect. This was presented by demonstrating the effect of $\text{HCl}_{(\text{aq})}$ and $\text{K}_2\text{Cr}_2\text{O}_7$ on the orange solution of potassium dichromate represented as $2\text{CrO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) \rightleftharpoons \text{Cr}_2\text{O}_7^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l})$ equilibrium. Before each addition, the researcher asked students to predict the colour change that would be observed and explain it. Then the researcher added the HCl solution and students who had not predicted correctly were surprised and wanted to understand why. Students were encouraged to construct a concentration versus time graph to explain how the colour change occurred. The lesson lasted one hour.

5.8.5 Procedure for control group

Lessons in the control group were presented following the sequences used for the experimental group. However, interpretations of equilibrium constant and graphs of equilibrium were taught separately from calculations involving the equilibrium constant.

Lesson one was chemical equilibrium and the subtopics were open and closed systems, reversible reactions and dynamic equilibrium. Reversibility, dynamism and incompleteness of reaction which are characteristics of chemical equilibrium, were explained to students using the diagram of a liquid-vapour equilibrium in a closed system from the students' Physical Science textbook. At the beginning of the lesson, the researcher made a sketch of the sealed transparent vessel that was about three-quarters full of water and then explained to students that it was an example of a closed system. Then the researcher explained a closed system as the system in which matter could not leave or enter, but energy couldn't move into and out of the system. An open system on the other hand was explained as the one in which both matter and energy could enter and leave the system. The researcher also explained that in a closed system, when products were formed, they remained in the system and started to form back the reactants. After that the researcher used the liquid-vapour equilibrium to explain step by step how the system proceeded from the start to equilibrium. The

researcher also explained that the two processes taking place inside the vessel as the water changed phase, were evaporation and condensation. At the beginning, there was less vapour inside the vessel, so evaporation occurred faster than condensation. As more vapour formed, evaporation slowed down while condensation picked up speed. At a specific point in time, rate of evaporation is equal to the rate of condensation, and at this point the systems is said to be in dynamic equilibrium. The researcher supported the analogy with equation of phase change between liquid water and water vapour and then stressed that at equilibrium, the two processes continued to occur at the same rate, the reaction did not stop even though visibly nothing appeared to be happening. After the presentation, the researcher invited questions from students. A few students asked questions for clarifications and the researcher responded to these students' questions. The lesson lasted for one hour.

Lesson two was about calculations involving the equilibrium constant, K_c . First, the researcher demonstrated how to use the RICEE table to obtain equilibrium concentration, set up the K_c expressions, substitute values from the table into the K_c expression and calculate the final value of K_c . Next, students were asked to solve a problem with a different constraint from the one used in the demonstration. Most students worked individually, but when they saw that they were not getting the answer, a few started to collaborate. After some time when it was clear to all the students that they could not solve the problem, they asked the researcher to provide the solution which they copied into their classwork books. After that the researcher gave students a second problem with a different constraint to solve. Students could not finish but requested to be allowed to solve the problem at home. The next morning when students were asked to bring their classwork books for marking, they said they had not solved the problem, but they would solve it if given a little time. They were allowed to work for some time but still could not solve the problem. Students then requested the researcher to solve and explain the steps for them. After the researcher had explained the constraints of the problem to the class, one student volunteered to solve that problem and he was allowed to do so. After he had solved the problem, other students requested explanations of the solution process again, which he gave. Students were then allowed to copy the solution into their classwork books. Students were then given a third problem with a different constraint to solve. After attempting to solve the problem for some time, some students recognised the constraints and asked for assistance. The researcher provided the needed assistance, but the period was over so students were told to complete the work at home. When it was time for the next Physical Science lesson, the researcher asked how many students had been able to solve the problem. About twelve of students

said they had tried but were not sure they were correct. The researcher provided feedback and the students realised that they were correct. When the students were interviewed on how they had managed to solve the question correctly, it was revealed that it had been done through collaboration with more able students. Students copied the feedback, and they were given a fourth problem with a different constraint to solve. The more able students solved the problem correctly and very fast. This session lasted three hours.

Lesson three was about the effect of concentration on equilibrium. The researcher began the lesson by asking to students to list and explain the factors that affect rate of reaction. Students took turns to list and explained how each factor affected reaction rate. Then the researcher asked students to define chemical equilibrium, upon which one student volunteered and gave the correct definition. The researcher then explained that when any of the factors that affected rate of reaction was altered, rates would no longer be equal. We then say the equilibrium is disturbed. At this point, the researcher mentioned Le Chatelier's principle and explained that it was the principle used to explain how the system responded to the disturbance in order to re-establish equilibrium. After that the researcher worked through an example of how to apply Le Chatelier's principle on the effect of concentration changes, using an example. After working the example for students, the researcher gave students a problem on the effect of concentration to solve. The problem was about the effect of increasing the concentration of $N_{2(g)}$ for the equilibrium reaction $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$. As students were solving the problem, the researcher went round to give support to students who were struggling. The researcher observed that many students were able to solve the problem. After they had been working for some time, the researcher asked students to stop writing for a class discussion. Feedback was given to students during this time. Students were then given a second problem on this subtopic to solve at home and submit for scoring. On the following day, the feedback on the assignment was given and students were asked to effect corrections. The lesson lasted for one hour and 50 minutes.

Lesson four was the effect of temperature on equilibrium. This lesson began by asking students to answer questions based on lesson three. The researcher also revised exothermic and endothermic reactions with students through questions and answers. The researcher then explained that the way Le Chatelier's principle was applied with respect to effects of temperature was not the same as concentration. After that the researcher stated that increasing temperature favoured endothermic reaction while decreasing temperature favoured exothermic reaction and wrote this statement on the

chalkboard. The researcher explained the procedure for applying the effect of temperature on the equilibrium as follows:

“Firstly identify the endothermic and exothermic reaction by referring to the sign of the heat of reaction. As a rule of thumb, the sign of the heat of reaction as given in the chemical equation applies to the forward reaction. By implication the reverse reaction takes the opposite sign of the heat of reaction. Thus, if the forward reaction is identified to be exothermic, the reverse reaction is automatically endothermic. Next you should consider how an increase or decrease in temperature affects exothermic and endothermic reactions.”

After teaching students the strategy for explaining the effect of temperature, the researcher solved an example problem for them. One student said she did not understand the solution. When the researcher asked how many students had similar problems, many students raised their hands, so there was a need for re-teaching. The researcher asked students which aspect of the explanation they were not comfortable with. They could not describe clearly, but upon further interrogation, it became clear that students could not identify the exothermic and endothermic reactions using the heat of reaction information provided. Also, when the researcher asked students to explain how increase in temperature affected rate of endothermic and exothermic reactions, one male student answered that increase in temperature increased the rate of endothermic reaction and decreased the rate of exothermic reaction. At this point, the researcher asked students to explain how increase in temperature affected the reaction rate, and a female student responded saying: “It increases the rate of reaction”. This view was supported by many other students but one male student who said: “Increase in temperature increases the rate of endothermic reaction and decreases the rate of exothermic reaction maintained his stance”. At this point, the researcher intervened by explaining: “Increase in temperature increases the rate of both endothermic and exothermic, but endothermic reaction rate increases more than exothermic reaction, and this is what we mean by saying endothermic reaction is favoured by an increase in temperature. Similarly decrease in temperature causes the rate of both endothermic and exothermic reactions to decrease, but endothermic reactions rate decreases more than exothermic reactions rate, and that is what is meant by saying a decrease in temperature favours exothermic reaction rate.”

Even after this explanation, some students were still not convinced that increase in temperature increases the rate of exothermic reaction. The researcher then prompted the students to think about effect of temperature on a number of effective molecular collisions, and finally the students became convinced that raising the temperature increases the rate of exothermic reaction as well.

Subsequently students were given a problem to solve. As they were solving the problem, the researcher went round to give support. After some time, students were asked to stop work for a class discussion during which feedback was given. One thing worth noting was that the explanation of effect of temperature presented on this page was not present in students' prescribed textbook of Physical Science. The lesson lasted for one hour and 30 minutes. Students were given homework to complete (problem to solve) and submit in the following lesson.

Lesson five was about the effect of pressure on equilibrium. The lesson was introduced by asking students to answer questions based on the lesson four. The researcher wrote the equilibrium reaction on the synthesis of ammonia on the chalkboard and explained that for the effect of pressure, one should consider the relationship between pressure and volume. Thus, increase in pressure causes a decrease in volume, so equilibrium position will shift to the side with fewer number of gas molecules. The researcher then guided students through questioning to identify the side of the ammonia synthesis reaction that has less number of gas molecules. After no one indicated that s/he experienced a challenge in understanding the equilibrium shift, the researcher asked students to deduce what would happen to the moles of reactants and products following an increase in pressure. Many students could not understand that following an increase in pressure, when equilibrium is re-established, the number of moles will increase for the side with fewer moles and decrease for the side with more moles. The researcher explained: "Equilibrium position shifts to the product side means more reactant reaction had occurred than product reaction, and as a result some of the reactants are used while additional products are formed as a new equilibrium is established." Some students became confused about old equilibrium and new equilibrium. The researcher then explained to the students that what Le Chatelier meant by saying that the system would counteract the change so as to restore equilibrium was that following a disturbance of a first equilibrium by altering pressure, a new equilibrium had to be re-established to neutralise the effect of the disturbance, and that was why equilibrium shift occurred. After the explanation, the researcher asked if there was any other student who did not understand, but most of the students said they understood. However, a few of them were quiet. Nevertheless, the majority of students said that the lesson could proceed. The researcher asked students to comment on what would happen to the concentration of the reactants or products following an increase in pressure. As expected, most of the students said concentration of reactants would decrease due to the equilibrium shift to the right. One student said that he believed the concentration of reactants would increase, but could not explain why. The researcher explained that concentration of all substances would increase due to a

decrease in volume. Some students then asked whether pressure was directly proportional to concentration and the researcher responded that it was because increase in pressure brings the gas molecules closer and the volume of the vessel decreases. As a result, there are more moles per unit volume, hence an increase in concentration. The students indicated they were not comfortable with the explanation because concentration was proportional to number of moles and if the number of moles decreased, concentration should also decrease. The researcher explained that moles and concentration do not mean the same thing; moles can decrease due to equilibrium shift but in explaining the effect of concentration, one must consider both change in moles and change in volume. Furthermore, equilibrium shift causes changes in moles, but for changes in concentration, volume change is considered. Students indicated that they understood the explanation. Then the researcher asked students to predict the effect of increasing pressure on the equilibrium amount and equilibrium position for the reaction $\text{NiO(s)} + \text{CO(g)} \rightleftharpoons \text{Ni(s)} + \text{CO}_2\text{(g)}$. Some students said equilibrium position would shift to the right while others said it would shift to the left, but they could not explain their answers. The researcher said neither of the answers given was right because in that case, there was no volume advantage. There were an equal number of gas molecule on both sides of the reaction because the other reactants were in the solid phase, hence equilibrium position would not be affected, but the concentration of gaseous substances would increase due to a decrease in volume. The concentration of solid substances would not be affected as they were constant. After that the researcher asked students to predict the effect of adding an inert gas to the system at equilibrium while keeping the volume constant, but students could not respond. The researcher explained to students that adding an inert gas to the system as constant volume was like adding more gas to a rigid gas cylinder: as you added more gas, the total pressure inside the cylinder increased, but since the inert did not react with the reactants or products, concentration did not change and equilibrium was not disturbed. The lesson lasted for one hour and 20 minutes.

Lesson six was on the effect of adding a solid to a heterogeneous equilibrium. The equilibrium reaction $\text{CaCO}_3\text{(s)} \rightleftharpoons \text{CaO(s)} + \text{CO}_2\text{(g)}$ was used as an example of a heterogeneous equilibrium. The researcher explained the effect of adding more solid CaCO_3 to the equilibrium mixture in the same way as he did for the experimental group; the only difference was that the diagram of microscopic representation was not used for the control group. Another difference was that while the students in the experimental group used the argument template to construct their own explanation, students in the control group only copied the explanation given by the researcher. This lesson lasted for 20 minutes.

Lesson seven was on common ion effect. This was presented by demonstrating the effect of $\text{HCl}_{(\text{aq})}$ and $\text{K}_2\text{Cr}_2\text{O}_7$ on the orange solution of potassium dichromate represented as $2\text{CrO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) \rightleftharpoons \text{Cr}_2\text{O}_7^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l})$ equilibrium. Here the researcher presented the demonstration to students and provided an explanation for the observed colour change in each case by applying Le Chatelier's principle. Students wrote down the teacher's answer into their notebooks. This lesson lasted for 35 minutes.

Lesson eight was on the interpretation of equilibrium graphs. The researcher presented leaflets of the different types of sketched equilibrium graphs to students, and interpreted each of them for the students. When students did not understand, they asked for further explanation and it was given. The students were given homework on interpretation of graphs. The lesson lasted for one hour and 30 minutes. A week after the implementation of the lesson, the post-chemical equilibrium achievement test and the chemical equilibrium metacognitive skills questionnaire were administered.

5.8.6 Data analysis

Data were analysed using statistical techniques such as means and standard deviations, *t*-test, and ANCOVA. An independent *t*-test was used to compare pre-test mean scores of experimental and control groups. The effect of conceptual change teaching activities (refer to table 5.13) based on metacognition development on students' achievement in chemical equilibrium and development of metacognitive skills was analysed using one-way ANCOVA with the Physical Science achievement scores and Physical Science metacognitive skill as the covariates, teaching strategy as the independent variable and the post-test as the dependent variable. The effect of conceptual change instruction based on metacognition development on metacognitive skills was analysed using one-way ANCOVA with Physical Science metacognitive skills as the covariate, teaching strategy as the independent variable and chemical equilibrium metacognitive skill score as the dependent variable. ANCOVA was appropriate for this data analysis because it controls for any pre-existing difference between the experimental and control groups as a result of non-randomization of subjects in group (Pallant, 2011). Cronbach's alpha was used to determine the reliability of the CEAT and MCAI-CE. All statistical analyses were done at 5% significant level. Practical significance of the conceptual change instruction based on metacognition development was determined by computing Eta Square. The Statistical Consultation Services of the North-West University inspected and approved the design of the questionnaires, achievement test and the statistical tools for data analysis as well as the sampling techniques. The Statistical Consultation Services also assisted in the analysis

of quantitative data. In this study Cohen's d index was used because it enables the researcher to measure "the difference between two means expressed in standard deviation units" (Sheskin, 2000, p. 835).

The criteria for identifying the magnitude of an effect size are as follows: A trivial effect size is below 0.2 standard deviation units; a small effect size is between 0.2 and 0.5 standard deviation units; a medium effect size is one that is between 0.5 and 0.8 standard deviation units; and a large effect size is one that is 0.8 or more standard deviation units (Rosenthal & Rosnow, 1984; Sheskin, 2000).

5.9 ETHICAL CONSIDERATION

The research was conducted in accordance with the ethical codes of the Faculty of Education of the North-West University. The ethics number for this study is NWU-00246-16-A2. All participants were contacted and informed about the purpose of the study and how data would be used. It was made known to all participants that they were not waiving any legal claims, rights or remedies because of their participation in the study. Participants were told that participation in this study was entirely voluntary as they had the right to withdraw at any stage without any penalty or future disadvantage whatsoever. Their withdrawal would in no way influence the relationship with the researcher. Parental informed consent forms and student consent forms were signed by all participants and their parents (see Appendix 5.9).

During data gathering, the researcher built trust between researcher and participants by discussing the purpose of the study and how data would be used. Personal impressions were not shared with teachers and the researcher did not use leading questions during interviews. During data analysis, multiple perspectives as well as contrary findings were reported. Pseudonyms were assigned to participants to keep their identity anonymous, while names of schools were not mentioned in the report.

Only the researcher and the supervisors had access to the completed metacognitive skills questionnaire, marked scripts of achievement tests and interview transcripts. Answers provided by participants were totally anonymous and participants' identities were not revealed under any circumstances. The results of this study have been presented at conferences, but again without revealing the identity of any participant in the research. The Mpumalanga Department of Education granted permission for the study (see Appendix 5.4) to be conducted in the schools. The School Governing Boards (SGBs) also granted permission for the study (see Appendix 5.5) to be conducted in their schools.

5.10 SUMMARY

This chapter described the research methodology, and provided an argument for mixed method research design as a design of choice for this study. The chapter presented the literature review process and the conceptual framework that informed field work in this study. The methods of data collection and analysis were described and motivated. The chapter also presented the development and implementation of the intervention on the fields. Finally ethical issues concerning this study were presented. The next chapter will deal with analysis of data and presentation of results

CHAPTER SIX: PRESENTATION OF DATA AND ANALYSIS

6.1 INTRODUCTION

In this chapter, the analysis of data and results of the fieldwork are described. The researcher begins with the presentation and analysis of the data from the qualitative phase of the study. Results of the qualitative phase are presented for each of the four think-aloud tasks, then followed by an analysis of errors students committed while solving chemical equilibrium problems. Then, for the quantitative data, the researcher begins by testing all statistical assumptions and then continues with the actual statistical tests. The results of the pilot testing of research instruments used in this study are also given in this chapter. The results of the analysis are presented in tables, charts and graphs. The chapter concludes with a summary

6.2 ANALYSIS OF QUALITATIVE DATA

6.2.1 Task 1

The main difficulty encountered by students in Task 1 was determination of equilibrium moles from the graph. The three high achieving students read the equilibrium moles correctly from the graph and were able to calculate the equilibrium constant accurately. None of the four low achieving students attended to the portions of the graph that indicate equilibrium moles although they attended to the initial moles. The episode for the determination of equilibrium moles by Eliot, a low achieving student, shows that he did not read the equilibrium moles from the graph: *and here we must find the equilibrium...we must use this product to find the equilibrium... and this one is 1 times this one (2,4) equals to 2,4...and this one is 4...*

Similarly, Morena, also a low achieving student, did not read the equilibrium moles from the graph; she used means-ends analysis to determine the equilibrium moles. Her think-aloud episode for the determination of the equilibrium moles is given: *from there to get the equilibrium I will say 2,4 minus 1 for this one...is equal to... 1,4...and 1,8 minus 0,3...is equal to 1,5...*

During the post-activity interview, the researcher observed that students were referring to initial moles as the equilibrium moles:

Researcher: What is the equilibrium mole for AB₂ from the graph?

Angela: 0,2 according to the scale.

Researcher: Can you show on the graph?

Angela: Here [pointing to the first horizontal grid line that corresponds to 0,2 on the mole axis where the label AB_2 is placed].

Researcher: What about the equilibrium mole for B_2 ?

Angela: B_2 , because the graph is going straight here it is 2,0 [which is the initial mole of B_2].

Further prompting drew students' attention to the portions of the graph corresponding to equilibrium and they read them correctly:

Researcher: I mean equilibrium mole not initial mole.

Angela: Hmm... the equilibrium mole is 1,2.

However she did not know in which cell on the RICEE table to place the figures:

Researcher: Did you write this on the table?

Angela: No.

Researcher: Why?

Angela: [silence]

Researcher: What about the equilibrium mole for A_2 ?

Angela: A_2 is 2,0.

Researcher: What about the equilibrium mole for AB_2 ?

Angela: It's 0,8.

Researcher: Did you write this in the table?

Angela: No.

Researcher: Is it needed in the table?

Angela: I'm not sure whether it is needed and where it should be.

Researcher: Thank you.

Figure 6.1 (a) and (b) shows the levels of metacognitive activities of high achievers and low achievers respectively on each step in the procedure followed in solving the task.

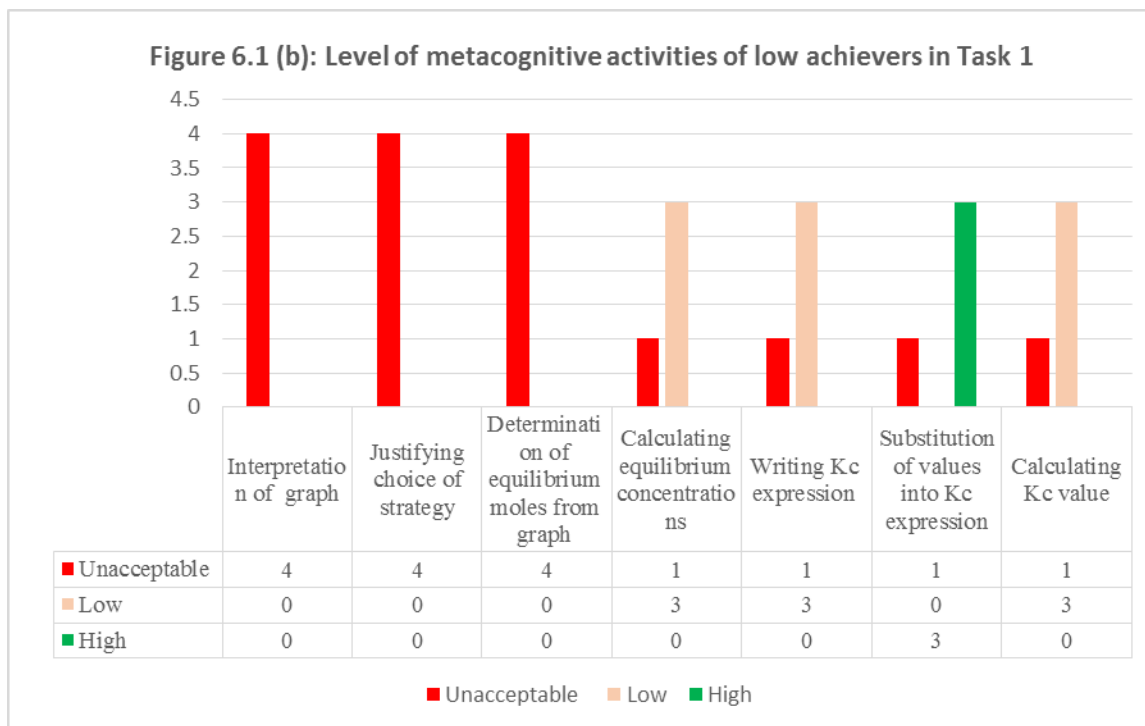
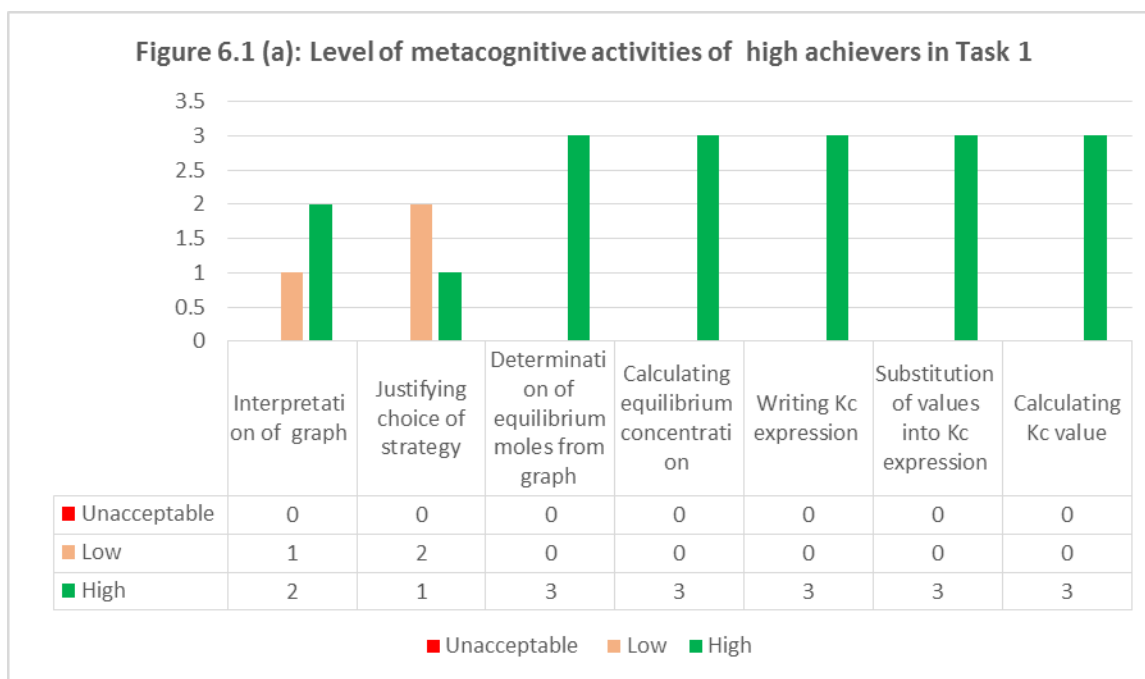


Figure 6.1(b) indicates that, except for substituting into the equilibrium constant expression, the metacognitive activities of the low achieving students were mostly low or unacceptable. They could not overcome the difficulty in the task which was the determination of equilibrium moles from graph. Only one of the three high achievers [Figure 6.1(a)] justified that there was no need to use the RICEE table since the equilibrium moles had been given on the graph and the volume was also

known. However, this justification utterance was made when he wanted to determine change moles and realised that it was not necessary. This is evidence of self-monitoring while performing the task. The other two high achievers did not demonstrate this evidence, although they also solved this task correctly.

6.2.2 Task 2

Task 2 required students to predict whether the forward reaction of a given reversible reaction was endothermic or exothermic, following an increase in temperature. To be able to solve this task successfully, students must remember how increase in temperature affects rates of endothermic and exothermic reactions of the reversible reaction, and interpret evidence provided by the graph on changes in moles of reactants and products. They should also be able to logically connect the graphical evidence to previous knowledge on the effect of temperature on exothermic and endothermic reactions. The three high achieving students were able to activate the prior knowledge, interpret the graph and make connections between graphical evidence and prior knowledge to arrive at the answer. Their ability to activate the relevant prior knowledge, interpret evidence and connect the two in a manner that support their claim indicated a high level of metacognitive activity. Their sequence of thinking is described as follows: first, they studied the evidence from the graph and then retrieved the relevant previous knowledge from memory; after that they used deductive reasoning to arrive at a conclusion which is the claim or answer to the task. The think-aloud episodes of Mashele, a high achieving student, illustrates this type of thinking:

1. *When reading from the graph... AB_3 is increasing and the temperature was increased.*
2. *Increase in temperature favours the endothermic reaction.*
3. *Which in this case is the forward reaction because products are increasing.*
4. *That means the production of AB_2 is endothermic.*

The four low achieving students did not indicate this type of thinking. They did not activate any prior knowledge, indicating unavailability of it in memory. One of them did not attempt to interpret the graph while three attempted to use the graph to substantiate their claims. They demonstrated a thinking pattern of first making a claim before attempting to substantiate the claim. It appears that, since they seem to lack the relevant prior knowledge, they constructed on-the-spot explanation of their claims by assuming a correspondence between increases in temperature (the cause of the change in the equilibrium system) and the increasing shape of the graph without considering what

was increasing with time on the graph. The post-activity interview of Angela (low achiever) illustrates this kind of reasoning:

Angela: my answer is exothermic because the graph is increasing.

Researcher: Graph is increasing? What does that mean?

Angel: It is that the temperature is increasing and the heat is coming out so it is exothermic.

Eliot (low achiever), who also did not activate any prior knowledge, predicted correctly the forward reaction was endothermic: *At ten minutes, the temperature was increased. Determine if the product (production) of AB_2 is exothermic or endothermic. So the correct answer is...endothermic...*

However, he ignored the graph and probably based his explanation of his prediction on his knowledge of the definition of endothermic reaction as a process that absorbs heat. This is illustrated in the post-activity the interview. “(Words in brackets have been added for clarity.)”:

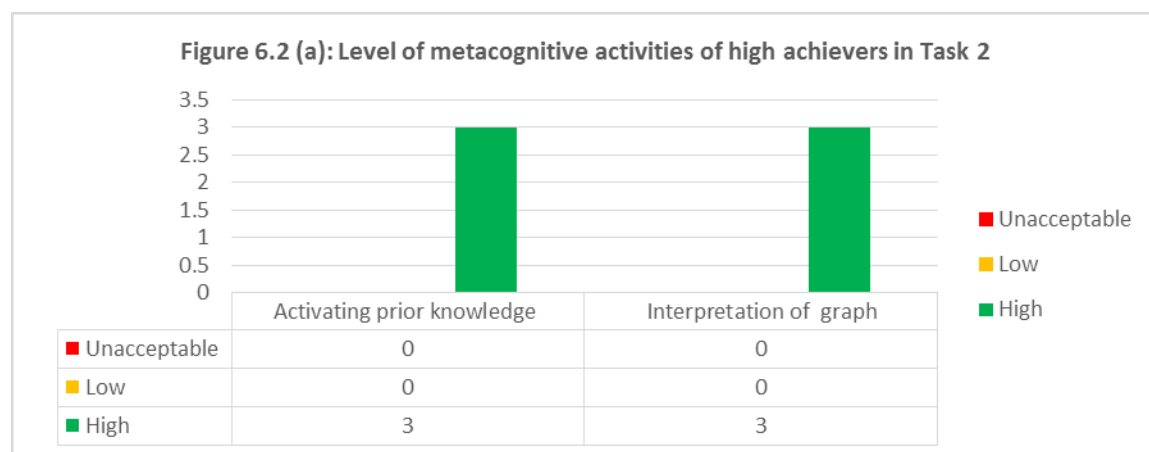
Researcher: Why do you think so?

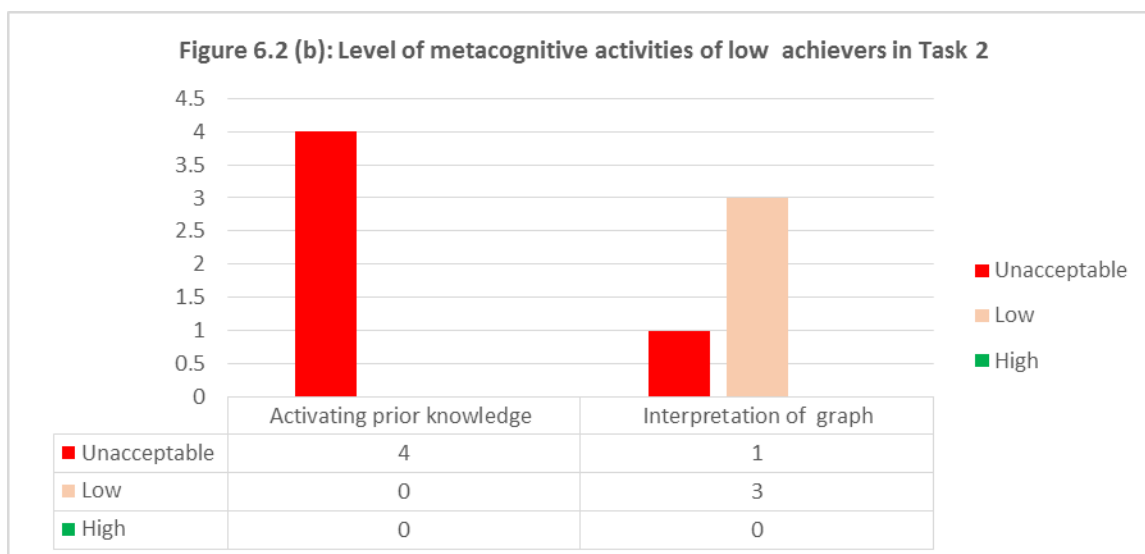
Eliot: Because the temperature on the flask was increased. That means [heat] it is added.

Researcher: Can you explain this from the graph?

Eliot: On the graph, ten minutes is, the temperature of the flask is increased. Obvious [heat] is added.

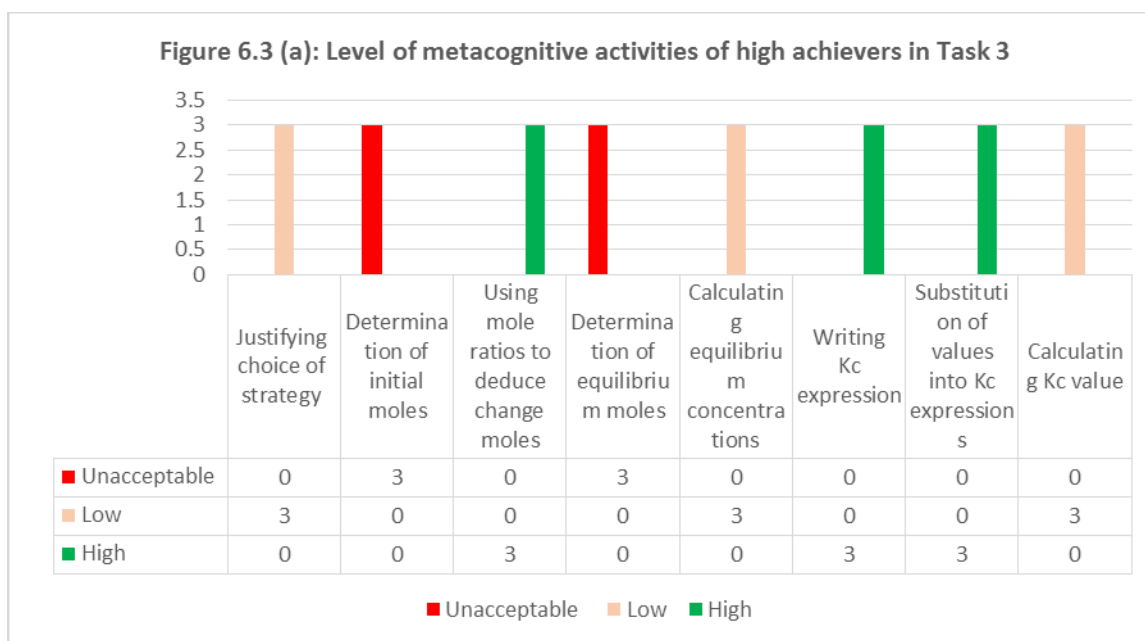
His reasoning can be summarized as follows: when temperature increases, it means heat is added and since endothermic reaction absorbs heat, the heat must be absorbed. Figure 6.2 (a) and (b) indicate level of metacognitive activities of high achievers and low achievers respectively.

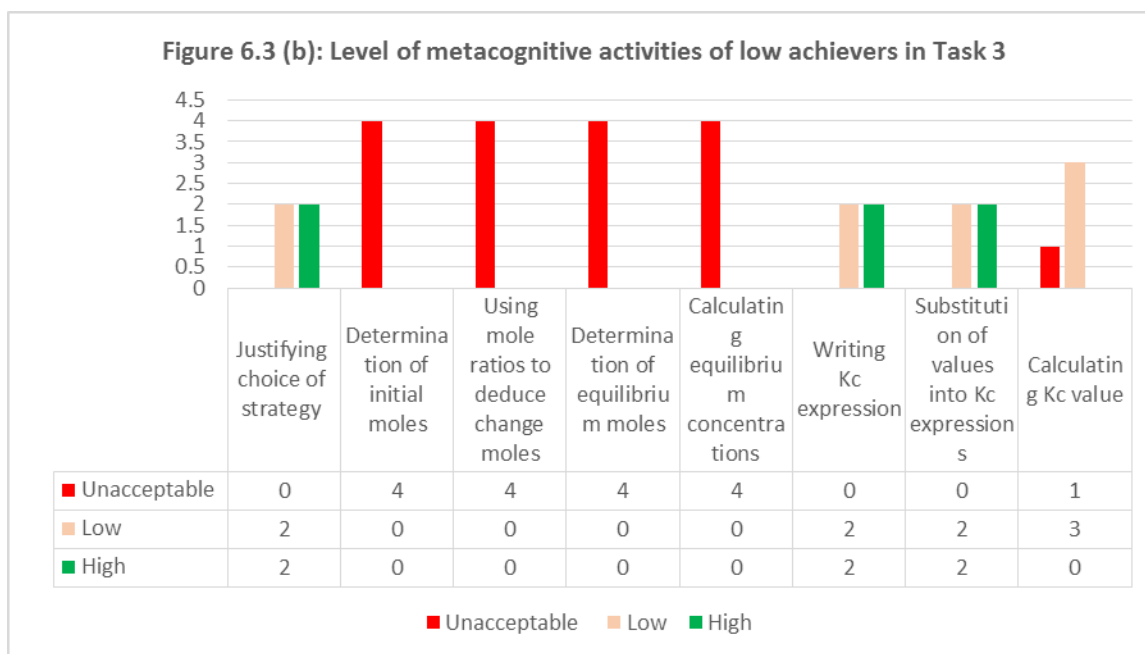




6.2.3 Task 3

Task 3 concerns equilibrium in aqueous solution. The main constraint to solving this task was the determination of initial moles of reactants from their given concentrations and volumes using the formula $n = c \times v$. As shown in Figure 6.3 (a) and (b), no student from either group thought this way and none was able to arrive at the correct answer.





Attempting to solve the problem, low achieving students ignored the volume and read out only the concentrations and used them in calculating the equilibrium constant. The protocol fragments from two students that illustrate this behaviour are given:

We don't use the table because we have the concentrations already [Eliot] and for this one there is no need to use a table because everything that we need is there [Morena].

The post-activity interview revealed that the students could not differentiate between initial and equilibrium concentrations, once again demonstrating lack of awareness of the equilibrium state. Instead students omitted any aspect of the problem they were not familiar with and applied a ready to use algorithm in solving the task:

Researcher: Morena, you said you used equilibrium concentrations in calculating the Kc. Can you show where these figures are in the problem statement?

Morena: Yes, here [pointing at the phrase 'at equilibrium' in the problem statement].

Researcher: Read let's hear.

Morena: At equilibrium, the concentration of $Fe(SCN)^{2+}$ is found to be $0,05 \text{ mol.dm}^{-3}$

Researcher: ok that's for only $Fe(SCN)^{2+}$

Morena: Yes.

Researcher: What about the concentrations of Fe^{3+} and SCN ? Are they also equilibrium concentrations?

Morena: Yes.

Researcher: Do you believe that?

Morena: Yes.

Researcher: What makes you believe?

Morena: I don't believe that.

Researcher: Then why do you think it should be so?

Morena: Why do I what? [Asking for clarification]

Researcher: What I mean is this. When I asked you previously that which concentrations in the problem statement were equilibrium concentrations you showed me the concentration of $Fe(SCN)^{2+}$ only. You did not show the concentrations of Fe^{3+} and SCN^- , but in your calculation, you used the concentrations of Fe^{3+} and SCN^- as equilibrium concentrations.

Morena: Eish! [Exclamation remark indicating a recognition of error or inconsistency]

Researcher: Is that correct?

Morena: No.

Researcher: Then why did you do it that way?

Morena: Aaah... Because I thought it's better if I do it that way.

Researcher: You mean you thought it would give you the answer you are looking for?

Morena: Yes.

Researcher: What convinced you?

Morena: Because we used the table to find the concentrations and now I see the concentrations written in the question.

The researcher also observed that due to the unawareness of the equilibrium state low achieving students were convinced of the correctness of their solution such that they tend not to attend to inconsistency in their problem solving approach even when prompted:

Researcher: Which concentrations did you substitute into the K_c expression? Is it the initial or the equilibrium?

Eliot: The beginning.

Researcher: Why do you mix equilibrium and initial concentrations in the calculating equilibrium constant?

Eliot: Eeiish! [Exclamation remark indicating a recognition of error or inconsistency]

Researcher: Do you see a problem?

Eliot: Aaah... I don't see a problem.

Researcher: Why not?

Eliot: It's because it's already, this is a general formula so, here I already have a product, and I already have a reactant.

Similarly, high achieving students ignored the volumes of the solution and read out only the concentrations. They however distinguished between initial concentrations and equilibrium concentrations and so went ahead to determine the equilibrium concentrations of reactants which were not given in the problem statement. The post-activity interview revealed that the students' inability to incorporate the given volumes of the solutions in their calculation was because they did not know how use the volume in their calculations:

Researcher: In the problem statement you were given the initial volumes of the Fe^{3+} and SCN solutions but you did not use them in your calculations. Do you think this information is important?

Percy: Ehmm... I think it's important

Researcher: Then why didn't you use them in you calculations?

Percy: I didn't know how I should use it.

Researcher: When you first saw the problem did you feel you could solve it?

Percy: Yes.

Researcher: Are you sure your answer is correct?

Percy: Ehmm... not really.

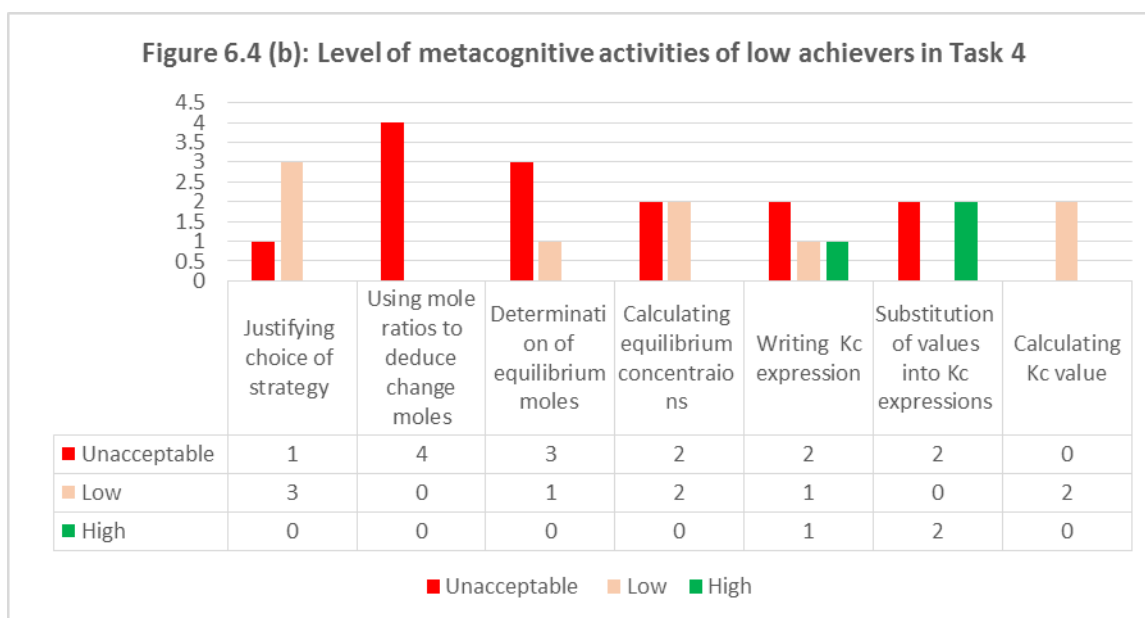
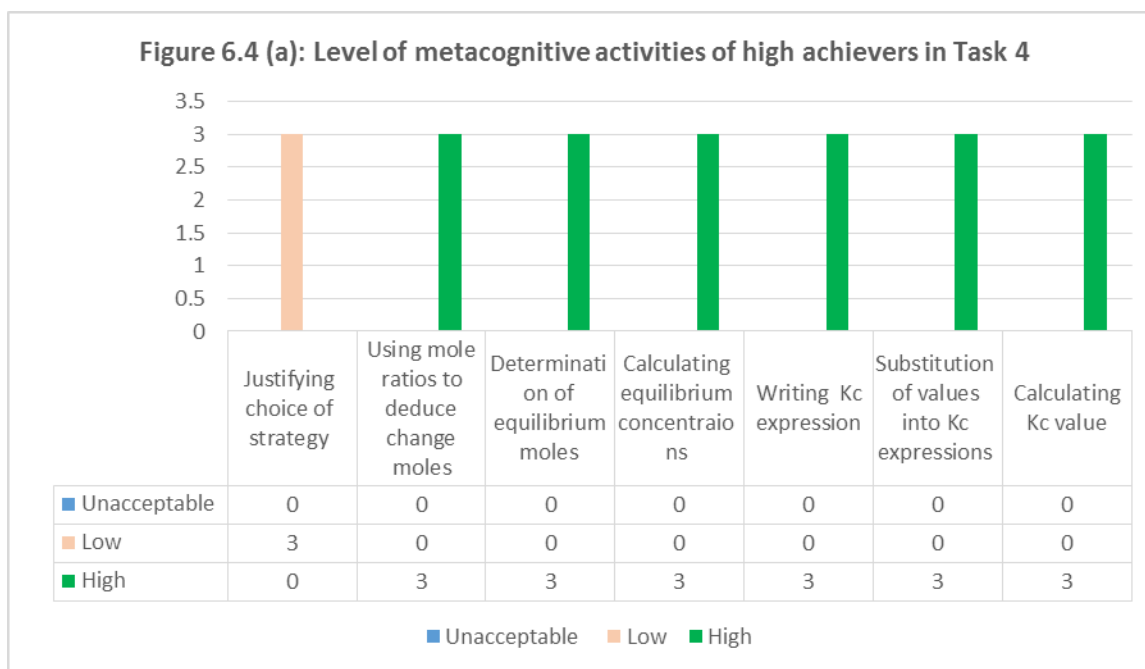
Researcher: Have you come across a chemical equilibrium problem like this before?

Percy: No.

This indicates that failure of the students to solve the task was due to lack of metacognitive skills in adapting the problem solving procedure to a different context from the one in which the problem solving procedure was taught.

6.2.4 Task 4

The constraint to solving Task 4 was the determination of equilibrium moles of product (SO_3) which was given as a percentage of a reactant (SO_2) that had disappeared when equilibrium was established. This critical step requires students to use the given percentage of reactant converted to determine the moles of reactant used or moles of product formed when equilibrium was established. As shown in Figure 6.4 (b) below, the four low achievers could not demonstrate the adaptive thinking needed to overcome this constraint.



This lack of adaptive thinking in the problem solving was revealed in the post-activity interview as a result of lack of familiarity with this type of problem:

Researcher: I realised one thing about your solution. There is information in the problem statement that you ignored, "That is, when equilibrium was reached, 94,3% of the Sulphur dioxide is converted to Sulphur trioxide". Why did you ignore this?

Morena: I'm not familiar with this information.

Further probing confirmed that low achieving students thought the table should be filled sequentially from top row to the bottom row, suggesting lack of metacognitive knowledge in using the RICEE table:

Researcher: from where do you start?

Morena: From here [pointing at the initial amount of SO₂ in the cell in the first row].

Researcher: Even in the first question you started from here.

Morena: Yes.

Researcher: Why not from O₂?

Morena I'm used to starting from here.

Researcher: Always?

Morena: Yes always.

Researcher: Why do you always start from there?

Morena: Because I know so.

Upon further questioning it became clear that the way the low achievers were using the RICEE table to determine equilibrium concentrations was their own “synthetic” construction of the strategy that resulted from instructional misunderstanding:

Researcher: Are confident with your solution?

Morena: No.

Researcher: That means you know that you have a problem?

Morena; Yes.

Researcher: And what did you do about it?

Morena: I tried. I went to find more information about it.

Researcher: Did you check textbooks to see how this type of problem is solved?

Morena: Yes but I did not understand.

6.2.5 Students errors in solving chemical equilibrium problems

1. The errors committed by students while solving the tasks were also noted. Two main types of errors noted were random and systematic errors. Table 6.1 below gives a coding scheme for categorising the type of errors. According to Kousathana and Tsapalis (2002), problem solving errors are random if they are caused, not by lack of relevant knowledge, but by hastiness, or by thoughtlessness, or by an overload of working memory, or by field dependence. They may also be caused by a combination of the above factors. On the other hand, problem solving errors are

systematic if they are caused by learning difficulty or difficulties, that is, by difficulties or failures in understanding of the underlying theory, concepts, or processes.

Table 6.1: Coding scheme for kinds of errors noted in students' think-aloud protocols

Type of error	Description
Random errors	Writing incorrect formula (FR)
	Making wrong substitutions (WS)
	Incorrect use of calculator (CL)
	Graph reading (GR)
Systematic errors	Writing incorrect formula (FS)
	Inappropriate use of mole ratio (MR)
	Misunderstanding of symbols of unit (MU)
	Misunderstanding of mnemonic (MM)
	Random behaviour (RB)
	Getting stuck (ST)

Table 6.2: Analysis of errors committed while solving the chemical equilibrium tasks

	Percy	Carren	Phindile	Angela	Eliot	Morena	Brenda
Random errors							
Task 1				GR	CL,	FR	GR, FR,CL
Task 3					WS,FR		
Task 4					FR, WS		
Systematic errors							
Task 1		MU	MU	MU, MR, ST	MU,MM MR,FS	MU,MM,MR	MU,MM, ST,RB
Task 3				FS			
Task 4				MM,ST	ST,RB	MM,MR	ST, RB, MR

2. The analysis of types of errors committed while solving the chemical equilibrium tasks is given in Table 6.2. The errors were classified into two categories, random and systematic. The random errors

include errors concerning the use of calculator (CL), writing wrong formula (FR), errors on reading mole values from graph (GR) and wrong substitution in Kc expression (WS). As shown in Table 6.2 below, wrong manipulation of calculator was noted for Eliot and Brenda in Task 1. This is illustrated in Eliot's computation of 12×20^2 which was entered as: $12 \times 20 = ^2 =$ which gave a wrong answer of 57600. Brenda also entered $(0,8)(0,11)^2/(1)^2$ in the calculator as $(0,8) + (0,11)^2 \div (1)^2 =$ which gave a wrong answer of 0,0921.

3. Wrong Kc formula involved writing the Kc expression as $\frac{[2AB_2]^2}{[A_2][B_2]^2}$ as noted for Morena's Task 1 protocol. However, the 2 (stoichiometric coefficient of AB₂) in the formula was not substituted and hence this error did not affect the final result of the calculation. Brenda wrote the Kc expression as $\frac{[reactants]}{[product]}$ and went on to substitute into the wrong formula.

She also wrote the concentration formula as $c = v/n$ and went on to substitute into the wrong formula. The post-activity interview suggested these errors came as a result of confusion which could have been corrected by monitoring performance:

Researcher: Are you really sure that this is correct?

Brenda: The formula? I'm not sure.

Researcher: Then why did you write it that way?

Brenda: I wrote it that way but I doubted it.

Researcher: So what do you believe in?

Brenda: That it must be product over reactant.

Researcher: Do you believe that?

Brenda: Yes.

Eliot also committed a random error in Task 3 concerning writing of equilibrium constant expression for the reaction $2SO_2 + O_2 \rightleftharpoons 2SO_3$. The action for the protocol fragment "Kc is equal to the concentration of product over the concentration of reactant... the equation is $Kc = \frac{[2SO_2]}{[2SO]^2[O_2]}$."

The first error in this formula is the inclusion of stoichiometric coefficient in the bracket which is usual for Eliot. The second error is omitting squaring of concentration of the product, and the third error is incorrect chemical formula of Sulphur trioxide and Sulphur dioxide in the formula. These errors indicate lack of self-monitoring.

4. Errors on reading moles from graph involves reading values on the graph that correspond to the location of the labels of curves of reactants and products. This was revealed in the post-activity interview in for Task 1 for Brenda, a low-achieving student:

Researcher: Then what about the initial concentration of B_2 ?

Brenda: Hmmm... 1,8.

Researcher: Where from the 1,8?

Brenda: Here.

Researcher: How did you read the 1,8?

Brenda: The scale.

Researcher: How? Point where the 1,8 is on the scale.

Brenda: Here. [Pointing at where the label B_2 is placed on the reactant B_2 curve]

Researcher: But can you see that this curve extends beyond B_2 and touches the mole axis at 2,0?

Brenda: Hhmmmm!

Researcher: Did you notice that?

Brenda: No I didn't notice that.

Researcher: Then what about the initial concentration of AB_2 ?

Brenda: I also used this one. [pointing at where the label AB_2 is place on the reactant AB_2 curve]

Researcher: Can you see that this graph starts at zero?

Brenda: Yes.

Researcher: Then why did you use this one?

Brenda: It's because of where AB_2 is located that is why I took this one.

5. The systematic error subcategories include misunderstanding of unit of temperature (MU), wrong use of mole ratio (MR), misunderstanding of mnemonic (MM), writing incorrect formula (FS), getting stuck (ST) and random behaviour (RB). Misunderstanding of unit was noted for almost all the students in Task 1. The students read 298K as 298 kilogram, 298 kilopascal, 298 'K' or skipped reading of the unit. It was clear that students were not familiar with the Kelvin as a unit of temperature. Another error noted was misunderstanding of the mnemonic SUPEC used to aid remembering of the order in which the rows on the table follow. SUPEC was supposed to mean Start mol/amount, Used mol/amount, Produced mol/amount, Equilibrium mol/amount and equilibrium Concentration. It appeared that students memorised the mnemonic without knowing that those preambles relate to moles and concentrations of reactants and products at the initial and

equilibrium states of the reactions and how much the amount of reactants and products change when equilibrium has been reached:

Researcher: I see this (SUPEC). What is the meaning of S?

Eliot: Start.

Researcher: Start what?

Eliot: Start the...the...the numbers on the product ratio.

Researcher: And U?

Eliot: Used.

Researcher: Used what?

Eliot: The numbers on the...on the equations.

Researcher: P is what?

Eliot: This one is product.

Researcher: This one is what (E)?

Eliot: Equilibrium.

Researcher: Equilibrium what?

Eliot: Equilibrium.

6. Another error noted was getting stuck (ST). As shown in Table 6.2, this error was noted in the protocols of Angelina, Eliot and Brenda for Task 1 and 4, where these students attempted to use the RICEE table to determine equilibrium concentration. Brenda got stuck when attempting to fill the rows of used and formed moles. In an attempt to get herself off the hook, she resorted to speculation of figures, committing another type of error noted as random behaviours (RB). This is shown in the following episode:

from here that is used and formed, we have...hmmm...eeh... I'm stuck...from here I think we will have zero, here we have 2...and here we have 0,2, that is $200 \text{ cm}^3/1000 = 0,2...$

Similarly, Angela got stuck when filling the used and produced rows. Eliot however got stuck in Task 4 when attempting to substitute the equilibrium concentration of the product, Sulphur trioxide which was not given in the problem statement. In attempting to find his way out, he added the given initial moles of the two reactants to get the moles of the product and then used it to calculate the missing equilibrium concentration of the product. This behaviour was only shown in this task and was formed out of necessity to get out of the predicament; it was considered to be a random behaviour (RB). This is illustrated in the episode below:

equals to the product is...no! I'm sticking...I must add this one [initial concentration of SO₂] and this one [initial concentration of O₂] to get the product... which mean...0.051 + 0.0285 [Punching the calculator] ...It's equal to...the product is... 0, 0795/ (0,051)²(0.0285)... “

7. Another error noted concerned inappropriate use of mole ratio (MR). Mole ratios are shown as the stoichiometric coefficients of reactants and products in balanced chemical equations and they indicate the relative proportions at which reactants disappear and products appear. Therefore, when the amount of a reactant that disappeared or product that formed upon reaching equilibrium is known, the mole ratios can be used to determine the change amounts of other reactants and products in the row on the table. Instead, students determined the used and formed moles by multiplying each initial mole by the corresponding mole ratio in the column:

from there...I find the produced for 2AB₂ ...er... 2,4 is 2....I use the ratio for AB₂, 2,4 is to 1 and... x is to 2...from the... I cross multiply...x = 2.4 × 2...equals to 4,8.

8.The next error noted was on writing K_c expression for the reaction: A_{2(g)} + 2B_{2(g)} ⇌ 2AB_{2(g)} Although the protocol fragment was “K_c is equal to product divided by reactants”, the action noted on the answer sheet was $\frac{[A_2][2B_2]^2}{[2AB_2]}$. There are two types of errors in this formula. The first is the inclusion of stoichiometric coefficient inside the bracket which could also be categorised as random error, because these coefficients were not substituted in the expression. The second error is about changing the positions of reactants and products in the formula. When the researcher first noted this he assumed it to be a random error, but to his surprise, the post-activity interview indicated that this was not the case as the student repeated this error in the equation:

Researcher: I see you write K_c = [product]/[reactant] but when you come here I see something different. Which one is your product?

Eliot: It's this one {Pointing at [A₂][2AB₂]²} the numerator in the K_c expression.

Researcher: Which one is the reactant?

Eliot: It is this one {Pointing to [2AB₂]} the denominator in the K_c expression...

Researcher: Let's go back to the equation A_{2(g)} + 2B_{2(g)} ⇌ 2AB_{2(g)}. Which one is the product?

Eliot: It's this one. [Pointing at A_{2(g)} + 2B_{2(g)}]

Researcher: And which one is the reactant?

Eliot: It's this one [Pointing at 2AB_{2(g)}].

Angela committed a different kind of error when writing the K_c expression for the reaction

$\text{Fe}^{3+}(\text{aq}) + \text{SCN}^{-}(\text{aq}) \rightleftharpoons \text{Fe}(\text{SCN})^{2+}(\text{aq})$ in Task 3. The action corresponding to the protocol fragment:

“I will use my formula for equilibrium constant...which is product... divided by reactant...is”

$$\frac{[\text{Fe}(\text{SCN})^{2+}]}{[\text{Fe}^{3+}][\text{SCN}^{-}]}$$

She went on to substitute into this formula and calculated the value of the equilibrium constant accordingly. It should be noted that Angela got stuck in Task 1 and 4 and could not continue before reaching the step of writing Kc expression. It was not possible to deduce whether this was her usual way of writing equilibrium constant expression. Eliot wrote the equilibrium constant expression for Task 3 exactly like Angela and substituted values accordingly, but when using the calculator, the multiplication button \times was pressed instead of the addition button $+$. In the post-activity interview, it emerged clearly that this error was committed as a result of hastiness:

Researcher: I see you write ‘+’ between the two reactants but when you press the calculator, you did not press +?

Eliot: This plus is not needed in the calculation.

Researcher: Then why did you write it?

Eliot: I forgot. This + must be out.

Researcher: Then why did you write it in the formula and the substitution?

Eliot: I make a mistake, I was rushing.

As seen in Table 6.2 above, Eliot committed the highest number of random errors (5) indicating a highest level of hastiness or lack of self-monitoring in the group. Percy did not commit any error while Carren and Phindile committed one systematic error each. In general, low achieving students committed more errors than high achieving students.

6.3 ANALYSIS OF QUANTITATIVE DATA

Quantitative data was analysed using parametric statistics. The basic assumption underlying the use of parametric statistics is that the scores are normally distributed. With large sample sizes, scores tend to be normally distributed, and this assumption may be taken for granted. However, with small sample sizes normality assumption cannot be taken for granted. Thus with the relatively small sample sizes ($n_{\text{exp}}=35$, $n_{\text{c}}=34$) used in this study, the normality assumption for using ANCOVA may be potentially at risk. Table 6.3 below indicates the variables measured in this study and the instruments used. These include two dependent variables (DV) abbreviated as CEAT and CEMS, and two covariates (CV) abbreviated as PSAT and PSMS. The chemical equilibrium achievement

test and the metacognitive skills questionnaires were developed and validated during the pilot study. The Physical Science achievement test was a district common test set by the Bohlabela district and was administered to the students in March before the study was conducted.

Table 6.3: Variables and instruments

Variable	Type	Measuring instrument	Abbrev.
Chemical equilibrium achievement	DV	Chemical equilibrium achievement test	CEAT
Chemical equilibrium metacognitive skill	DV	Chemical equilibrium metacognitive skills questionnaire	CEMS
Physical Science achievement	CV	Physical Science achievement test	PSAT
Physical Science metacognitive skills	CV	Physical Science metacognitive skills questionnaire	PSMS

6.3.1 Checking for outliers in the dependent variable

As part of the initial screening of data, box plots were used to check for outliers. In the process, one univariate outlier was detected in the post-knowledge test scores (CEAT) of the control group. The case was deleted as the score was far above the mean for the group (Tabachnick & Fidell, 2013).

6.3.2 Tests of Normality

Next, normality assumption of the dependents variable was tested using the Kolmogorov-Smirnov and Shapiro-Wilk tests. As shown in Table 6.4, neither of the two tests was significant (i.e. Sig. was greater than 0.05), indicating that the distributions did not deviate significantly from a normal distribution, and therefore parametric statistics could be used.

Table 6.4: Tests of Normality of group residuals

	Group	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
CEAT	Experimental	.098	35	.200*	.958	35	.204
	Control	.086	34	.200*	.940	34	.060
CEMS	Experimental	.095	35	.200*	.983	35	.841
	Control	.078	34	.200*	.984	34	.889

* *This is a lower bound of the true significance.*

Lilliefors Significance Correction.

The corresponding normal Q-Q plots for Table 6.4 is shown in Figures 6.5, 6.6, 6.7 and 6.8

Figure 6.5: Normal Q-Q Plot of Posttest (CEAT) for Experimental Group

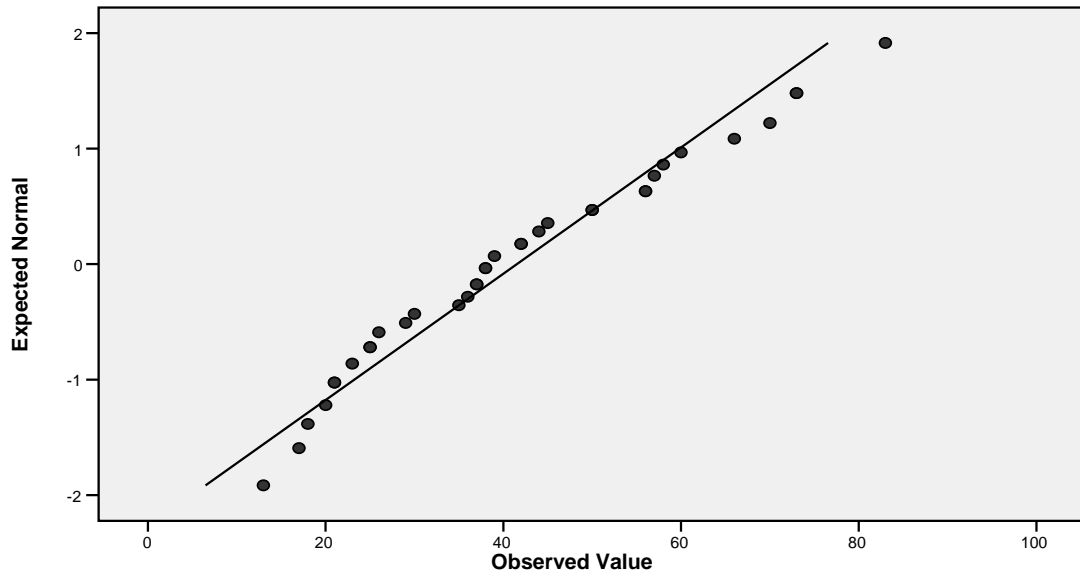


Figure 6.6: Normal Q-Q Plot of Posttest (CEAT) for Control Group

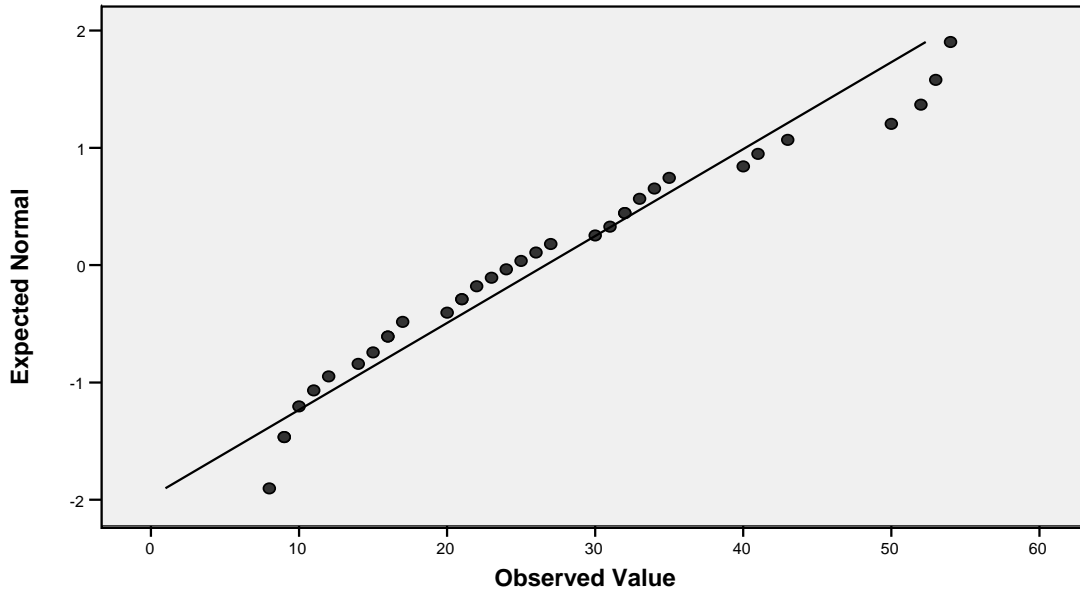


Figure 6.7: Normal Q-Q Plot of CEMS for Experimental Group

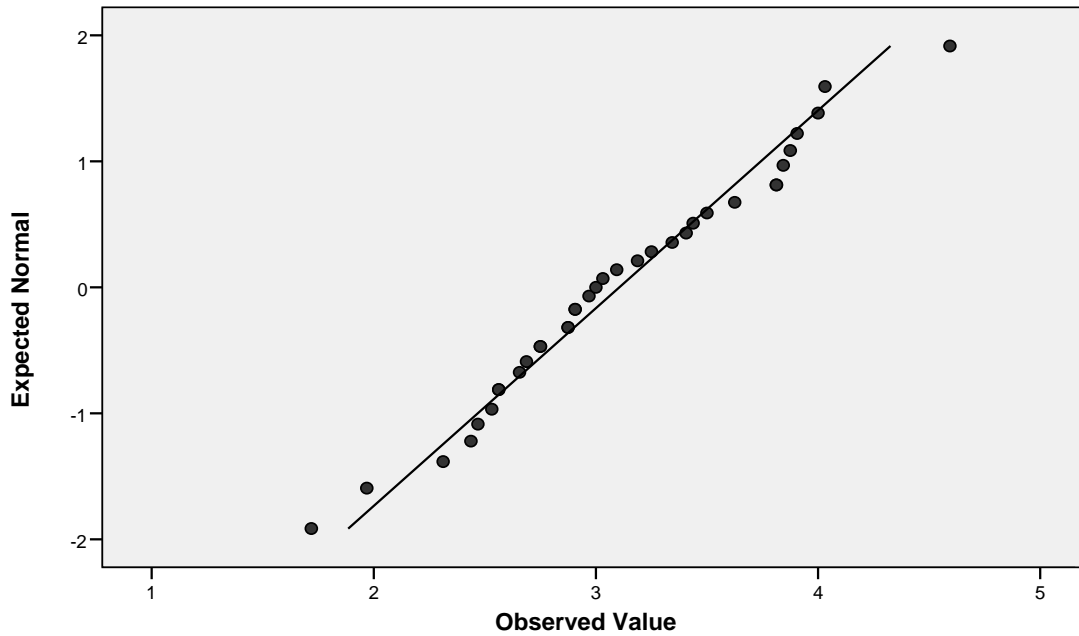
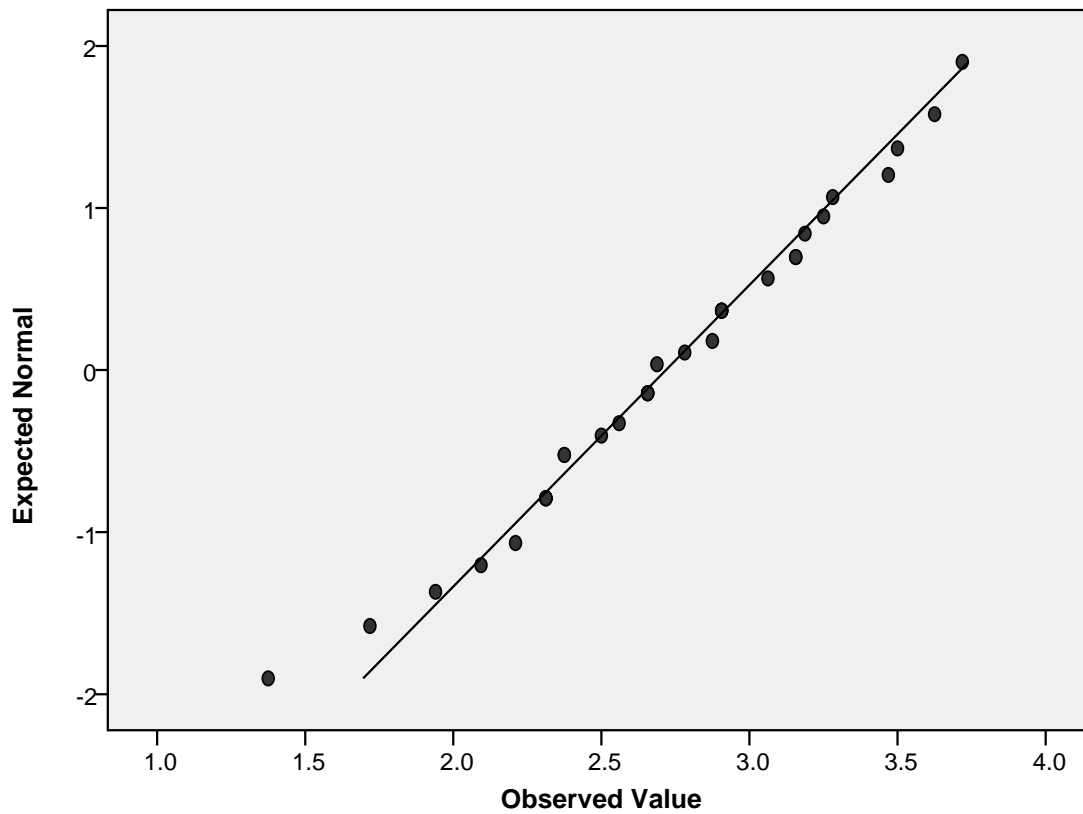


Figure 6.8: Normal Q-Q Plot of CEMS for Control Group



6.3.3 Correlations among covariates and dependent variables

The Pearson correlations between each covariate and dependent variables were computed. As shown in Table 6.5, there is a reasonable correlation between each pair of covariate dependent variable suggesting linear trends between these pairs of variables. There is moderate correlation between the Physical Science metacognitive skill (PSMS) and Physical Science achievement test (PSAT) scores. This correlation is reasonable (less than 0.8), so including both covariates in the analysis will not lead to the problem of overlapping variance (Pallant, 2011).

Table 6.5: Correlations matrix for covariates and dependent variables

		PSMS	PSAT	CEMS
PSMS	(CV)			
PSAT	(CV)	.538**		
CEMS	(DV)	.685**	.479**	
CEAT	(DV)	.498**	.734**	.648**

** Correlation is significant at the 0.01 level (2-tailed).

The scatter plots of each covariate and dependent variable in Figure 6.9, 6.10 and 6.11 confirm this linear trend line.

Figure 6.9: Scatter plot of CEAT versus P SAT

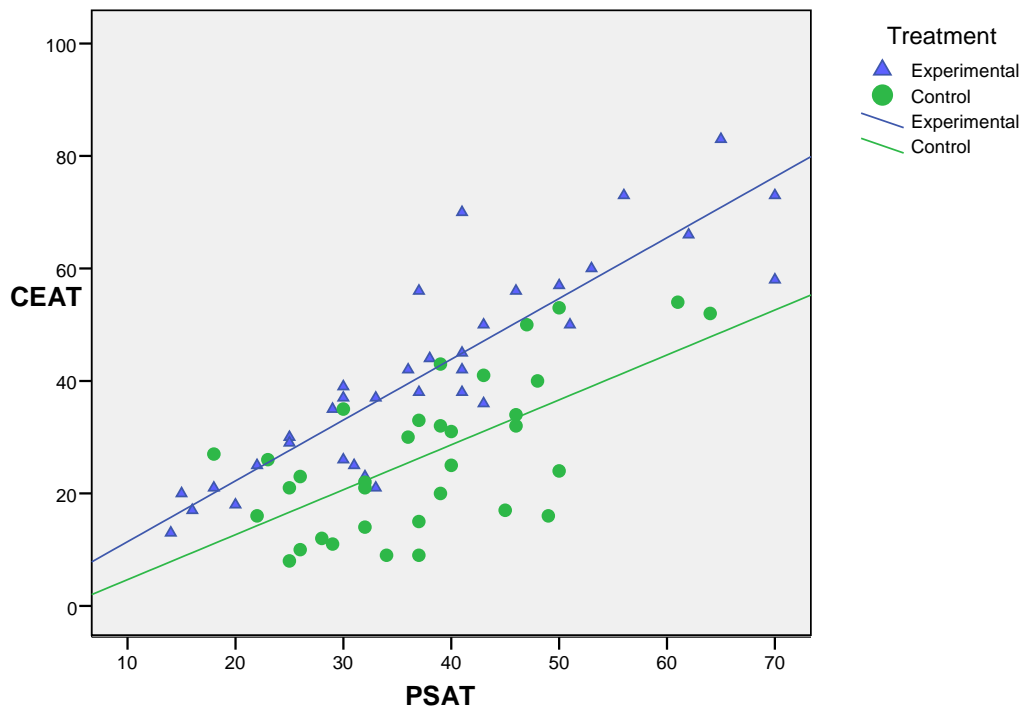


Figure 6.10: Scatter plot of CEAT versus PSMS

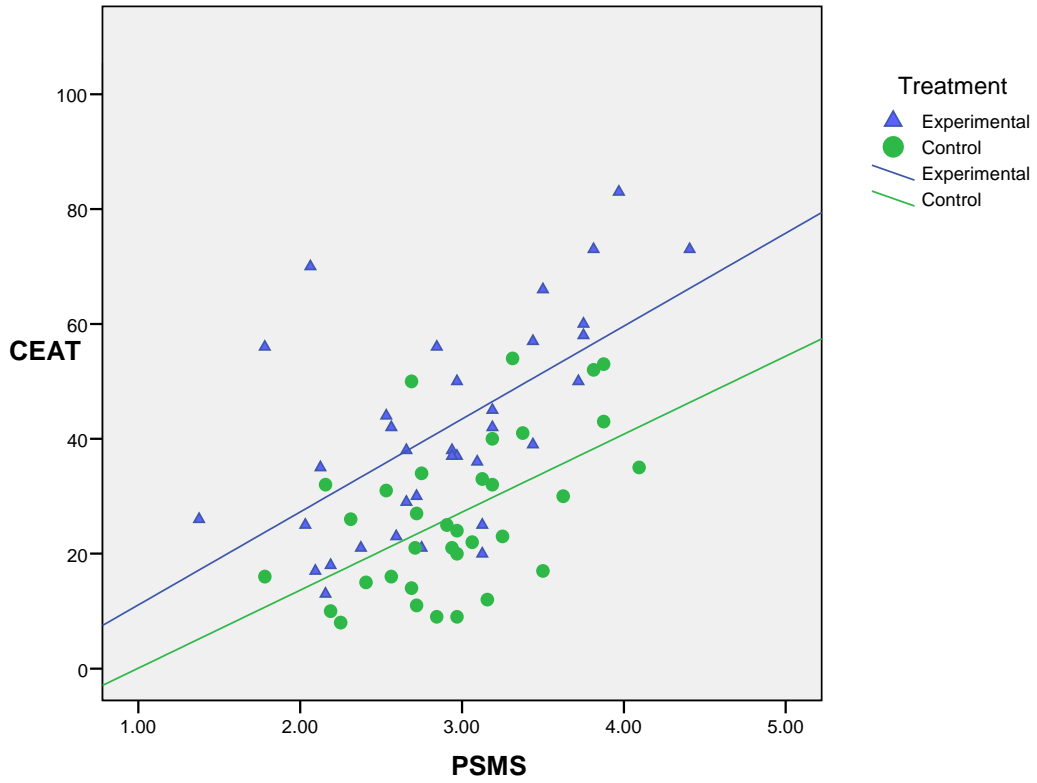
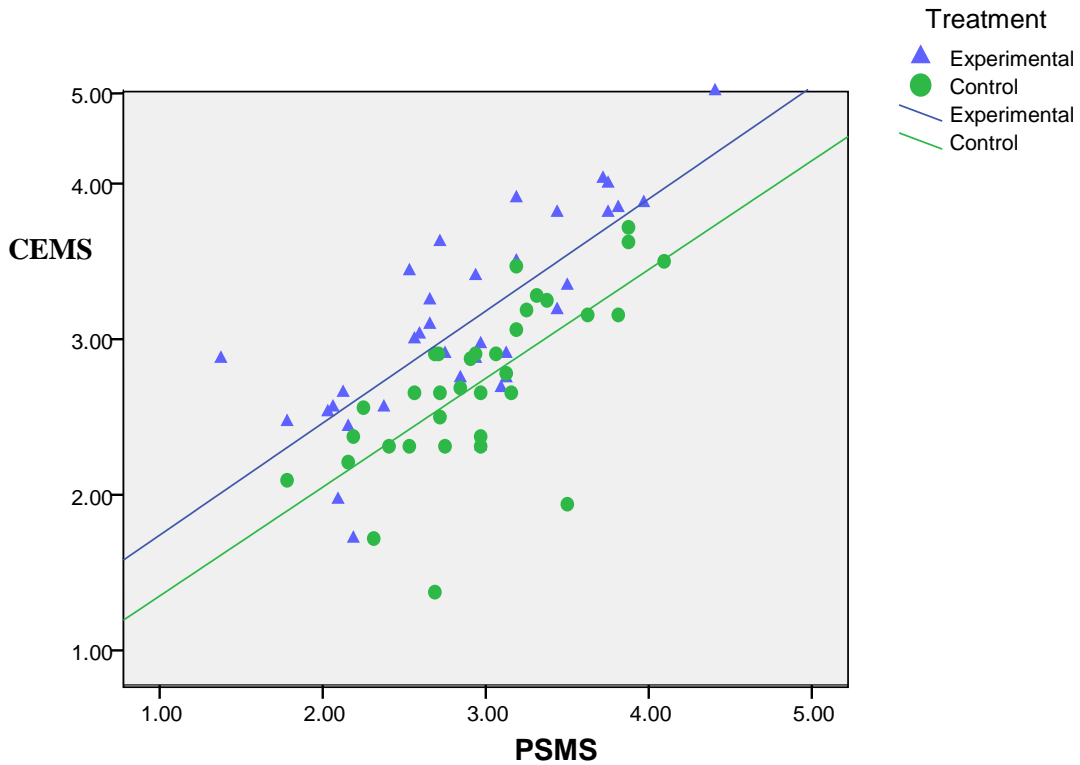


Figure 6.11: Scatter plot of CEMS versus PSMS



6.3.4 Homogeneity of regression slopes

Homogeneity of regression slopes was explored by fitting in regression lines at subgroups in each scatter plot as shown in Figures 6.9, 6.10 and 6.11 above. There was no “crossing over” in each case, suggesting absence of interaction effects, thus this assumption had not been violated. However, further statistical tests were run to confirm the absence of interaction effects. Table 6.6 indicates that the homogeneity of regression slopes had not been violated in each case as the tests did not reach significance. This supports earlier conclusions drawn from an inspection of the scatterplots for each group.

Table 6.6: Test of homogeneity of regression slopes

Test variable pair	DV	df.	F	p (Sig.)
Group*PSAT	CEAT	(1, 65)	2.25	0.139
Group*PSMS	CEAT	(1, 65)	0.23	0.635
Group*PSMS	CEMS	(1, 65)	0.02	0.876

6.3.5 Independence of covariate

Next, the relationship between each covariate and the independent variable (treatment group) was explored using *t*-test. Table 6.6 shows that there was no significant difference between the PSAT mean scores of experimental group ($M = 37.83$; $SD = 15.03$) and control group ($M = 37.50$; $SD = 10.85$), $t(67) = 0.104$, $p = 0.918$. There was also no significant difference between the Physical Science metacognitive skills (PSMS) scores of experimental group ($M = 2.88$; $SD = 0.68$) and control group ($M = 2.95$; $SD = 0.54$) prior to treatment, $t(67) = -0.509$, $p = 0.613$. Therefore these covariates are appropriate as they could reduce the error variance in order to obtain a better estimate of the effect of the experimental treatment.

Table 6.7: Independent t-test for covariates

	Group	N	M	SD	df	t	p
PSAT	Experimental	35	37.83	15.03	67	0.104	0.918
	Control	34	37.50	10.85			
PSMS	Experimental	35	2.88	0.68	67	-0.509	0.613
	Control	34	2.95	0.54			

6.4 PRETEST RESULTS

Based on the data obtained from the pre-administration of CEAT), pretest mean scores for experimental and control groups were compared using *t*-test as there were only two groups. Table 6.8 shows that there was no significant difference between the mean scores of experimental group ($M = 15.97$, $SD = 6.67$) and control group ($M = 14.74$, $SD = 6.12$) prior to the intervention, $t(67) = 1.193$, $p = 0.237$.

Table 6.8: Comparison of pretest scores of experimental and control groups

	Group	N	M	SD	df	<i>t</i>	<i>p</i>
Pre-CEAT	Experimental	35	15.97	6.67	67	1.193	0.237
	Control	34	14.74	6.12			

The Pre-CEAT scores indicate that prior to the implementation of the conceptual change based on metacognition development instruction, both groups performed at the same level with respect to achievement in chemical equilibrium.

6.5 POSTTEST RESULTS

In order to test the research hypothesis, the analysis of covariance, ANCOVA, was run to determine the effects of experimental treatment on students' achievement in chemical equilibrium measured with post-CEAT. The covariates of this analysis were the Physical Science Achievement Test (PSAT) scores and Physical Science Metacognitive Skills (PSMS). The scores of these tests satisfied all the conditions to be used as covariates. Table 6.9 shows the summary of ANCOVA results. The Levene's test of equality of variance did not reach significance, $F(1, 67) = 1.47$, $p = 0.23$, suggesting that the assumption of equal variance was not violated. Table 6.9 indicates three main effects.

Table 6.9: ANCOVA Summary, DV: Post-CEAT

Source	SS	df	MS	<i>F</i>	<i>p</i>	η^2
Covariates						
PSA	5932.399	1	5932.399	68.620	.000	.514
PSMS	518.267	1	518.267	5.995	.017	.084
Group	3849.973	1	3849.973	44.533	.000	.407
Error	5619.427	65	86.453			

As shown in Table 6.9, there was a significant difference in post-intervention chemical equilibrium achievement between students taught with conceptual change instruction based on metacognition development (experimental group) and those taught with traditional lecture approach (control group) $F(1, 65) = 44.53$ $p < 0.0001$. The results show that students in the experimental group ($M = 41.57$, $SE = 1.57$) outperformed the students in the control group ($M = 26.58$) (see Table 6.9). Effect size was 0.407, indicating that treatment accounted for 40.7% of the total variance in achievement. The Cohen's d index was 0.94 standard deviation units which indicate a large effect. Also, students' Physical Science achievement made a statistically significant contribution to the variation in students' chemical equilibrium achievement $F(1, 65) = 68.62$, $p < 0.0001$. Physical Science achievement accounted for 51.7% of variance in chemical equilibrium achievement. Interestingly, Physical Science metacognitive skills also made a significant contribution to the chemical equilibrium achievement $F(1, 65) = 5.99$, $p = 0.017$, accounting for 8.4% of the variance in chemical equilibrium achievement. Table 6.10 below shows the posttest means and standard deviations as well as the adjusted means and standard errors for both experimental and control groups.

Table 6.10: Post-CEAT mean scores for experimental and control groups

	Group	N	<i>M</i>	<i>SD</i>	<i>M</i> [Adjusted]	<i>SE</i>
Post-CEAT	Experimental	35	41.51	18.29	41.57	1.57
	Control	34	26.65	13.49	26.58	1.57

The second research hypothesis was tested using ANCOVA statistics with teaching strategy as the independent variable, chemical equilibrium metacognitive skills as the dependent variable and Physical Science metacognitive skills as the covariate. Levene's test of equality of variance was significant: $F(1, 67) = 0.56$, $p = 0.456$. Table 6.11 shows two main effects. The adjusted mean score of the experimental group ($M = 3.11^a$, $SE = 0.067$) was significantly higher than that of the control group ($M = 2.69^a$, $SE = 0.068$) with regard to chemical equilibrium metacognitive skill $F(1, 66) = 21.25$, $p < 0.0001$ (see Table 6.11). The Cohen's d index was 0.67 standard deviation units, indicating a medium size effect. Physical Science metacognitive skills made a significant contribution to the variance in chemical equilibrium metacognitive skills $F(1, 66) = 82.16$, $p < 0.0001$, accounting for 55.4% of the variance. Also, the experimental treatment accounted for 24.4% of the variation in chemical equilibrium metacognitive skills.

Table 6.11: ANCOVA Summary, DV: CEMS

Source	SS	df	MS	F	<i>p</i>	η^2
Covariate						
PSMS	12.951	1	12.951	82.148	.000	.554
Group	3.351	1	3.351	21.253	.000	.244
Error	10.405	66	.158			

Table 6.12 below shows the posttest means and standard deviations as well as the adjusted means and standard errors for both experimental and control groups

Table 6.12: Post-CEMS scores for experimental and control groups

Group	N	M	SD	Adj. Mean	SE
Experimental	35	3.11	.637	3.13	0.067
Control	34	2.72	.537	2.69	0.068

To test whether students' achievement level moderated the relationship between teaching approach and achievement in chemical equilibrium, a two-way ANCOVA was run with chemical equilibrium achievement as the dependent variable; students' achievement level and teaching approach as the independent variables, while Physical Science metacognitive skills and Physical Science achievement were used as the covariates. Levene's test of equality of variance was not significant $F(3, 65) = 0.50, p = 0.681$, indicating that equal variance assumption was not violated. Table 6.13 indicates that there was no significant interaction between teaching approach (Group) and achievement level (AL). These results show that the effect of the teaching approach is not significantly different for high achievers and low achievers within both experimental and control groups $F(1, 63) = 0.79, p = 0.375$.

Table 6.13: Two-way ANCOVA Summary, DV: CEAT

Source	SS	df	MS	F	<i>p</i>	η^2
Covariate						
PSMS	470.014	1	470.014	5.558	.022	.081
PSA	4441.911	1	4441.911	52.526	.000	.455
Group	2726.497	1	2726.497	32.241	.000	.339
AL	228.129	1	228.129	2.698	.105	.041
Group * AL	67.402	1	67.402	.797	.375	.012
Error	5327.650	63	84.566			

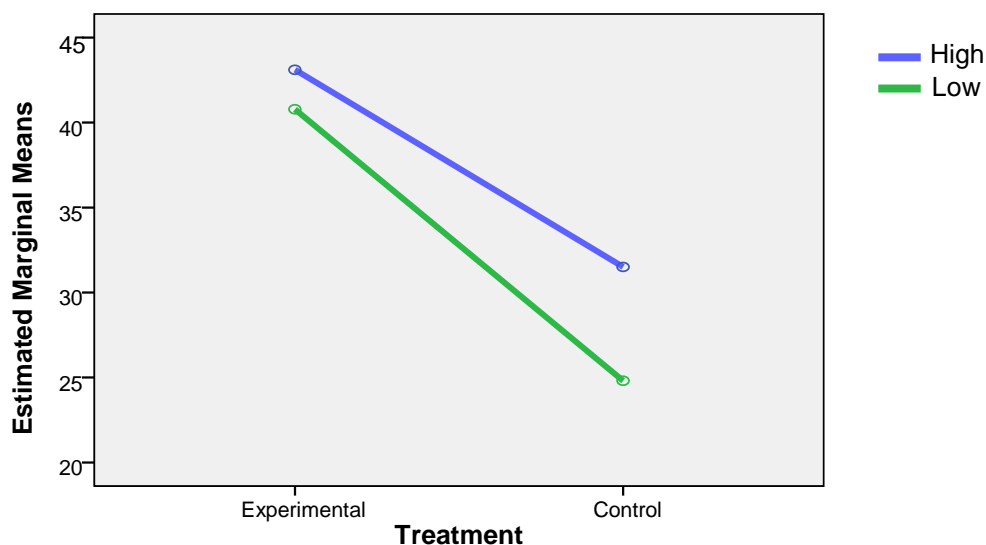
However, after controlling for the effect of the covariates, the gap between the adjusted mean for high achievers in the experimental group was $M = 43.11$, $SE = 2.86$ and that of low achievers in the same group was $M = 40.78$, $SE = 2.00$ narrowed (see Table 6.14). On the other hand, the achievement gap between high and low achievers in the control group did not close that much. The adjusted mean for high achievers in the control group was $M = 31.95$, $SE = 3.15$ and that of low achievers in the same group was $M = 24.81$, $SE = 1.86$.

Table 6.14: Post-CEAT means by achievement level for Control and Experimental groups

Group	AL	N	M	SD	Adjusted	
					Mean	SE
Experimental	High	12	53.25	17.89	43.11(a)	2.86
	Low	23	35.39	15.59	40.78(a)	2.00
Control	High	9	38.44	15.87	31.95(a)	3.15
	Low	26	22.40	9.77	24.81(a)	1.86

This achievement level gap between high achievers and low achievers within the experimental and group is shown in Figure 6.12.

Figure 6.12: Achievement-level gap within group based on post-test



To test whether students' achievement level moderated the relationship between teaching approach and students' chemical equilibrium metacognitive skills, a two-way ANCOVA was run with chemical equilibrium metacognitive skills as the dependent variable and achievement level and

teaching approach as the independent variables, while Physical Science metacognitive skills was used as the covariate. Levene's test of equality of variance did not reach significance $F(3, 65) = 0.91, p = 0.442$, indicating no violation of the equal variances assumption. Table 6.15 shows that there was no significant interaction between teaching approach (Group) and achievement level (AL), indicating that the effect of the teaching approach was not significantly different for high achievers and low achievers within both experimental and control groups $F(1, 64) = 0.813, p = 0.371$.

Table 6.15: Two-way ANCOVA Summary, DV: CEMS

Source	SS	df	MS	F	<i>p</i>	η^2
Covariate						
PSA	9.600	1	9.600	62.830	.000	.495
Group	3.026	1	3.026	19.808	.000	.236
AL	.481	1	.481	3.145	.081	.047
Group * AL	.124	1	.124	.813	.371	.013
Error	9.778	64	.153			

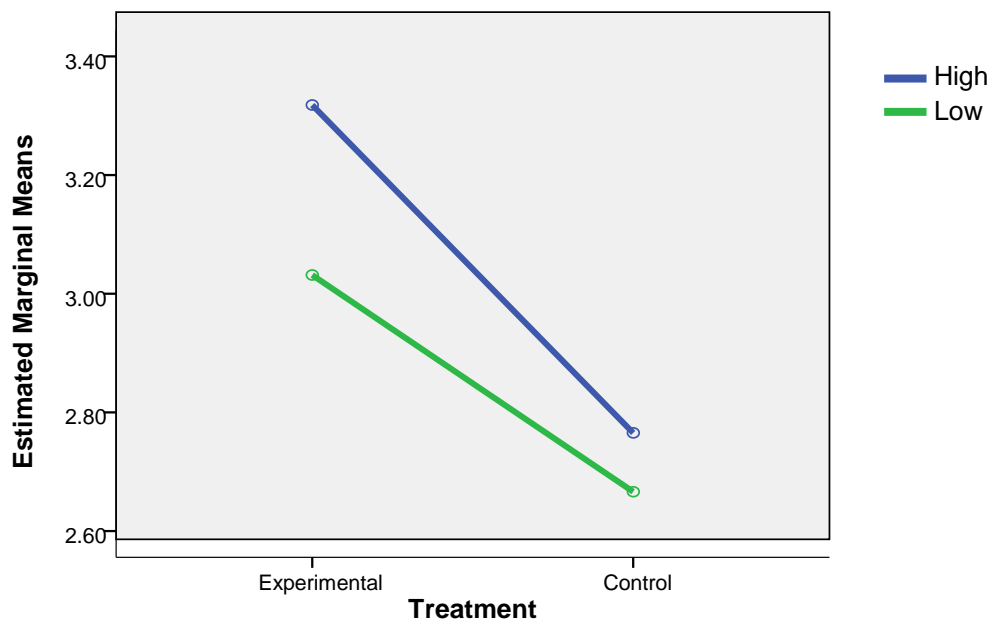
However, after controlling for the effect of the covariate, the adjusted mean for high achievers in the experimental group was ($M = 3.32, SE = 0.12$) and that of low achievers in the same group was ($M = 3.03, SE = 0.08$) (see Table 6.16). This suggests a narrowing of metacognitive skills gap between high and low achievers in the experimental group but the graph in Figure 6.13 shows the metacognitive skills gap between high and low achievers in the experimental group is not as close as the achievement gap (refer to Figure 6.12). On the other hand the metacognitive skills gap between high and low achievers in the control group is narrow (Figure 6.13). The adjusted mean for high achievers in the control group was ($M = 2.76, SE = 0.13$) while that of low achievers in the same group was ($M = 2.67, SE = 0.08$) (see Table 6.15).

Table 6.16: Post-CEMS means by achievement level for Control and Experimental groups

Group	AL	N	M	SD	Adj. Mean	SE
Experimental	High	12	3.54	0.56	3.32(a)	.12
	Low	23	2.88	0.55	3.03(a)	.08
Control	High	9	2.92	0.63	2.76(a)	.13
	Low	26	2.64	0.49	2.67(a)	.08

Figure 6.13 below shows the achievement gap between high achievers and low achieve within the each group.

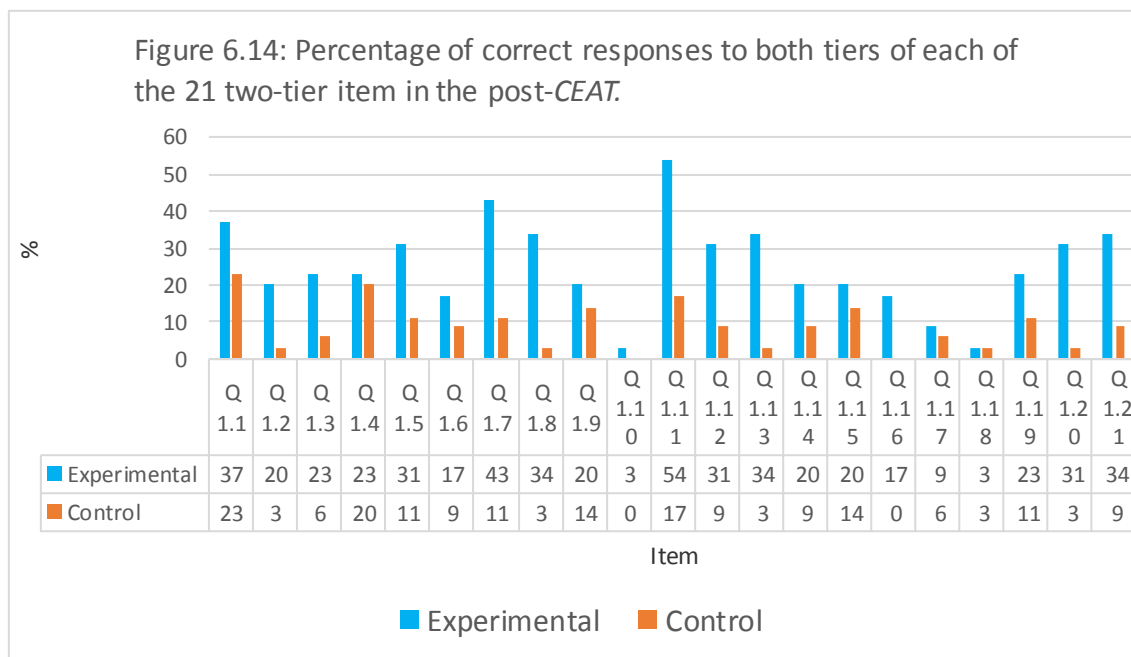
Figure 6.13: Achievement-level gap within group based on post-metacognitive skills



6.6 ITEM ANALYSIS

Item analysis enables teachers and researchers to see which items were difficult to students or which aspects of the problem the teaching intervention need to be improved. In this session the researcher presents the item analysis of students' performance on the post-CEAT. Figure 6.14 shows the percentage of students in each group who answered both tiers of each of the 21 two-tier items correctly. The second tier of each item was open ended and required students to explain their choices in the first tier. This gives knowledge of the reasoning used in selecting the response in the first tier so that we could determine whether the students understood the content knowledge being examined or not. Figure 6.14 shows that, except in item number 1.18 where the proportion of students who responded correctly to the two tiers is equal, more students in the experimental group obtained full marks in the items than the control group. This suggests that the conceptual change instruction based on metacognition development was generally effective in promoting understanding of all aspects of chemical equilibrium. However, a variation in performance of both experimental and control groups on similar items was observed across contexts. Item 1.1 and 1.9

examined students' understanding of the effect of concentrations on the value of the equilibrium constant, but the performance in item 1.1 was better than 1.9. In item 1.1 the cue was “constant temperature” while in item 1.9 it was “same temperature”.



This suggests the words constant and same had different meanings for these students, or there were some contextual elements in item 1.9 that distracted the students. This needs to be investigated further.

Another variation imposed by context of item was observed in item 1.2 and 1.7 which examined students' understanding of the effect of changing the concentration of solid CaCO_3 in equilibrium with its decomposition products CaO and CO_2 represented as $\text{CaCO}_3(s) \rightleftharpoons \text{CaO}(s) + \text{CO}_2(g)$. In 1.2, solid calcium carbonate was removed from the system while in 1.7 solid calcium carbonate was added to the system. As shown in Figure 8.12, removal and addition of solid calcium carbonate had different effects on equilibrium, at least for some of the students. Thirty-four per cent (34%) of the experimental group and 23% of the control group thought that removal of some solid calcium carbonate would favour the reverse reaction. Using this same item, Karpudewan et al. (2015) also found that 46.4% students incorrectly applied Le Chatelier's to suggest that more calcium carbonate was produced because $\text{CaO}(s)$ and $\text{CO}_2(g)$ had reacted to replace the calcium carbonate that was removed. Furthermore, 11% of the control group who also thought the reverse reaction would be favoured explained that the reactant would be absent and only the reverse reaction could take place.

Nine per cent (9%) each of experimental group and control group got the first tier correct, i.e. “none of the reactions will be favoured”, but their explanation was that removing the solid calcium carbonate from the system would leave products only in the system and no reaction could occur. The students’ difficulties may be explained as follows: the students did not pay attention to the cues from the context of the item which was “some of the solid”, or they did not understand the idea that concentration of pure solids is constant. By saying the concentration of pure substance is constant it means when you increase or decrease the amount of the pure substance in a system, its amount changes but its amount per unit volume does not change. Students often confuse amount of substance with concentration (Bergquist & Heikkinen, 1990) and use the two interchangeably. In either case, this result suggests the influence of context on conceptual change learning (Georghades, 2000). Items 1.11, 1.12 and 1.13 tested students’ understanding of the effect of changing temperature on equilibrium positions. Figure 6.14 indicates that at least 30% of the experimental group and less than 20% of the control group responded correctly to both tiers of each of the items. This indicates that using argument writing templates with adult and peer review can encourage students to construct scientific explanations of phenomena better. However, as shown in Figure 6.14, students could not explain the effect of concentration on the equilibrium (items 1.10, 1.17 and 1.18). The item in which the students performed worst was 1.10. This item involved an orange solution of 0.5mol/dm^3 $\text{Na}_2\text{Cr}_2\text{O}_7$ in which the following equilibrium system was established: $2\text{CrO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) \rightleftharpoons \text{Cr}_2\text{O}_7^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l})$.

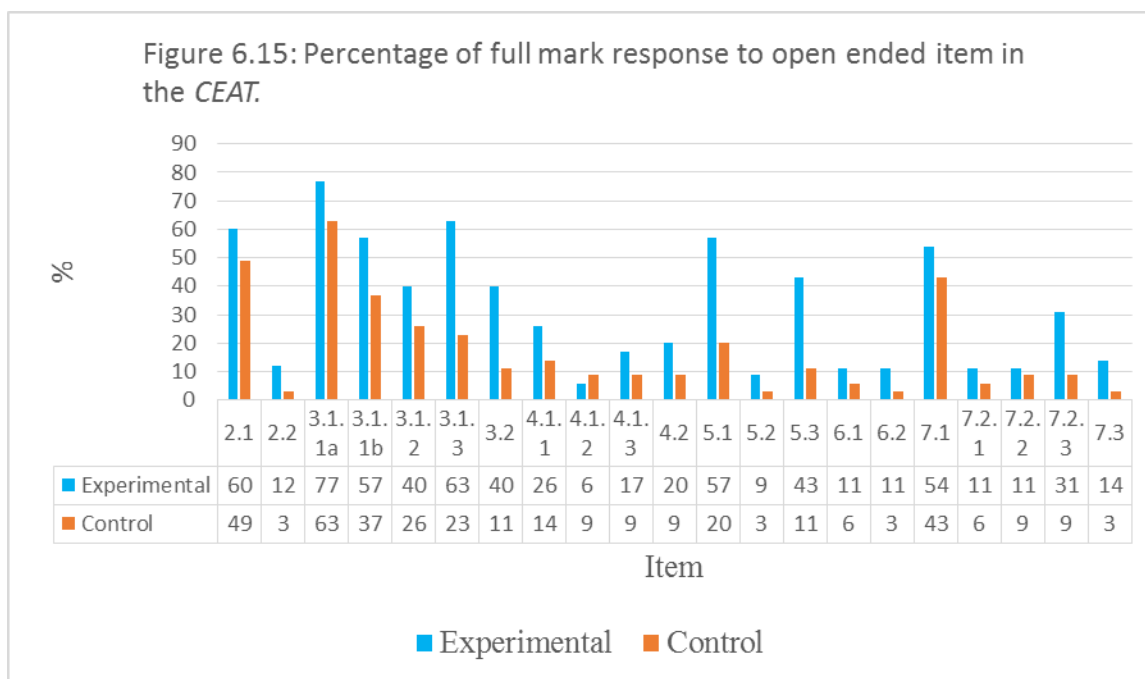
Yellow

Orange

Students had to predict the change in colour when 10cm^3 of orange 0.5mol/dm^3 $\text{Na}_2\text{Cr}_2\text{O}_7$ solution was added. Only one student (3%) from the experimental group realised that the $\text{Na}_2\text{Cr}_2\text{O}_7$ that was added had the same concentration as the equilibrium mixture and therefore the colour would not change. Twenty-six percent of the experimental group (26%) and eight percent (8%) of the control group thought that the colour would turn yellow because the reverse reaction would be favoured. Karpudewan et al. (2015) also noted that 32.1% of their sample used this type of reasoning and predicted incorrectly. Other students who also predicted a change in colour used different types of reasoning. Fourteen percent (14%) of the experimental group and 14% of the control group thought the colour would change because more concentration had been added. They did not realise that the concentration of the incoming solution was the same as the concentration of the test solution. Eleven percent (11%) of the experimental group and three percent (3%) of the control group were influenced by the acid (H^+) in the equation and thought colour change was due to the acid. Another

11% of control the group thought the dichromate would dilute the orange solution and turn it yellow. The students' reasoning on this this item provides further evidence of context dependent reasoning among students. It appears students' reasoning is cued by features of the representation of the problem (diagrams, symbols or text) and that differs from one student to another. The behaviours of the students support the notion that students' cognitive structures consist of independent mental entities called p-prims (diSessa, 2002, p. 38). According to diSessa, p-prims constitute the bulk of intuitive science, the precursor knowledge that gets reconstructed into schooled competence. They have such characteristics as being fluid, data driven, obvious, lack of conflict resolution, and fairly simple abstractions of familiar events.

Figure 6.15 shows the proportion of students in each group who scored full marks on each of the open ended items. Generally, more students in the experimental group scored full marks on each of the items than the control group. The main reason for the difference is that the control group did not engage in metacognitive activities as already shown in the quantitative analysis of metacognitive skills. Consequently the control group committed more errors than the experimental group. Items 2.1, 2.2, 3.1.1a, 3.1.1b, 4.1.1, 4.1.2, 4.1.3, 4.2, 7.2.1, 7.2.2 tested interpretation of equilibrium graphs. The researcher will attempt to explain the difference in performance on these items. The performance on items 2.1, 3.1.1a and 3.1.1b was high. The reason may be that these were relatively easy as they required recall of information. For instance, in 2.1 students were required to indicate which of the two curves indicated the reverse reaction of a rate versus time graph. In 3.1.1a and 3.1.1b, students were required to indicate on the mole versus time graph when the reaction reached equilibrium for the first time (3.1.1a) and for the second time (3.1.1b) after temperature had been increased. As shown in Figure 6.15, students were able to show the time when equilibrium was reached for the first time better than for the second time. The most common problem observed on their scripts was that students focused attention on when the disturbance occurred (i.e. the time when the graph started to curl) rather than when the graph started to be horizontal again. The same information that they could read in one context, they could not read in another context. In item 2.2, students were asked to indicate and explain the change that caused both the forward and reverse rates of a rate versus time graph to instantaneously increase and then level off again. Although students, particularly those in the experimental group, answered similar questions fairly well in both tiers (see item 1.5 and 1.8), they could not answer 2.2. This also illustrates the effect of context on students' thinking. Items 4.1.1, 4.1.2, 4.1.3 and 4.2 were based on one graph involving three different changes to concentration, temperature and pressure at different times; t_1 , t_2 and t_3 .



Students were required to indicate which change was made at each time. As seen from Figure 6.15, most students did not score full marks on this question. One problem with students' responses was that the students appeared to be confused by the combination of the graphs as they could not distinguish which change was which. Another problem was that students' responses were not complete. For instance, instead of saying concentration was increased or pressure was decreased, they would simply say concentration or pressure. Another problem was that the students focused on where the change was taking place (i.e. the curls) rather than where the change started. In items 7.2.1 and 7.2.2 students were asked to indicate on the mole versus time graph where only the forward reaction was shown, how the rate of the forward and reverse reaction compared at some time t_1 (before equilibrium was reached) and another time t_2 (after equilibrium was reached). Most of the students responded correctly that the rate of the forward reaction was greater at t_1 but could not explain that the slope of the graph was higher at t_1 . In item 7.2.2, the students responded correctly that the rates of the forward and reverse reaction were equal, but simply said equilibrium had been reached instead of saying the concentrations remained constant at t_2 . Items 3.1.3 and 5.2 tested the significance of the equilibrium constant value. The experimental group performed fairly well on these items. Item 6.2 tested the effect of temperature on the equilibrium constant value; however, the question was indirect. Students were required to indicate whether the forward reaction of an equilibrium was endothermic or exothermic, given that an increase in temperature caused the value of the equilibrium constant to decrease. Many students who predicted correctly did not get full

marks because their explanation did not include how a decrease in equilibrium constant value affected the amount of reactants and products.

Items 3.1.2, 5.2 and 7.2.3 were word problems involving equilibrium constant calculations. In item 3.1.3, students were required to calculate the equilibrium constant, having been given the initial and equilibrium moles on the graph. The performance on this item was fairly good in the experimental group. In item 5.2, the item involved a change from an initial equilibrium state to a final equilibrium state following a change in temperature. Most students failed to determine the equilibrium concentration using the RICEE table. The major problem was that, following an increase in temperature, the reverse reaction was favoured because it was the endothermic reaction. As a result, in the final equilibrium, the moles of products decreased. Most students did not take this into account and went on to fill the table as if reactants decreased and products increased. In items 6.1 and 7.2.3, most students committed errors in filling the table and manipulating the figures in the equations.

6.7 SUMMARY

The chapter presented the analysis and the results of the field work for this study. The results of the study will have implications for the teaching and learning of chemical equilibrium in the Bohlabela district, but as they stand now, it is difficult to suggest any useful line of action. In the next chapter, the researcher will discuss and interpret these results of the study.

CHAPTER SEVEN: DISCUSSIONS AND INTERPRETATIONS

7.1 INTRODUCTION

This chapter discusses the interpretations of the results. In the discussions the researcher makes connections between the results of this study and those of previous studies. The discussion is presented according to the layout of the design of the study. The first section of the chapter addresses the first research question which sought to explore the students' level of metacognitive skillfulness and the factors influencing students' use of metacognitive strategy in solving chemical equilibrium problems. The last two sections are based on the quantitative phase of the study and they address the research hypotheses. The research questions and hypotheses are reformulated as section headings. Finally the chapter concludes with a chapter summary. Before proceeding further with the discussions and interpretations of findings the research questions and hypotheses restated:

1. What is the level of metacognitive skillfulness of grade 12 Physical Science students in solving chemical equilibrium problems?
2. What factors influence students' use of cognitive strategies in solving chemical equilibrium problems?
3. How well do the two measures of learning strategy (learning approach and metacognitive skills) predict achievement in chemical equilibrium based on CEAT scores? How much variance in chemical equilibrium achievement can be explained by scores on these two scales?"
4. How can conceptual change instruction be effectively implemented in Physical Science to foster deep learning and the development of metacognitive skills.
5. Students taught chemical equilibrium through the conceptual change instruction based on metacognition development will:
 - c) achieve significantly better in chemical equilibrium than students taught through the traditional lecture approach, and;
 - d) develop significantly better metacognitive skills in chemical equilibrium than students taught through the traditional lecture approach.
6. Conceptual change instruction based on metacognition development will narrow the achievement gap between high and low achievers in chemical equilibrium.
7. Conceptual change instruction based on metacognition development strategy will not narrow the metacognitive skills gap between high and low achievers in chemical equilibrium.

7.2 METACOGNITIVE SKILLFULNESS IN SOLVING CHEMICAL EQUILIBRIUM PROBLEMS

From Task 1 through Task 4 of the chemical equilibrium problems solved during the think-aloud sessions, low achieving students consistently demonstrated low or unacceptable level of metacognitive awareness, while high achieving students demonstrated relatively high levels of metacognitive skillfulness when solving the problems. Also, evidence such as: *“not attending to all aspects of the chemical equilibrium graph and unawareness of the equilibrium state, and not being able to explain the meaning of the mnemonic SUPEC”* indicates that low achievers were using the RICEE table cognitive strategy at a surface level while solving the chemical equilibrium. In other words low achievers have tacitly accepted the RICEE table strategy as presented to them and memorised it without making meaningful links between the pieces of information on the RICEE table (Warren, 2004). This implies that the low achievers adopted a surface learning approach devoid of metacognitive skills while using the RICEE table strategy (Chin & Brown, 2000; García, Cueli, Rodríguez, Krawec & González-Castro, 2015). In terms of knowledge structure and coherence, the declarative knowledge of low achievers can be regarded as knowledge in pieces (diSessa, 2002). This shows that the achievement difference between high and low achievers may be due to differences in the use of metacognitive skills when solving problems. This finding supports previous studies (Doğanay & Demir, 2011; Zhang & Wu, 2009) which indicate that high achievers tend to use metacognitive strategies during performance of tasks more often than low achievers.

7.3 FACTORS THAT INFLUENCED THE USE OF COGNITIVE AND METACOGNITIVE SKILLS IN SOLVING CHEMICAL EQUILLIBRIUM PROBLEMS BY LOW AND HIGH ACHIEVERS.

7.3.1. Declarative knowledge of chemical equilibrium

Inattention by low achievers to the equilibrium moles portions of the chemical equilibrium graph, and treating initial moles as equilibrium moles during performance, indicate that the mental model of chemical equilibrium state is lacking in students' long term memory and therefore not part of their declarative knowledge. Furthermore, the inability of low achievers to relate information on the graph to the appropriate cell on the table indicates that declarative knowledge of low achievers about chemical equilibrium has not achieved the status of structural or conceptual knowledge. Declarative knowledge is presumably the precursor for development of the entire metacognitive system since it forms the basis of thinking (Jonassen et al., 1993). Thus, failure by low achievers to

use the table procedure in achieving the goals of Task 1 to Task 4 is partly attributed to lack of some of the elements of students' declarative knowledge of chemical equilibrium, preventing the development of appropriate conceptual knowledge, resulting in inappropriate execution of the procedure.

7.3.2 Scientific reasoning

Task 2 was conceptual in nature requiring the student to use evidence from change in moles with time represented on the graph following an increase in temperature to predict whether the forward reaction of the reversible reactions was exothermic or endothermic. This question was about predicting the effect of an increase in temperature on equilibrium position. This question was answered very well by the high-achieving students. Analysis of their responses indicates that they followed the argument model of explanation involving claim, evidence and reasoning (Rex, Thomas & Engel, 2010). Moreover, their explanations showed a pattern of reasoning in which examining evidence and reasoning preceded making a claim. The claim was stated as a conclusion drawn after examining the evidence and reasoning deductively or making inferences. The ability to activate relevant previous knowledge, examine available evidence and make logical connections between previous knowledge and current evidence to achieve the goal of the task shows that the declarative knowledge of this kind of problem has reached a conceptual knowledge status. Specifically high achieving students' level of reasoning may be described as scientific reasoning. Low-achieving students, however, could not activate the relevant previous knowledge, but focused on the "surface" feature of the graphical evidence. This indicates that the relevant previous knowledge is not available in long-term memory, or available but not integrated with the other memory elements in the long term memory, and therefore not useful (Jonassen et al., 1993). Instead, low achieving students started explaining by making a claim (unwarranted claim) and then trying to support it with evidence on the surface.

Although low achieving students generally supported their claims with surface features of the graph, their claims were not the same. In some instances, when asked to explain their claims, low achievers made comments like "it is obvious" suggesting that the claim was self-explanatory; behaviour which may be described as p-prims in action (diSessa, 2002). As the low achievers seemed not to have the requisite previous knowledge in solving the task, they relied upon intuition in which p-prims form the bases of their explanatory framework.

7.3.3. Conditional knowledge

Both high-achieving and low-achieving students solved Task 3 by attending to only the recognisable data in the problems statement (i.e. concentrations of solutions of substances), and ignored other information (i.e. volumes of solutions) which did not fit in their usual way of using the table to solve chemical equilibrium problems of that kind. The students “reduced” the new problem to fit their procedural model for solving that kind of chemical equilibrium problem, and then applied the familiar procedure to solve the problem instead of adapting their procedural model to fit new demands in the task. Their failure to adapt the cognitive strategy to suit the new environment is attributed to lack of conditional or contextual knowledge. According to Zimmerman (2000), conditional knowledge forms an integral part of self-regulation. In self-regulated learning the student is able to make adaptations to problem-solving strategies to changing personal and contextual conditions. Since conditional knowledge is believed to exist in long term memory as propositions in networks, and linked with the declarative and procedural knowledge to which it applies (Schunk, 2012), it can be inferred that the link between the condition of Task 3 and the associated procedural and declarative knowledge of the table strategy has not been established in the students’ cognitive structure.

7.3.4. Confidence judgement

There were differences in the ways high achievers and low achievers responded to the unfamiliar condition in Task 3. Firstly, high achieving students used the RICEE table procedure, recognizing that the initial concentrations of reactants and equilibrium concentration of products were given, and therefore went on to find equilibrium concentration of reactants. Low achieving students on the other hand did not distinguish between initial and equilibrium concentrations, but assumed all given concentrations to be concentrations at equilibrium and therefore thought it was not necessary to use the table. As in Task 1, the low achieving students demonstrated lack of mental model (declarative knowledge) of the chemical equilibrium state. Secondly, the feelings about solution correctness were different among the two groups of students. While high achieving students were generally uncertain about the correctness of their solution to the task, low achieving students were generally confident about the correctness of their solution and ignored inconsistencies in their thinking even when their attention was drawn to it. This study suggests that students with poor declarative knowledge have the tendency to be overconfident. Mathabathe and Potgieter (2014) explain overconfidence of low achievers as due to an illusion of knowing where knowing is compromised

by the presence of misconceptions, or where mathematical skills are inadequate and mistakes go unnoticed. According to Mathabathe and Potgieter (2014), this places low achievers at risk by negatively affecting decisions regarding self-correction. The analysis of errors in this study shows that both systematic and random errors were committed while solving chemical equilibrium problems. These errors were mostly committed by the low achieving students, confirming the negative consequences of overconfidence on low achievers regarding self-correction.

7.3.5. Metacognitive knowledge of the RICEE table

The design and the sequencing of steps in completing the RICEE table for the low achieving students was different from those of the high achieving students. While the RICEE table for the high achieving students consisted of five rows representing Start moles, Used moles, Produced moles, Equilibrium moles and equilibrium Concentration (SUPEC), the RICEE table used by the high achieving students consisted of four rows representing Start moles, Change moles, Equilibrium moles and Equilibrium concentration (SCEE). The difference between these two designs is the separation of Change moles into two rows of Used moles and Produced moles which appeared to constrain low achieving students' ability to determine change moles and use mole ratio to deduce the unknown change moles of other substances present in the reaction when equilibrium is established. Also in filling the table, low achieving students started from the top row by entering initial moles in the appropriate cells and then worked downward through the Used moles row and the Produced moles row and then to the Equilibrium moles row. Finally they calculated equilibrium concentration in the last row. As indicated by one of the low achieving students in the interview, they did not understand how to use the RICEE table when they were taught, which suggests that low achieving students had poor metacognitive knowledge of the RICEE table. The design of the table used by low achievers appears to constitute an extraneous cognitive load that hampered the use of the RICEE table (De Jong, 2010). Consequently the means-ends-analysis strategy used by low achievers imposed a germane cognitive load that consumed a substantial chunk of working memory, leaving students with limited capacity for monitoring and control of strategy use, hence the high rate of random errors (Sweller, 1988). High achieving students were able to use the RICEE table more easily and accurately as fewer errors were observed compared to low achieving students, indicating that the strategy instruction was effective. They demonstrated good metacognitive knowledge of the RICEE table. The difference in the way high and low achieving students used the RICEE table suggests the need for teachers to teach strategies and not to assume that students can learn them

through textbooks, which many scholars in metacognition have advocated (for example, Pintrich, 2002; Schraw, 1998; Schraw, Crippen & Hrtley, 2006)

7.4 THE EFFECT OF CONCEPTUAL CHANGE INSTRUCTION BASED ON METACOGNITION DEVELOPMENT ON STUDENTS' ACHIEVEMENT

The findings of this study indicate that a conceptual change instruction based on development of metacognition was more effective than a traditional lecture approach in enhancing students' understanding of concepts and problem solving in chemical equilibrium. The students in the experimental group achieved significantly better in chemical equilibrium than students in the control group after the intervention. The results of the study support the findings of previous studies (Yuruk, Beeth & Andersen, 2009). Also, the use of metacognitive skills by students in the experimental group when solving chemical equilibrium problems was significantly better than students in the control group. This is revealed in the significantly higher reported use of metacognitive skills among students in the experimental group than students in the control group. The metacognitive activities in the instructional programme for the experimental group supported the development of students' improved overall metacognitive awareness. Certain features of the intervention contributed to this improved performance. In the first place, the use of the disc analogy to simulate how a reversible reaction proceeds from the initial state to equilibrium state promoted spontaneous conceptual change through enriched observation of the concept provided by the simulation (Vosniadou, 1994). The representation of chemical equilibrium using the analogy, the corresponding tabulated information and the resulting graph constituted multiple representation which assisted in developing a better mental model or declarative knowledge about chemical equilibrium (Edwards-Leis, 2012). The use of multiple representation in improving mental model of students has been reported in the literature (Kurnaz & Arslan, 2014; Sunyono, Yuanita, & Ibrahim, 2015a; Sunyono, Yuanita & Ibrahim, 2015b). Secondly, discs in the analogy highlighted the microscopic features of a chemical equilibrium system, making students aware of the composition of the initial and equilibrium states and the sequence of events leading from initial to equilibrium state. The explicit mapping of information on the microscopic representations onto the cells on the RICEE table improved conceptual knowledge about the table (Jonassen et al., 1993). Thirdly, knowledge of the correct answer ahead of the solution of a complex problem encouraged and motivated students to monitor and regulate the way they used cognitive strategies leading to improved strategy knowledge. Finally, graphical modelling of changes in the chemical equilibrium system following a disturbance, and argumentation writing activities using the "our argument

template”, supported critical thinking and construction of explanation, as students had to reflect on the context of the problem, and think about appropriate evidence and warrants before writing down their explanations (Chin & Osborne, 2010).

Another interesting finding in this study is the narrowing of the achievement gap between high achievers and low achievers within the experimental group. This finding suggests that conceptual change instruction based on metacognitive activities can offer ‘level playing field’ to both high and low achievers. This finding is consistent with previous studies (Akkus, Gunel Hand, 2007) Kingir, Geban & Gunel , 2012; Nam, Choi & Hand, 2011) who found that high quality implementation of science writing heuristics, a conceptual change teaching approach involving group discussions, argumentation and writing activities, decreased the achievement gap between high and low achievers.

7.5 THE EFFECT OF CONCEPTUAL CHANGE ISTRUCTION BASED ON METACOGNITION DEVELOPMENT ON STUDENTS’ METACOGNITIVE SKILLS

The findings of this study also indicated that conceptual change instruction based on metacognition development not only influenced students’ achievement in chemical equilibrium, but students’ metacognitive skills as well. Students in the experimental group reported using metacognitive skills significantly more than students in the control group. Change in metacognitive skills usage is another level of change that should be demonstrated in conceptual change learning to be considered transferable and durable (Georghiades, 2000).

Phan (2009) found that sophisticated epistemological beliefs positively affected deep processing strategies via effort expenditure among a sample of university students. Cano (2005) found that students’ epistemological beliefs affected achievement directly and indirectly via the students’ learning strategies. In this study there was wide gap between high achievers and low achievers regarding the use of metacognitive skills in the experimental group, unlike the control group. With reference to the studies mentioned above, it implies that students’ epistemological beliefs negatively influenced the adoption and use of deep learning strategies among low achievers as seen in the widening of metacognitive skill gaps between high and low achievers within the experimental group. The influence of immature epistemological beliefs in adopting learning strategies may also explain the findings of Park and Chung (2012) where the development of science process skills and

metacognition was limited to high achievers only, although both high and low achievers improved in scientific reasoning after a conceptual change intervention.

On the other hand, the significant difference in reported use of metacognitive strategies between the experimental and control groups supports the claim that metacognitive skills or learning strategies are teachable (Pintrich, 2002; Schraw, Crippen & Hartley, 2006). Furthermore, the reported low level of use of metacognitive skills among high achievers in the control group suggests that, although metacognitive skill are teachable, a traditional teacher-centred approach to teaching is not likely to trigger their use.

The conceptual change instruction based on metacognition development intervention pushed low achievers closer to high achievers in terms of achievement, but not in terms of metacognitive skills. This may be explained by Leopold and Leutner (2015) who report that visualisation may compensate for lack of metacognitive self-regulation in science text comprehension. Similarly, Sunyono et al. (2015a) found that learning with multiple representation was more suitable for low achievers than high achievers.

7.6 SUMMARY

This chapter discussed the implications of the results of this study from literature. To encapsulate, the discussions have shown that the advantage that high achievers have over their low achiever counterparts is their ability to use metacognitive skills while solving chemical equilibrium problems. The discussions also demonstrated that although the development of metacognition may occur naturally, certain types of instructional experiences are more likely to enhance this natural process than others. In the next chapter, the researcher will present the conclusions of this study and its significance to the body of scholarship and teaching practice.

CHAPTER EIGHT: CONCLUSIONS

8.1 INTRODUCTION

This chapter presents the conclusions of the study. It begins with an overview of research problem and methodology and then continues with the presentation of findings and conclusions. Implications for educational practice and contributions of this study to knowledge are also presented. Subsequently, the limitations of the study as well as an agenda for further study are presented. Finally, it concludes with reflection on the research study.

8.2 OVERVIEW OF RESEARCH PROBLEM AND METHODOLOGY

This study was motivated by the persistent poor performance of Physical Science students in chemical equilibrium knowledge area in grade 12 exit examination in the Mpumalanga province of South Africa. Chapters one and two indicated that chemical equilibrium is considered as one of the difficult topics to understand. This research therefore sought to find out if conceptual change instruction based on metacognition development could promote students' achievement and metacognitive skills in chemical equilibrium among grade 12 Physical Science students. To achieve these, the study adopted an exploratory sequential mixed method research approach which involved an initial qualitative phase and a final quantitative phase. The qualitative phase involved the exploration of seven grade 12 Physical Science students' difficulties in solving chemical equilibrium problems. The think-aloud method was used as a tool for data collection in the qualitative phase. The quantitative phase was a quasi-experiment and involved 69 grade 12 Physical Science students. Qualitative analysis of students' difficulties solving chemical equilibrium resulted in the development of conceptual change instructional activities such as argumentation and modelling based teaching activities, which were used in the quantitative phase to teach chemical equilibrium. This study was undertaken in Bohlabela district of Mpumalanga Province in South Africa. Performance of students in this district has generally been poor compared to other districts. The content of chemical equilibrium covered in this study was within the scope of the Physical Sciences curriculum of South African FET schools. The purpose of the study was translated to the following overarching question "To what extent does conceptual change instruction based on metacognition development promote students' achievement and metacognitive skills of grade 12 Physical Science students in Mpumalanga province?" Four secondary research questions were formulated from the overarching question. They were:

1. What is the level of metacognitive skillfulness of grade 12 Physical Science students in solving chemical equilibrium problems?
2. What factors influence students' use of cognitive strategies in solving chemical equilibrium problems?
3. How well do the two measures of learning strategy (learning approach and metacognitive skills) predict achievement in chemical equilibrium based on CEAT scores? How much variance in chemical equilibrium achievement can be explained by scores on these two scales?
4. How can conceptual change instruction be effectively implemented in Physical Science to foster deep learning and the development of metacognitive skills.

In addition to the research questions, the following hypotheses were tested:

1. Students taught chemical equilibrium through the conceptual change approach based on metacognition development approach will:
 - a) achieve significantly better in chemical equilibrium than students taught through the traditional teacher centred approach.
 - b) develop significantly better metacognitive skills in chemical equilibrium than students taught through the traditional teacher centred approach.
2. Conceptual change teaching based on metacognition development approach will narrow the achievement gap between high and low achievers.
3. Conceptual change teaching based on metacognition development approach will not narrow the metacognitive skills gap between high and low achievers.

8.3 FINDINGS

The following difficulties of students emerged from the analysis of qualitative data:

- i. Low achieving students did not know on which cell of the RICEE table to place the figures from the graph (see paragraph four of 6.2.1).
- ii. Low achieving students referred to initial moles as the equilibrium moles (see paragraph one of 6.2.3).
- iii. The way low achieving students used the RICEE table to determine equilibrium concentration was their own “synthetic” construction of strategy that resulted from lack of understanding (see paragraph three of 6.2.4).
- iv. Low achieving students thought the RICEE table should be filled sequentially from top row to the bottom row (see paragraph two of 6.2.4).

- v. Low achieving students did not check for errors while using the RICEE table to solve chemical equilibrium problems (see paragraph one of 6.2.5).
- vi. Low achieving students did not activate prior knowledge when it was needed (see paragraph two of 6.2.2).
- vii. Low achieving students constructed on-the-spot explanation of their claims by assuming a correspondence between increases in temperature and the increasing shape of the graph without considering what was increasing with time on the graph (see paragraph two of 6.2.2).
- viii. In problem-solving involving the calculation of equilibrium constant both high and low achieving students ignored information in the problem statement that they were not familiar with and used only those information they were familiar with in calculating the equilibrium constant (see paragraph three of 6.2.3).
- ix. Low achieving students were convinced of the correctness of their solution, to such an extent that they tended not to attend to inconsistency in their problem solving approach even when prompted (see paragraph two of 6.2.3).
- x. Low achieving students wrote incorrect equilibrium constant formulae (see paragraph three of 6.2.5).
- xi. Low achieving students used the calculator incorrectly (see paragraph two of 6.2.5).
- xii. Low achieving students read values which corresponded to the location of the labels of the graph instead of reading values from the axis of the graph (see paragraph of four 6.2.5).
- xiii. Low achieving students used mole ratio as factors by which the initial amounts changed when equilibrium was reached (see paragraph seven of 6.2.5).
- xiv. Both low and high achieving students misinterpreted the symbol K (of Kelvin) as Kilogram or Kilopascal (see paragraph five of 6.2.5).
- xv. Low achieving students did not understand the meaning of the letters in the mnemonics they were using as aids to remember names of the rows of the RICEE table (see paragraph five of 6.2.5).
- xvi. When low achieving students could not use the complete RICEE table, they guessed the figures and moved on with the problem solving (see paragraph six of 6.2.5),

The following results were obtained from the analysis of quantitative data:

- i. Students who were taught chemical equilibrium through the conceptual change instruction based on metacognition development performed significantly better on the post-chemical

equilibrium achievement test than students who were taught through the traditional teacher-centred approach (refer to paragraph one of 6.5).

- ii. Students who were taught chemical equilibrium through the conceptual change instruction based on metacognition development performed significantly better on metacognitive skills tests than students who were taught through the traditional teacher-centred approach (see paragraph two of 6.5).
- iii. Conceptual change instruction based on metacognition development narrowed the achievement gap between high and low achievers (see paragraph three of 6.5).
- iv. Conceptual change instruction based on metacognition development did not narrow the metacognitive skills gap between high and low achievers (see paragraph four of 6.5).
- v. Metacognitive skills as measured by the chemical equilibrium metacognitive activity inventory (MCA-CE) were a significantly better predictor of chemical equilibrium achievement than study approach as measured by the revised two-factor study process questionnaire (R-SPQ-2F) (see paragraph three of 6.6).

The following secondary findings also emerged during the implementation of the interventions

- i. When students have knowledge of the correct answer in complex problem solving they tend to engage deeper with the problem solving process.

The following misconceptions also emerged as secondary findings:

- i. Students thought that increase in temperature increases the rate of endothermic reaction and decreases the rate of exothermic reaction.
- ii. Many students could not understand that following an increase in pressure, when equilibrium is re-established, the number of moles will increase for the side of the reaction with fewer gas molecules and decrease for the side with more gas molecules moles.
- iii. Most of the students thought that following an increase in pressure concentration of reactants will decrease due to the equilibrium shift to the right.
- iv. Students thought that removing some of the solid calcium carbonate from an equilibrium mixture of calcium carbonate and its decomposition products will leave products only in the system and no reaction can occur.

8.3.1 Research question one

Research question one sought to find grade 12 Physical Science students' level of metacognitive skillfulness in learning chemical equilibrium. The findings of this study indicate that the level of metacognitive activities among low achievers is unacceptable or low while that of high achievers is relatively high (see paragraph one of 7.2). These were illustrated by the various errors and conceptual inaccuracies demonstrated particularly by low achievers while solving chemical equilibrium problems.

8.3.2 Research question two

Research question two sought to find the factors that influence the use of the cognitive strategy in solving problems in chemical equilibrium. Findings indicate that the way students used the cognitive strategies in solving chemical equilibrium problems was influenced by the following metacognitive factors: (1) mental model/declarative knowledge of chemical equilibrium; (2) scientific reasoning; (3) conditional knowledge; (4) confidence judgement; (5) metacognitive knowledge of the RICEE table (see 7.3.5). These factors accounted for the difference in metacognitive skills usage between low achievers and high achievers.

8.3.3 Research question three

Research question three sought to determine how much variance in chemical equilibrium achievement can be explained by scores on the chemical equilibrium metacognitive skills questionnaire (MCAI-CE) and the revised two-factor study process question (R-SPQ-2F). The findings of this study indicate that the chemical equilibrium metacognitive skills questionnaire was a better predictor of achievement than the revised two-factor study process questionnaire (see paragraph five of 6.6).

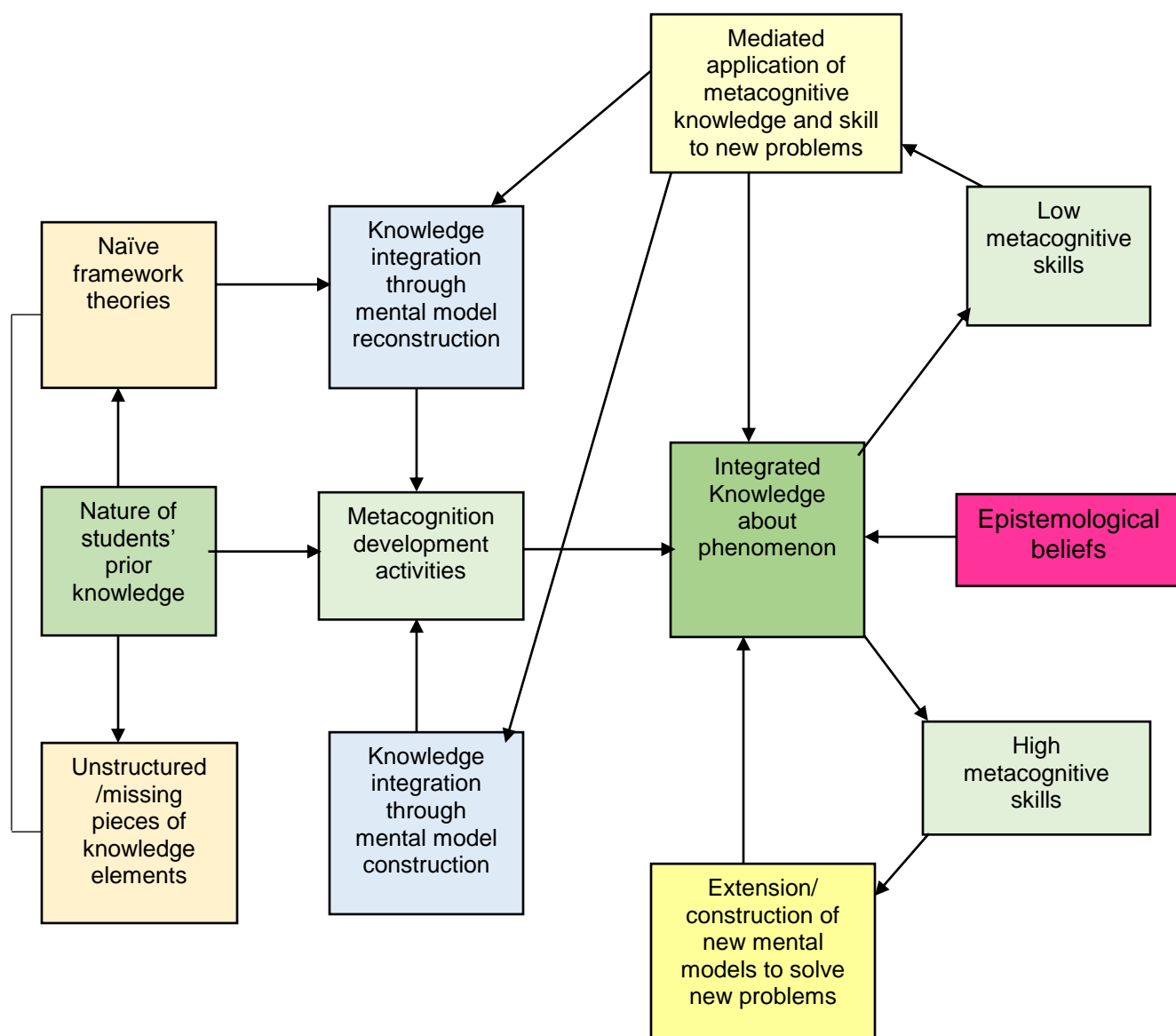
8.3.4 Research question four

Research question four sought to develop a framework for the effective implementation of conceptual change instruction in Physical Science to foster conceptual change and development of metacognitive skills.

The framework for the implementation of conceptual change teaching in chemical equilibrium developed in this study is shown in Figure 8.1. The development of the framework was based on two main assumptions about students' knowledge structure. The assumption that students' knowledge structure consists of *naïve framework theories* was informed by students' prior belief that at equilibrium, concentration of reactants is equal to the concentration of products (see

paragraph one of 5.8.3) and also that increase in temperature increases the rate of endothermic reaction but decreases the rate exothermic reaction (see paragraph four of 5.8.4). On the other hand, the assumption that students' knowledge structure consists of *unstructured and/or with missing pieces of information* was informed by students' lack of awareness of the chemically equilibrated state (see paragraph one of 7.3.1).

Figure 8.1: A framework for the implementation of conceptual change instruction in Physical Sciences



In figure 8.1, there is a line joining the two kinds of students' knowledge structures, meaning a student's knowledge structure about a particular science topic to be learnt may be either of them or both of them.

Conceptual change in this framework is labelled as *knowledge integration* (i.e. the degree of connectedness or coherence among knowledge elements in students' cognitive structure) and may be achieved through mental *model re-construction or construction*. The meaning of mental model was discussed (see paragraph one of 4.10).

Re-construction in this framework means that the mental model needed to think in a learning situation is available but faulty; therefore modelling activities should focus on testing the expressed mental model. Metacognition development activities such as modelling and argumentation writing and questioning should focus on creating metacognitive awareness of students' expressed models to facilitate rejection of their mental models and consideration of a competing model. *Construction* of mental model in this framework means that the mental model needed for thinking in a learning situation is weak or not available, therefore modelling and argumentation activities should focus on model building, and the metacognition development activities should focus on fostering integration among model elements. This suggests that teachers ought to be aware of the nature of students' knowledge concerning the science subject matter to be taught either through the science education research literature or through assessment in order to be able to take appropriate action.

The position of knowledge integration (i.e. between metacognition development activities and epistemological beliefs) indicates that both the *epistemological beliefs* of the student and the quality of *metacognition development activities* in the conceptual change lesson influence the degree of knowledge integration that the student can achieve. High quality metacognition development activities will foster critical thinking and reflecting, leading to high degree of knowledge integration. However, the students' epistemological beliefs may affect the level of student engagement with learning activities. If the student is inclined to constructivists learning beliefs, s/he will put in more effort in constructing knowledge but if the student is inclined to didacticism, s/he will be seeking knowledge from the teacher or the textbook and will not put in much effort in constructing knowledge. This directly determines the level of *metacognitive skills* that the students will develop from the knowledge construction/re-construction process.

If students' metacognitive skills that develop from engagement with learning activities are high, the student will independently or with minimum support be able to construct new models to solve new problems leading to the development of a more complex or integrated knowledge. If students' metacognitive skills that develop from engagement with learning activities are low, the application of the metacognitive skills to solve new problems must be mediated through visual aid, or peer or teacher support. This could lead to the development of a more complex or integrated knowledge

structure. It could also lead to failure to construct a mental model to solve the new problem. When failure occurs, the knowledge construction process is restarted from knowledge construction/re-construction.

8.3.5 Research hypothesis one.

Research hypothesis one sought to determine the effect of conceptual change teaching approach based on metacognition development on students' achievement and metacognitive skills in chemical equilibrium. The findings of this study indicate that the conceptual change instruction based on metacognition development is a better instructional approach than the traditional teacher centred approach in promoting:

- a) students' understanding and problem solving in chemical equilibrium (see paragraph one of 7.4);
- b) metacognitive skills in chemical equilibrium (see paragraph one of 7.4).

8.3.6 Research hypothesis two

Conceptual change instruction based on metacognition development

- a) narrowed the achievement gap between high and low achievers (see paragraph four of 7.4);
- b) did not narrow the metacognitive skills gap between high and low achievers (see paragraph four of four of 7.4).

8.4 CONCLUSIONS

This study has shown that the relationship between study approach and academic achievement was mediated by metacognitive skills and therefore no direct relationship between learning approach and academic achievement was found. Also, as revealed in this study, conceptual change instruction based on metacognition development has a tendency to bring equity in learning chemical equilibrium in the science classroom among grade 12 Physical Science students. Furthermore, this study has demonstrated that explicit instruction in metacognition tends to promote the use of metacognitive skills in solving chemical equilibrium problems, which then leads to better achievements.

An initial exploration and analysis of students' learning difficulties in chemical equilibrium through think-aloud problem solving activities gave an account of students' difficulties that supported the "knowledge in pieces" view of naïve knowledge coherence structure. This view of students' naïve ideas, as well as the knowledge on the metacognitive factors that influence the use of cognitive

strategies in solving chemical equilibrium problems, leads to careful selection of teaching and learning activities that could promote students' achievement and metacognitive skills. However, instances of students' faulty mental models that suggested a view of naïve knowledge coherence as "knowledge as theory" were observed during the teaching of chemical equilibrium. Whether naïve knowledge is viewed as constituting theory-like nature with some explanation power or pieces of independent elements, what the findings of this study indicate is that promotion of metacognitive knowledge is at the heart of effective implementation of conceptual change for deep learning chemical equilibrium. While considering the promotion of metacognition, it is noteworthy to remember that students' epistemological beliefs and motivation for learning play a significant role in the development of metacognition. These conclusions reaffirm the researcher's initial proposition that conceptual change is multifaceted, with each theoretical perspective forming a facet of this process, and that focusing on the development of metacognition is a way to reconcile all these theoretical perspectives in promoting effective conceptual change.

8.5 IMPLICATIONS FOR EDUCATIONAL PRACTICE

The findings of this study have implications for teaching and learning of chemical equilibrium to improve conceptual knowledge:

1. Teaching should ensure that mental models of incompleteness of reaction, reversibility and dynamism which are the defining attributes of the chemical equilibrium concept are developed simultaneously by using metacognition development activities (e.g. mental model construction/re-construction).
2. Multi-modal representation should be encouraged in order to help students visualise all the aspects of the concepts as each mode of representation in a multi-modal representation highlights specific aspects of the chemical equilibrium concept. For instance graphical representations may highlight the changes to the rates and concentration of substances from the beginning of the reaction to equilibrium while practical test tube demonstrations may highlight reversibility and analogies may highlight dynamism. Multi-modal representations when used simultaneously make conceptual inconsistencies explicit, thus prompting a search for conceptual coherence (Parnafes, 2007). This can foster conceptual integration which leads to the development of an accurate conceptual model of the chemical equilibrium phenomenon.
3. As revealed in this study, the structure of explanations of the high achieving students with the conceptual task mimics the structure of scientific argument. Low achieving students virtually

made claims without any logical support which indicated lack of knowledge of argumentation. Therefore, argumentation should be explicitly taught as it could enhance the construction of explanation about the effect of changes in concentration, temperature and pressure on chemical equilibrium phenomenon. The argument template should be used to support students' argumentation writing. Awareness of the structure of an argument such as claims, evidence and warrant on the argument template could prompt students to reflect on the explanation they are constructing, thus leading to construction of better explanations. Modelling-based activities such as modelling changes in concentrations when equilibrium is disturbed should be part of students' argumentation writing as this could improve students' argumentation skills and interpretation of chemical equilibrium graphs.

4. This study also revealed that both high and low achieving students were familiar with the RICEE table strategy of solving chemical equilibrium problems involving the equilibrium constant, but the metacognitive knowledge of the RICEE table for low achievers was poor. Therefore teachers should use models to help students develop conceptual knowledge of the order to improve students' metacognitive knowledge of the using the RICEE table. As shown in this study, the design of the RICEE table as well as sequencing of the steps used by high achieving student was different from those of low achieving students. Since different textbooks on chemical equilibrium have different designs and sequencing of the steps in completing the RICEE table, teachers should not only model the table strategies to students but should also make students aware of the existence of alternative design and sequencing of steps in completing the table so that students can be flexible in their use of the RICEE table. In this way procedural knowledge of students can be enhanced. Practising the use of the RICEE table in different contexts is important for enhancing conditional knowledge. However, this can be more effective when students' declarative knowledge of chemical equilibrium as well as their metacognitive knowledge of the RICEE table is sound. Question prompts can be used to focus students' attention on the context of the task and to scaffold students' thinking especially in unfamiliar or the ill-structured problems. Furthermore, students' knowledge of the correct answer can be used to promote students' motivation to put in effort to complete the given chemical equilibrium task. Part of this effort could be channelled into self-monitoring and evaluation of performance particularly in in complex problem solving in order to detect and correct errors.

5. The current practice where chemical equilibrium content is sequenced according to the “logic” of the textbook or the curriculum material needs review. In the current Physical Science CAPS document the content of chemical equilibrium is sequenced as follows: chemical equilibrium, equilibrium constant, Le Chatelier’s principle, interpretation of equilibrium graphs, and application of rate and equilibrium principles to industrial applications (DBE, 2011). Though the intention of the sequencing of content of chemical equilibrium by the CAPS document is not prescriptive, supporting district curriculum materials such as annual teaching plans and recommended textbooks for Physical Science such as “Solutions for all” and “Study and Master” communicate this to teachers as prescribed sequence of lessons to be followed. As a result information is presented to students in a discrete and unrelated manner. For example, graphs of chemical equilibrium which could be a supporting tool for application of Le Chatelier’s principle are usually taught as the last item after students have supposedly learnt the application of Le Chatelier’s principle. Teachers should be oriented on integrating content elements of chemical equilibrium as was done in this study so that concepts can be learned in wholes as much as possible. This could support students’ understanding of concepts and the development of metacognitive skills need for problem solving and self-regulation.

8.6 CONTRIBUTION OF THIS STUDY TO KNOWLEDGE

This study made contributions to the extant literature on the relationship between learning approach and teaching approach. In chapter one, one of the gaps identified concerning this relationship was the inconsistencies in the results that emerged from studies of the relationship between learning approach and teaching approach. This study, like a few other ones cited in this report (for instance Choy, O’Grady and Rotgans, 2012; Loyens, Gijbels, Coertjens and Cote’, 2013) has attempted to explain these inconsistencies in previous studies as lack of direct relationship between teaching approach and learning approach as measured by the revised two-factor study process questionnaire (R-SPQ-2F). Metacognitive skills of students mediated this relationship. In other words, a teaching approach supposed to promote deep learning will do so only when the students’ metacognitive skills are also improved. Secondly this study has made a modest contribution to our understanding of students’ misconceptions on chemical equilibrium and conceptual change. Previous research findings in this area assumed that students have stable misconceptions in chemical equilibrium which impede their learning and that these misconceptions must be elicited and restructured through conceptual change instruction. This study has revealed that students’ difficulties in learning chemical equilibrium are beyond misconceptions and that conceptual change involves knowledge

restructuring, both at the ontological level (i.e. ideas) as well as the epistemological level (i.e. learning strategies).

This study made methodological contributions as well. The study developed a valid and reliable questionnaire for measuring metacognitive skills in chemical equilibrium. This questionnaire can be adapted to measure metacognitive skills in other topics in Physical Science. Also this study has developed a methodology for investigating students' difficulties in Physical Science. This methodology may be used to investigate other knowledge areas in Physical Science.

Furthermore, the study made contributions to practice. The students' worksheets and the knowledge test on chemical equilibrium developed for the study may be used by teachers and students as teaching and learning materials. Most importantly, this study developed a framework for the implementation of conceptual change to foster deep learning and metacognition in Physical Science.

8.7 LIMITATIONS OF THE STUDY

The findings of this study cannot be generalised to the entire grade 12 Physical Sciences student populations because the sample was not randomly selected. This research was conducted using the pragmatists' paradigm which allowed the researcher to combine qualitative and quantitative methods. As a result problem-solving on only four chemical equilibrium tasks were observed. If the study had been based on the interpretive paradigm only, for instance, it would have allowed the observation of more different kinds of chemical equilibrium problems which could have generated more information on students' difficulties than what is reported here. Another limitation of this study relates to the bias inherent in interpretation of qualitative data and the use of fellow Physical Science teachers as co-raters of students' think-aloud protocols. Despite that, the researcher tried as much as possible to transcribe every detail of the think-aloud protocols there is no doubt that some details of the think-aloud data might have been missed.

Another limitation of this study is that the factors of MCAI-CE revealed in this study have not been confirmed. A confirmatory factor analytic study is required. Given the many perspectives on the dimensions of metacognition and the fact that the total variance explained by MCAI-CE factors is only about 41%, it cannot be claimed that the questionnaires cover all aspects of metacognition needed to solve chemical equilibrium problems.

The aim of this study was to determine the extent to which conceptual change instruction modelled on metacognition development can promote deep learning and metacognition among grade 12

Physical Science students, and these aims were translated into specific research objectives. In this study, each of these five objectives was achieved; but as outlined below, further research work is needed to progress this research area to fruition.

8.8 SUGGESTIONS FOR FURTHER RESEARCH

Though the findings of the study implied that epistemological beliefs might interfere with the development of metacognitive strategies, this study did not measure students' epistemological beliefs to determine how the interventions imparted on these beliefs. Further research in this area is recommended. According to Georghiades (2000), forgetting what has been learned in a very short time is a common problem of student learning. Although this study may claim that the experimental treatment caused students to use deep learning strategies, it cannot make any claims about durability of learning as this was not investigated. Further research that investigates durability by giving delayed post-tests may be conducted. Also items analysis of post-tests have shown that the intervention was not effective in promoting deep learning on all the knowledge areas tested in this study. A further qualitative probe in this regard is recommended. This will assist in determining future lines of action on how to improve the intervention. Further research may also combine MCAI-CE with other metacognitive instruments to see if the two instruments could result in a better model of the relationship between achievement and metacognition. This may be a test of convergent validity for MCAI-CE.

8.9 REFLECTIONS ON THE RESEARCH STUDY

Looking back at the on the research journey, I have come to believe that pursuing a doctoral study is the greatest learning experience one can have in life and I am beginning to understand my role as a science educator. I have learnt a lot from doing this research; in the first place, I have gained more knowledge about my profession as a teacher. Through the reading of science education literature, I have come to understand more about what science teaching and learning is. Numerous concepts about science education such as conceptual change, inquiry learning, and the nature of science have been clarified for me. This study has also enlightened me on problems such as causes of students' learning failures in science and I can say I am now in a better position to address students' learning challenges. Conducting this study has also given me the opportunity to know leading researchers in the field of science education through their writings. My thinking as well as line of reasoning in this study was greatly influenced by these scholars. This study has also taught me a lot about life. Through conducting this research, I came to understand what my former lecturer once told me about

the academic journey. He said the academic journey was like this: “You are flown in an aeroplane into an unknown island where no one lives and you are dropped from the aeroplane into the land by parachute. You have been given all the instruments such as a compass, a map and a boat to help you sail to a nearby country. Your task is to try to find your way out using these instruments although you might not have been taught how to use them, and your success depends on how well you can use these instruments.” What I have come to understand from this analogy in relation to my study is that the research journey is not a straightforward one; there are curves and bends, detours, U-turns and dead ends without warning signs. What I deduced from my study is reflexivity; that innovation, creativity, resilience and discipline are crucial for success in this journey. Finally I have come to understand that pursuing the academic journey can forfeit some good relations with colleagues, friends and even family members.

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APPENDIX 5.1: THINK-ALOUD TASK

1	Consider the following hypothetical reaction that takes place in a closed 200cm^3 flask at 298 K.: $\mathbf{A_2(g) + 2B_2(g) \rightleftharpoons 2AB_2(g)}$ The graph represents the change in the number of moles of each gas in the flask over a period of 20 minutes.
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	<p>Calculate the equilibrium constant K_c for this reaction at 298 K.</p>
2	<p>Refer to the graph in Q1. At 10 minutes the temperature of the flask was increased. Determine if the production of AB_2 is exothermic or endothermic?</p>
3	<p>Consider the following reaction: $Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons [Fe(SCN)]^{2+}(aq)$</p> <p>$50\text{cm}^3$ of $0.1\text{mol. dm}^{-3} Fe^{3+}(aq)$ are added to 30cm^3 of $0.2\text{mol. dm}^{-3} SCN^{-}(aq)$.</p> <p>At equilibrium, the concentration of $[Fe(SCN)]^{2+}(aq)$ is found to be 0.05mol. dm^{-3}. What is the equilibrium constant, K_c, for the reaction?</p>
4	<p>A crucial reaction in the manufacture of Sulphuric acid involves the oxidation of Sulphur dioxide to Sulphur trioxide by oxygen in the air: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$</p> <p>$\Delta H = -197\text{ KJ}$. In an experiment, a mixture of 1.59 moles of SO_2 and 0.855 mole of O_2 is introduced to a 2dm^3 container at 800K. When equilibrium is reached, it is found that 94.3% of Sulphur dioxide is converted to Sulphur trioxide.</p> <p>Calculate the equilibrium constant, K_c, at 800K.</p>

APPENDIX 5.2: TRANSCRIPTS OF THINK-ALOUD PROTOCOLS

ANGELA (Low achiever)

Task 1

1. I will start by drawing my table....and this are my ratios...S stand for start...and the U for used...P for the product... and C for concentration ... no! E for equilibrium and C for concentration yes...and my reaction is as follows ... and when you come here, we've got A_2 gas and the B_2 and it is a gas and lastly, the product $2AB_2$ gas...these ones are the reactants (A_2 and $2B_2$) and this one is the product ($2AB_2$)...And when you come to the ratios, it is 1:2:2
2. and to the start, we are going to use the graph to get the point from the graph...and here ($A_{2(g)}$), we've got 2,4 mole... and on this one (B_2) we've got 2,0 so we are going to write 2,0 here...and here, we have zero so we are going to write zero...
3. and when we come to the used...to the product we are going to write zero here, zero and zero here...and we are going to find the value for the product here...and we've got ... hmm...product....from here we have 2,4:1 ratio...and here we are going to use X:2 ... and our X is going to be 4,8 and that's what we are going to see here...(writing 4,8 in the cell corresponding to equilibrium mole of AB_2(long pause). I'm stuck...

Interview

Researcher: Can you explain the meaning of these symbols (SUPEC)

Angel: S is for the start of the reaction, U is for used.

Researcher: Used what?

Angel: Used..., P is for the product that come from the reaction and...

E is the equilibrium...

Researcher: Equilibrium what?

Angel: Equilibrium constant...

And then C is the concentration, the volume of the reaction...

Researcher: You were talking about product here and then you were talking about here.

Angel: Yes

Researcher: what is the equilibrium mole for AB_2 from the graph?

Angel: 0,2 according to the scale.

Researcher: Can you show on the graph?

Angel: here (pointing to the first horizontal grid line that corresponds to 0,2 on the mole axis where the label AB₂ is placed)

Researcher: what about the equilibrium mole for B₂?

Angel: B₂, because the graph is going straight here it is 1,2

Researcher: I mean equilibrium mole not initial mole.

Angel: Hmmm... the equilibrium mole is 1,2.

Researcher: Did you write this on the table?

Angel: No

Researcher: Why?

Angel: (silence)

Researcher: What about the equilibrium mole for A₂?

Angel: A₂ is 2,0 (Pointing at the initial mole of A₂ on the graph)

Researcher: What about the equilibrium mole for AB₂?

Angel: it's 0,8.

Researcher: Did you write this in the table?

Angel: No

Researcher: Is it needed in the table?

Angel: I'm not sure whether it is needed and where it should be.

Researcher: Thank you.

Task 2:

1. The question says, at 10 minutes, the temperature of the flask was increased. Determine if the product [production] is exothermic or endothermic.
2. and we get AB₂ here from the graph...and in 10 minutes it was increased...the temperature was increased...and I must determine if the production was exothermic or endothermic.
3. and my answer is exothermic because the graph is increasing .

Interview:

Researcher: Graph is increasing? What does that mean?

Angel: It is that the temperature is increasing and the heat is coming out so it is exothermic.

Task 3

1. to calculate the equilibrium constant...first, I will convert the volume to dm³ by dividing thousand...Converting from centimeter to dm³ is... 30...divided by... 1000...is...0.03 dm³...

2. and I will use the formula for the equilibrium constant...which is the product...over reactant and... I'm going to use the reaction to...calculate my equilibrium constant...and my product here is...Iron Fe...Plus... SCN^- (writing $[\text{Fe}^{3+}] + [\text{SCN}^-]$)...over the reactant... No! no! no! no! no! (Cancelling)...The product is this one... (Writing $[\text{Fe}(\text{SCN})^{2+}]$)...over the reactant which is... (Writing $[\text{Fe}^{3+}] + [\text{SCN}^-]$)...
3. and I'm going to use the values here...for iron it is 0,1 mol...and the reactant of this one.....(long pause).
4. OK here I have to convert the centimeters for the reaction... The volume is 50/1000 so that...It can be converted to dm^3 [Reading the problem again] I will use my formula for equilibrium constant...which is product...over reactant, divided by reactant...
5. And my product here... my product is... $[\text{Fe}(\text{SCN})^{2+}]$ and my reactant is... $[\text{Fe}^{3+}] + [\text{SCN}^-]$...
6. and I'm going to put on the moles here to substitute... for the product of iron $[\text{Fe}(\text{SCN})^{2+}]$ is... 0,5... all over...the iron which is the reactant...which is 0,1 mol...plus the SCN which is 0,2 mol... [Punching 0.1+0.2 on the calculator]...0,05...all over...0,3...
7. and my equilibrium constant is... 0,05 divided by 0,3...(punching 0.05 / 0.3)...which is 0,17....I'm not sure of the unit.

Task 4

1. For this one I'm going to draw my own table first, the table of SUPAC...my S... my U...and my P...and the concentration... and this is for the mole ratio...here, we are going to have the reactants, Sulphur dioxide, SO_2 ...and oxygen O_2 ... and my product is... $2\text{SO}_3(\text{g})$... now I'm going to write my ratios because here (pointing to the stoichiometric coefficient of SO_2 in the equation) there is 2... I'm going to say 2:1:2...
2. and the start here, I'm going to put the moles of for SO_2 here...it's 1, 59 for oxygen..... (Silence) [Reading the question again] here for oxygen is 0.855mol... in the table...and... in the SO_3 the moles hei! Sir I'm stuck.....[Reading the question again] hmmm....I don't understand the question...

Interview

Researcher: do you see any other information in the problem statement that could be useful?

Angel: Yes the information is here but know how to use it...it is found that 94,3% of SO_2 is converted to SO_3 .

Researcher: is it important? (That information)

Angel: I'm not sure...

Researcher: Do you believe it is important?

Angel: yes but I can't use it.

ELIOT (Low achiever)

Task 1

1. the graph is shown... number of moles against time...the question...calculate the equilibrium constant for this reaction at two hundred and ninety-eight K
2. hmmm.... let's start to solve the question...Er we must use the table to calculate the Kc...the table is this one...(drawing the table)... first, we must write the product on top of the table... A₂...plus 2B₂...and 2AB₂...we have the ratio...the ratio is 1 is to 2 is to 2...
3. A₂ is 2,4...B₂ is 2,0...and AB₂ is 0...and we must find the other...
4. and this one is 0...oh! no! no! no!...2 times 2,4 is 4,8...and here is 4,8... and here is 0, and 0 this one is 2,4 times 1 equals to 2,4...and here is 2 time 2,0 equals to 4...
5. and here we must find the equilibrium...we must use this product to find the equilibriums... and this one is 1 times this one (2,4) equals to 2,4...and this one is 4...
6. calculate the concentration is $c = \text{number of moles} / \text{volume}$...number of moles is equal to 2,4 divided by...200 divided by 1000...to get the volume...it's er 0,2 and its equal to 2,4 divided by 0,2 [Punching the calculator]...it's equal to 12 concentration... even this side (the cell corresponding to equilibrium concentration of B₂ [Writing $c = n/v$] is equal to 4 divided by 0,2... it's equal to $4 \div 0,2$ [punching the calculator] is equal to 20...this side is 4,8 and concentration is equal to... [Writing $c = n/v$] and 4,8 divided by 0,2 is equal to...[punching the calculator] 24...we use the general formula for Kc...
7. Kc is equal to product divided by reactants the product is...[writing $\frac{[A_2][2B_2]^2}{[2AB_2]^2}$]
8. is equal to...the concentration of A₂ is 12...and the concentration of 2B₂ is 20² ...divided by... and the concentration of 2AB₂ is 24² ...
9. and you calculate... and $12 \times 20 = 240 \wedge 2 = 57600$... [Punching the calculator] divided by... 24²... [Punching the calculator] so the final answer is 100.

Interview:

Researcher: How did you do this one? I mean (12)(20)² ? Can you repeat it on the calculator?

Eliot: (12)(20)² [Punching the calculator]...

Is equal to 4800...

Ooh! There was a little bit mistake here...

Yes, ok let's crash this one... [Cancelling the first calculation]...

4800 divided by 576...

So the final answer is 83,3.

Researcher: I see you write $K_c = \frac{[product]}{[reactant]}$ but when you come here I see something different. Which one is your product?

Eliot: it's this one {Pointing to $[A_2][2B_2]^2$ } the numerator in the K_c expression.

Researcher: Which one is the reactant?

Eliot: it is this one {Pointing to $[2AB_2]$ }, the denominator in the K_c expression...

Researcher: Let's go back to the equation $A_{2(g)} + 2B_{2(g)} \rightleftharpoons 2AB_{2(g)}$. Which one is the product?

Eliot: it's this one [Pointing to $A_{2(g)} + 2B_{2(g)}$].

Researcher: And which one is the reactant?

Eliot: it's this one [Pointing to $2AB_{2(g)}$].

Researcher: I see this (SUPEC). What is the meaning of S?

Eliot: Start

Researcher: Start what?

Eliot: Start the...the...the numbers on the product ratio.

Researcher: And U?

Eliot: Used.

Researcher: Used what?

Eliot: The numbers on the...on the equations

Researcher: P is what?

Eliot: This one is product.

Researcher: This one is what (E)?

Eliot: Equilibrium

Researcher: equilibrium what?

Eliot: Equilibrium.

Researcher: How did you get this 2,4?

Eliot: from this one [Pointing to the product cell]. Always if I can get the product, this one and this one will be the same. Product row and equilibrium row will be the same.

Researcher: I see that you wrote $2B_2$ and $2AB_2$ in the K_c expression. Why do you include the 2 twos?

Eliot: Because it is in the equation.

Task 2

1. At ten minutes, the temperature was increased. Determine if the product (production) of AB₂ is exothermic or endothermic.
2. So the correct answer is...endothermic...

Interview:

Researcher: why do you think so?

Eliot: because the temperature on the flask was increased. That means [heat] it is added

Can you explain this from the graph?

Eliot: On the graph, ten minutes is, the temperature of the flask is increased.

Obvious [heat] is added.

Task 3

1. Now we have the reaction...0,1...we have the volume...must divide by 1000... 0,1 = c of Fe³⁺...50/1000 = 0.05 = V...0,2 = c of SCN⁻ 30/1000 = 0,03 = V...
2. so we need to calculate the equilibrium constant so we go straight to the table...we don't use the table because we have the concentrations already...we need to calculate...
3. $K_c = \frac{[\text{product}]}{[\text{reactant}]}$...product is $[\text{Fe}(\text{SCN})^{2+}]/[\text{Fe}^{3+}] + [\text{SCN}^-]$...
4. so we substitute...the concentration of Fe³⁺... = $\frac{(0.1)(0.02)^{2+}}{(0.1)+(0.02)}$ [punching the calculator]
5. it's equal to 2 to the power negative three (2×10^{-3}) divided by...0,1×0.02 [Punching the calculator].... it's equal to 2×10^{-3} ...the answer is 1 I'm done.

Interview:

Researcher: Now let me ask this question. What is this? $\frac{50}{1000} = 0.05 = V?$

Eliot: It's the volume.

Researcher: why did you do this division? Did you use it in the calculation?

Eliot: I did not use it.

Researcher: Then what is the reason for writing it out?

Eliot: I was using (tabulating) the data.

Researcher: Do you have to tabulate an information that you will not need to solve the problem?

Eliot: No it's not good to do that.

Researcher: Then why did you tabulate it?

Eliot: For the sake of, I just used (tabulated) because sometimes, they can be needed.

Researcher: Where did you get this 0,1 from?

Eliot: 0,1 is the concentration of Fe^{3+} .

Researcher: Which concentration is that? Is it the initial or equilibrium?

Eliot: This one?

Researcher: Yes.

Eliot: It is equilibrium.

Researcher: Where in the problem statement can you show that it is the equilibrium concentration?

Eliot: [Skimming through the problem statement]... ooh!... Can I start the question afresh?

[Requesting to restart solving the question]

Researcher: Why do you want to start the question afresh?

Eliot: I didn't use this one in the calculation [Pointing to equilibrium concentration of $\text{Fe}(\text{SCN})^{2+}$ which is $0,05 \text{ mol.dm}^{-3}$.

Researcher: Start afresh.

Eliot: Ok.

$K_c = K_c = \frac{[\text{product}]}{[\text{reactant}]}$...

Product is $[\text{Fe}(\text{SCN})^{2+}]/[\text{Fe}^{3+}] + [\text{SCN}^-]$...

$= (0,05)/(0,1) + (0,2)$

$= 0,05 \div (0.1)(0.2)$ [Punching the calculator]

$= 2,5$

Researcher: I see you write '+' between the two reactants but when you press the calculator, you did not press +?

Eliot: This plus is not needed in the calculation.

Researcher: Then why did you write it?

Eliot: I forgot. This + must be out.

Researcher: Then why did you write it in the in the formula and the substitution?

Eliot: I make a mistake, I was rushing.

Researcher: So next time what must you do to avoid this mistake?

Eliot: I must check my solution for mistakes.

Researcher: before you continue with question three I see some information here that you did not make use of in your calculation. Are they important?

Eliot: Aah... they are not important.

Researcher: Why do you think so?

Eliot: Because here we already have the concentrations.

Researcher: You mean the concentrations are given?

Eliot: Yes.

Researcher: of which concentrations are this? [Referring to the initial concentration of Fe^{3+} and SCN^-].

Eliot: This is the concentration of Fe^{3+} .

Researcher: Is it the initial or equilibrium?

Eliot: This one is the equilibrium [Pointing to the initial concentration of Fe^{3+}]. Ooh! This one is the initial [Referring to the initial concentration of Fe^{3+}], this one is the initial (referring to the initial concentration of SCN^-) and this one is the equilibrium (referring to the equilibrium concentration of $\text{Fe}(\text{SCN})^{2+}$).

Researcher: Which concentrations did you substitute into the K_c expression? Is it the initial or the equilibrium?

Eliot: the beginning

Researcher: Why do you mix equilibrium and initial concentrations in the calculating equilibrium constant?

Eliot: Eeish!

Researcher: Do you see a problem?

Eliot: Aaah! I don't see a problem.

Researcher: Why not?

Eliot: It's because it's already in, this is a general formula so, here I already have a product, I already have a reactant.

Researcher: What is the meaning of the symbol []?

Eliot: I don't know.

Researcher: You mean you know that these are reactants' and products' concentrations and they have been given and are enough to solve the question so any other information is not important?

Eliot: Yes.

Task 4

1. So we have... number of moles of SO_2 is 1,59...we have er...for oxygen...it's equal to... 0,855...and we already have volume is...30...this is the volume...and here the volume is... is also 30...

2. we need to calculate the concentration first...moles of SO₂... SO₂ = 1.59/30 = V O₂ = 0.855/30 = V we need to calculate the concentration first... c = n/v...number of moles of SO₂ is...1, 54 divided by 30...is equal to...1.54 ÷ 30 [Punching the calculator]... is equal to 0,051 SO₂...so we have to calculate the concentration of oxygen...is c = n/v... so we are calculating the concentration of oxygen...number of moles is 0,855...divide by 30...is equal to... 0,0285 O₂...this one is for oxygen
3. so now we calculate the Kc... Kc = $\frac{[\text{product}]}{[\text{reactant}]}$...the equation is 2SO₂ + O₂ ⇌ 2SO₃... product is 2SO₂/[2SO]²[O₂]...
4. equals to the product is...no! I'm sticking...I must add this one (initial concentration of SO₂) and this one (initial concentration of O₂) to get the product... which mean...0.051 + 0.0285 [Punching the calculator]...It's equal to...the product is... 0, 0795/ (0,051)²(0.0285)...
5. the final answer is... [Punching the calculator] and the answer is...1077, 46...this is the final answer

Interview

Researcher: To get the product, I saw you adding the reactants. Is that correct?

Eliot: Yes it is correct.

Researcher: What makes you think so?

Eliot: Because the product here in the ...in the...question is not here (not given). I must add from the...from the...this two....this two gases...

Oxygen and SO₂...

Does this make sense?

Eliot: Yes it makes sense

Researcher: Is that how you were taught or that's what your belief?

Eliot: Aah not really. I don't believe in that.

Researcher: But it makes sense to you?

Eliot: Yes.

Researcher: there was other information in the problem statement that you did not use. I mean the percentage.

Eliot: Yes. [Reading this portion of the problem – when equilibrium is reached, it is found that 93,4 % of Sulphur dioxide is converted to Sulphur trioxide].

Elliot: Aah yes, this percentage is not included here.

Researcher: I beg your pardon?

Eliot: It's not included

Researcher: Do you mean it is not important?

Eliot: Yes.

Researcher: Are you sure it's not important?

Eliot: Aaah! This percentage is not important.

Researcher: Do think it's not important or you don't know how to use it?

Eliot: Aaah! This percentage is not important. This percentage shows you how Sulphur dioxide is converted to Sulphur trioxide.

Researcher: And you think it's not important?

Eliot: Yes, I've never got (come across) a question that is having this percentage before.

Researcher: So you mean because you are seeing this type of problem for the first time you think it's not important?

Eliot: Yes. I don't know how I can use it.

Researcher: Therefore it's not important?

Eliot: Yes

Researcher: Thank you.

MORENA (Low achiever)

1. I use the SUPEC method to find the Kc... [Drawing vertical and horizontal lines] and I put the elements...A₂...gas...plus...2B₂...gas...equals to...2AB₂...gas...then as I know that the product for the reaction is zero, I put zero on the table...and as I know that the product on the start is zero...and used is zero...
2. I go to the graph... And I look at the moles for A₂... [Writing 2,4] and the moles for B₂ is 1,8...
3. and I was given...volume is equal to 200 cm³... I divide it by 1000...So that it can give me 0.2 dm³...
4. from there...I find the produced for 2AB₂ er 2,4 is 2....I use the ratio for AB₂, 2,4 is to 1 and... X is to 2...from the... I cross multiply... $X = 2.4 \times 2$...equals to 4,8...I put it...from there, I use the produced from the 2AB₂ to find the used for A₂ and the used for 2B₂...1.8 is to 2...X is to 2...from this one...so...hmmm....cross multiple is $1,8 \times 2 = 3,6$ $\frac{2x}{2} = \frac{3,6}{2}$ X is equal to... I think it's wrong... 1,8 is to 2...4,8X is to 2... I cross multiply... $\frac{9,6x}{9,6} = \frac{3,6}{9,6}$ X is 0,3...from there, I

find the used too for A₂...2,4 is to 1 4,8x is to 2...I cross multiply... 4,8x × 1 is equal to 4,8x.
2,4 × 2 is equal to 4,8...divided by 4,8...is equal to 1...

5. From there to get the equilibrium, I will say 2,4 minus 1, for this one...is equal to... 1,4...and 1,8 minus 0,3...is equal to 1,5...

6. From there, I will get my concentration.... $c = \frac{1,4}{0,2} = 7$ $c = \frac{1,5}{0,2} = 7,5$ $c = \frac{4,8}{0,2} = 24$

7. Then I use the formula to get the K_c... $K_c = \frac{[product]}{[reactant]}$...as I know that my product is... $\frac{[2AB_2]^2}{[A_2][B_2]^2}$

8. I use the concentration that I have calculated to substitute into the formulae for K_c... $K_c = \frac{(24)^2}{(7)(7,5)^2}$

9. = $24^2 \div 7(7,5)^2$...is equal to 1,46.

Researcher: I want to know what this (pointing at SUPEC) stands for.

Morena: S is for start.

Researcher: Start what of what?

Morena: Start of the reaction.

Researcher: And what is this?

Morena: The used.

Researcher: The used what?

Morena: Used of the reactant.

Researcher: And what about the P?

Morena: Product.

Researcher: What is the product?

Morena: The product is something that is formed from the reaction.

Researcher; Then what about the E?

Morena: Equilibrium.

Researcher: Equilibrium what?

Morena: Equilibrium moles

Researcher: And what about the C?

Morena: Concentration:

Researcher: Which concentration?

Morena: Per decimeter cube.

Researcher: Are confident with your solution?

Morena: no

Researcher: that means you know that you have a problem?

Morena; yes.

Researcher: and what did you do about it?

Morena: I tried. I went to find more information about it.

Researcher: did you check textbooks to see how this type of problem is solved?

Morena: yes but I did not understand.

Task 3

1. For this one there is no need to use a table because everything that we need is there...
2. So we write the formula...product over reactant... $\frac{[product]}{[reactant]}$...equals to...the product is... $\frac{[Fe(SCN)^{2+}]}{[Fe^{3+}][SCN^-]}$...
3. $0.05/(0,1)(0,2)$
4. 2,5 I'm done.

Researcher: you think there is no need to use a table?

Morena: yes

Researcher: why do we use the table?

Morena: to find the concentration.

Researcher: which concentrations?

Morena: eeh the decimeter cube

Researcher: which concentration is that?

Morena: eeh what we call the product and the reactant.

Researcher: at which stage of the reaction? Equilibrium or initial?

Morena: equilibrium.

Researcher: there were other information given in the problem statement that that you did not use. For example 50 cm^3 , 30 cm^3 , and 80 cm^3 . Do you think these are not important for solving the problem?

Morena: for me, no. I don't think they are important.

Researcher: so you think the examiner just put those quantities there for decoration?

Morena: yes (laughing)

Researcher: you said you used equilibrium concentrations in calculating the K_c . Can you show where these figures are in the problem statement?

Morena: they have written them in the question.

Researcher: can you make reference to specific statements in problem statement that shows that these concentrations are equilibrium concentration?

Morena: yes, here (pointing at the specific words).

Researcher: read let's hear.

Morena: at equilibrium, the concentration of $\text{Fe}(\text{SCN})^{2+}$ is found to be $0,05 \text{ mol.dm}^{-3}$.

Researcher: ok that's for only this one [referring to $\text{Fe}(\text{SCN})^{2+}$]

Morena: yes.

Researcher: what about the concentrations of Fe^{3+} and SCN^- ? Are they also equilibrium concentrations?

Morena: yes

Researcher: do you believe that?

Morena: yes

Researcher: what makes you to believe?

Morena: I don't believe that.

Researcher: then why do you think it should be so?

Morena: why do I what?

Researcher: what I mean is this. When I asked you previously that which concentration in the problem statement were equilibrium concentrations you showed me the concentration of $\text{Fe}(\text{SCN})^{2+}$ only. You did not show the concentrations of Fe^{3+} and SCN^- , but in your calculation, you used the concentrations of Fe^{3+} and SCN^- as equilibrium concentrations.

Morena: eish!

Researcher: is that correct?

Morena: no.

Researcher: then why did you do it that way?

Morena: aah because I thought it's better if I do it that way.

Researcher: you mean you thought it would give you the answer you are looking for?

Morena; yes

Researcher: what convinced you that it was the right approach?

Morena: because we use the table to find the concentrations and now I see the concentrations written in the question.

Researcher: go ahead and solve question three.

Task 4

1. Ok... On this one you will use a table to find the concentration....[drawing the table]...we will write the element, SO₂, O₂ and 2SO₂...
2. from there we will put the moles...1,59 for SO₂... 0,855 for O₂ zero, zero, zero, zero...
3. we will use the SO₂ start to find the product of the SO₃...1,59 is to 1...X is to 2 X is equal to 1,59 × 2/1...is equal to 3,18... and here, 3,18...
4. from there we will use this one (3,18) to find O₂ and SO₂ used....for SO₂ is... 1,59 is to 1... 3,18x is to 2...you cross multiply...and x is equal to 1... for O₂... 0,855 is to 1... 3,18x is to 2...cross multiply... $\frac{3,18x}{3,18} = \frac{1,71}{3,18}$ X = 0,53
5. From here we minus 0,53 from 0,855...is equal to 0,33...and then 1,59 minus 1...is equal to 0,59
6. from there we calculate the concentration of SO₂ and O₂ and 2SO₃...we are given the volume which is 30 dm³...there is no need to convert it... 0,59/30 = 0,02...0,33/30 = 0,01...3,18/30 = 0,11...
7. From there we calculate K_c...K_c = $\frac{[\text{product}]}{[\text{reactant}]}$ = (2SO₂)²/(SO₂)²(O₂)
8. (0,11)/(0,02)(0,01)...
9. K_c = 60,5...

Interview

Researcher: how did you get the 3,18 here?

Morena: this one I used SO₂, this one (pointing at 1,59 which is the initial concentration of SO₂) and the ratio of it.

Researcher: its ratio is one therefore x multiply by the 3,18 (equilibrium concentration of the product) is equal to the 2 (the mole ratio of SO₃). What is x?

Morena: x is the used (amount) of SO₂ or O₂...

Researcher: where do you start from?

Morena: from here (pointing at the initial amount of SO₂ in the cell).

Researcher: even the first question you started from here.

Morena: yes

Researcher: why not from O₂?

Morena I'm used to starting from here

Researcher: always?

Morena: yes always.

Researcher; why do you always start from there?

Morena: because I know so.

Researcher: I realized one thing about your solution. There is an information in the problem statement that you ignored that is when equilibrium was reached, 94,3% of the Sulphur dioxide is converted to Sulphur trioxide. Why did you ignore this?

Morena: I'm not familiar with this information.

BRENDA (Low achiever)

Consider the following hypothetical reaction that takes place in closed 200 cm³ flask at 298 Kelvin. There, we have our reaction which is A₂ grams plus 2B₂ ehee grams... is equals to which is a reversible reaction 2AB₂. The graph represents the change in number of moles of each gas.... In the flak over a period of 20 minutes. Calculate the equilibrium constant, K_c for the reaction at 298 kelvin.

1. The reaction is... $A_{2(g)} + 2B_{2(g)} \rightleftharpoons 2AB_{2(g)}$ and then to calculate the K_c, I must have this

$$\text{formula... } K_c = \frac{[\text{Reactant}]}{[\text{Product}]} \dots$$

2. Then to find the used, I must use the table...[Drawing the table]... One, two, three ok...[Counting the number of reactants and products in the equation]... Here, we have A₂... And then 2B₂... here we 2AB₂...here we have initial mole...and here is used and formed... then here we have equilibrium mole... and here equilibrium constant... Oh nooo! Oh! concentrate...

$$c = \frac{v}{n} \text{ our initial mole for } A_2 \text{ is}$$

3. From the graph is 2,4...and for B₂ it will be hmmm...1,8....and for this one (2AB₂), it will be 0,2...

4. from here that is used and formed, we have...hmmm...eeh I'm stuck...from here I think we will have zero, here we have 2...and here we have 0,2, that is 200 cm³/1000 = 0,2...

5. and here I think it will be 0,2 but I'm not sure...

6. we have our volume divided by 2,4 that is 0,2/2,4 = 0,08...and here, 0,2/0,2 = 1...and here 0,2/1,8 = 0,11...

$$7. K_c = \frac{[\text{Reactants}]}{[\text{Products}]} = \frac{[A_2][2B_2]}{[AB_2]}$$

8. (0,8)(0,11)... I think I have to square because of this two... (0,8)(0,11)²/(1)²

9. (0,8) + (0,11)² ÷ (1)² [punching the calculator] the answer is 0,0921

Question 1.2

At 10 minutes, the temperature of the flask was increased. Determine if the product (production) of AB_2 is exothermic or endothermic.

1. At 10 minutes...The temperature of the flask...Was increased...
2. I think the reactions was exothermic.

Researcher: you see this one, you started by saying $K_c = \frac{[Reactants]}{[Products]}$. Are you really sure that this is correct

Brenda: the formula? I'm not sure.

Researcher: then why did you write it that way?

Brenda: I wrote it that way but I doubted it

Researcher: so what do you believe in?

Brenda: that it must be product over reactant.

Researcher: do you believe that?

Brenda: yes.

Researcher: then why didn't you write it that way?

Brenda: I will correct it

Researcher: if it were an exam this is what you would have submitted. When were you going to correct it?

Brenda: I was gonna go back and check.

Researcher: but you were continuing with the next question.

Brenda: yes, when I'm done also check before I submit my work.

Researcher: so you mean you finish solving all the questions before checking for mistakes?

Brenda: no, sometimes I leave what I don't know and continue with what I know first.

Researcher: I saw you put zero here.

Brenda: yes

Researcher: where does it come from?

Brenda: I'm not sure, I don't know, I just wrote it.

Researcher: then what about the initial concentration of B_2 ?

Brenda: hmmm 1,8

Researcher: where from the 1,8

Brenda: here

Researcher: how did you read the 1,8?

Brenda: the scale.

Researcher: how? Point where the 1,8 is on the scale

Brenda: here [pointing at where the label B₂ is place on the reactant B₂ curve]

Researcher: but can you see that this curve extend beyond B₂ and touches the mole axis at 2,0?

Brenda: hmhhh!

Researcher: did you notice that?

Brenda: no I didn't notice that.

Researcher: then what about the initial concentration of AB₂?

Brenda: I also used this one [pointing at where the label AB₂ is place on the reactant AB₂ curve]

Researcher: can you see that this graph starts at zero?

Brenda: yes.

Researcher: then why did you use this one?

Brenda: it's because of where AB₂ is located that is why I took this one.

Task 3

1. Ok... I first write the data...I have for Fe³⁺ 0,1 mol.dm⁻³... And for SCN⁻ is equal to 0,2 mol.dm⁻³...And for Fe(SCN)²⁺ is equal to 0,05 mol.dm⁻³...
2. And the formula is ... $K_c = \frac{[\text{product}]}{[\text{reactant}]}$ which is $[\text{Fe}(\text{SCN})^{2+}]/[\text{Fe}^{3+}][\text{SCN}^-]$...
3. which is 0,05/(0,1)(0,2)
4. which is equal to 2,5 I'm done.

Researcher: let's look at the data. Which concentrations are this? (Referring to the initial concentrations of Fe³⁺ and SCN⁻).

Brenda: it is the final concentrations

Researcher: let's consider the problem statement again (researcher reads the problem statement).

There are three different concentrations given. Which ones are for the beginning and which ones are the final?

Brenda: I don't know which ones are but I think they are final.

Researcher: which concentrations do we substitute into the K_c expression?

Brenda: what?

Researcher: which concentrations do we use in calculating the value of K_c?

Brenda: concentration?

Researcher: I mean is it the initial or equilibrium concentration?

Brenda: equilibrium

Researcher: that means these are all equilibrium concentrations?

Brenda: yes.

Researcher: what can you show from the problem statement that what you are saying is correct?

Brenda: at equilibrium the concentration of $\text{Fe}(\text{SCN})^{2+}$ is found to be.....but I considered everything to be at equilibrium.

Researcher: why

Brenda: (laughing) that's how I understand it..

Researcher: so what happened to the volumes given in the problem statement? I mean the 50 cm^3 , 30 cm^3 and 80 cm^3 ?

Brenda: what happened to these volume?

Researcher: yes I mean are they needed to be able to solve the problem?

Brenda: I don't think so because we already have the final concentrations.

Task 4

1. Ok, now I gonna use the table to calculate the K_c ...first we write the concentration here... 2SO_2 , O_2 , and 2SO_3 ...
2. Initial mole we have...1,59 for SO_2 , then we have... 0,855 for O_2 ...And for this one (SO_3), we have...
3. Ok...Used or formed we have....emmmm...I'm stuck....[silence]

PERCY (High achiever)

Task 1

1. the graph below represents the initial mole of A_2 ... is 2,4 mole and then 2,0 mole of B_2 and then the graph represents our product, and then it tells us that our initial mole of the product is Zero (0) mole because when we are starting the reaction, our product is not yet formed. Then when we are looking here, the question says calculate the equilibrium constant for this reaction.
2. First of all we need to draw a table ... that will show the ... start moles ... start moles ... of the reaction... our reaction is $\text{A}_2 + 2\text{B}_2 \rightleftharpoons 2\text{AB}_2$ produces 2AB_2 This one is a gas, this one is a gas, and this one is a gas.
3. Emm since...we are having the number of moles...Initial mole of A_2 ... in the graph... we will say is 2,4 mole...and then we are having...2,0...mole of B_2 ...and then our graph tells us that the initial mole of AB_2 is zero mole...

4. and then we have to find our used or produced...mole...for this reaction...and then we calculate the equilibrium mole...
5. and our aim for calculating this using a table is to find the equilibrium concentrations of reactants and products in order for us to calculate the value of K_c . We need the equilibrium concentrations...concentration...equals to n over v (n/v), at the value of 200cm^3 ...and then...er...
6. the graph shows us that after ...er 5 minutes is the graph has reached equilibrium... and then the new number of moles of A_2 is now 2,0 mole and then ...the new number of moles at equilibrium is...1,2 mole for B_2 ...and then our product formed is 0,8mole...
7. since we are having the equilibrium moles, there is no need to calculate the used or produced moles, therefore we can calculate the equilibrium concentration using the equilibrium mole.
8. er since we are having the number of moles at equilibrium...er we can calculate the concentration $c = n/v$...and then our number of moles is 2,0 divided...er when we are calculating equilibrium constant, we are using cubic decimeters, therefore we have to convert this volume to dm^3 . We have to say $2000 \div 1000$... and then you get 0,2. And then $2 \div 0,2$ gives us $10\text{mol}\cdot\text{dm}^{-3}$. And then here, $c = n/v$, number of moles (1,2) $\div 0,2$...we are getting [punching the calculator] $6\text{mol}\cdot\text{dm}^{-3}$. And then for the product formed, is equals to n/v ... number of moles is $0,8 \div 0,2$...[punching the calculator] then we get $4\text{mol}\cdot\text{dm}^{-3}$.
9. Then from here, K_c is always...the concentration of the product which is... AB_2 square over A_2 multiply by B_2 square ($[AB_2]^2/[A_2][B_2]^2$).
10. And then we substitute our concentration which is $4^2/10 \times 6^2$,
11. and then from here we can use our calculator is... $4^2/10 \times 6^2$ [punching the calculator] and then we are getting 0,04... since K_c doesn't have a unit we will have to write our final answer like this.

Task 2

1. And then question 1.2...they say at 10 minutes, the temperature of the flask was increased. Determine if the production of AB_2 is endothermic or exothermic.
2. An increase...an increase...in temperature...always...favours the endothermic reaction...
3. and which in this case is the forward reaction...
4. and then since we know that our favoured reaction is endothermic and it is forward,
5. the concentration of A_2 and B_2 will decrease since the concentration of AB_2 increases.

Task 3

1. Ok...we are having the equilibrium...the equilibrium...the equilibrium concentration... [drawing table] and then this is the Fe^{3+} ...eish...plus I made a mistake...and SCN^- ...and this reaction is reversible...is... $\text{Fe}(\text{SCN})^{2+}$...
2. and then we are given the concentration of the product formed... is $0,05 \text{ mol} \cdot \text{dm}^{-3}$.
3. Since we are given the concentration of the product at equilibrium...er we can find...this one is at equilibrium. We can find the used...or...produced...equilibrium...it means our initial equilibrium is zero...and the used or formed is $0,05 \text{ mol} \cdot \text{dm}^{-3}$, and then we compare the mole ratio...is 1:1:1, that means here will be $0,05 \text{ mol} \cdot \text{dm}^{-3}$ and then is $0,05 \text{ mol} \cdot \text{dm}^{-3}$...
4. and then since were are having $0,05 \text{ mol} \cdot \text{dm}^{-3}$ used or produced, they gave us the initial concentration of ... $0,1 \text{ mol} \cdot \text{dm}^{-3}$ of the reactant...and $0,2 \text{ mol} \cdot \text{dm}^{-3}$ so we are looking for the equilibrium concentration, we substitute this from that and then we get the equilibrium concentration, and then it is $0,1 - 0,05$...it gives me $0,05 \text{ mol} \cdot \text{dm}^{-3}$...and then $0,2 - 0,05$...gives me...and then is $0,15 \text{ mol} \cdot \text{dm}^{-3}$...
5. and then since we are having the equilibrium concentrations, we can calculate the value of $K_c = \frac{[\text{Fe}(\text{SCN})^{2+}]}{[\text{Fe}^{3+}] [\text{SCN}^-]}$ multiply by $[\text{SCN}^-]$...
6. and then we substitute our equilibrium concentrations and then we say $(0,05)/(0,05)(0,15)$.
7. And from here I'm using a calculator...is $0,05$ over... $0,05$...multiply by $0,15$...and then a get $6,67$... K_c doesn't have a unit...and then my answer for the equilibrium constant is ... $6,67$.

Task 4

1. and then it means that we are drawing our table...and then start mole...the reaction is as follows, $2\text{SO}_2 + \text{O}_2$ produces 2SO_3
2. and then our start mole... we have been given, that is... $1,59 \text{ mol}$ of SO_2 ...and then $0,855 \text{ mol}$ of O_2 and then...our product is not yet formed, it's zero mol...and then here will be used or produced...mol...and then...equilibrium concentration...is equal to n/v ...and then the volume is 30 dm^{-3} ...
3. and then they told us that at equilibrium, $94,3\%$ of SO_2 is converted to SO_3 and that means that moles of SO_3 at equilibrium is $94,3$ divided by 100 ...multiply by $1,59$ and then... $94,3 \div 100 \times 1,59 = 1,5 \text{ mol}$ of SO_3 at equilibrium...and here will be $1,5 \text{ mol}$...
4. and then we compare the mole ratio...is 2:2 that means here is $1,50 \text{ mol}$...and then 1:2...that we divide the number of moles by two and then we get $0,75 \text{ mol}$

5. and then equilibrium moles we subtract the produced moles from the start moles, it will be 1,59 – 1,5, which gives 0,09 mol of SO₂ at equilibrium and then 0,855 – 0,75 and then we get 0,105mol of SO₂ at equilibrium
6. and then since we are having the equilibrium mole, we can calculate the equilibrium concentration which says $c = n/v$, and then number of... is 0,09...since we are given the volume in dm⁻³, there is no need to convert... $0,09/30 = 3 \times 10^{-3} \text{ mol.dm}^{-3}$...and then we calculate the concentration of O₂ at equilibrium is 0,105/30 and then we find that it is $0,105 \div 30$...and then we find that it is $3,5 \times 10^{-3} \text{ mol.dm}^{-3}$
7. and then we calculate the concentration of SO₃, we are having the equilibrium mole of $1,5 \div 30$ and then this one will give us 3...will give eerh...[punching $1,5 \div 30$ on the calculator] which is 0,05mol.dm⁻³.
8. and then from here we can calculate the value of $K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2}$ multiply by [O₂]
9. and then we substitute the equilibrium concentration of reactants and products...for the product is $(0,05)^2 / (3 \times 10^{-3})^2 (3,5 \times 10^{-3})$...
10. from here we are using our calculator is $0,05 \div 3 \times 10^{-3}$ and then $3,5 \times 10^{-3}$
11. ooh! we have to square here...[squaring SO₂ concentration in the formula] and then we find that our K_c...let me check if there is some mistake... $1,59 - 1,50$...I'm getting 0,09 its correct, the equilibrium concentration is $0,09 \div 30$ and then I get this... it's correct and then let me check if here I'm correct, $0,855 - 0,75$ which is 0,105 which is correct.... and then I add this, and then $1,50 \div 30$ I'm getting 0,05
12. and it means that $0,05^2 \div [(3 \times 10^{-3})^2 \times 3,5 \times 10^{-3}]$ and then we get 79 365,08.

CARREN (High achiever)

Task 1

1. before I go to the question, I will have to study the graph and see how the reactants and products are, the moles of reactants and products. During the start, the moles of the reactants initially for A₂ is 2,4 mole and for the B₂ is 2,0 mol, then for the AB₂ is zero because it is in the start. So when they reacted after five minutes, they reach equilibrium where we have the moles f A₂ to be 2,0 and the moles of B₂ to be 1,2, so the moles of AB₂ is 0,8 mol. The temperature it seems...it was increased (at 10 minutes) and an increase in temperature favoured the forward reaction which caused the graph to increase for the reactant, for the product...er...No! not the reactant for the product, the product moles have increase so, now, it has reached another equilibrium

after 15 minutes and equilibrium moles for A_2 is 1,6, for the B_2 is now 0,6, and for the AB_2 is at 1,4 mol. Now I will have to look at the question, calculate the equilibrium constant K_c for this reaction at 298 kilopascal.

2. so I have to set up my table, the table will have a block for each reactant and product...so this is at the start, initially, here is our reactant, A_2 which is in gas plus $2B_2$, which is also in gas to form a reversible reaction which is $2AB_2$, also in gaseous phase,
3. so from the graph our initial moles is 2,4 for the A_2 ...then I will have to write 2,4 mol, then for the B_2 is 2,0... 2,0 mol, then for the AB_2 is 0 mol, then we go to column number two, which is either produced or used...you don't know how many moles are being produced, you go to the equilibrium...
4. At equilibrium, for the A_2 we have 2,0 mol...and for the B_2 we have 1,2 mol, and for the AB_2 we have 0,8 mol...
5. to get our moles which are being used or produced, we have to subtract the smaller one from the bigger one. Then for the A_2 we say, $2,4 - 2,0$, then we get 0,4 mol which is being used from A_2 which is in gaseous phase, and for the B_2 , $1,2 - 2,0$...No! I made a mistake it's $2,0 - 1,2$ and we get 0,8. So for the product which is the $2AB_2$, the moles because we have to add here, it is 0 plus a number which must give us 0,8, and we know any number which we can add to zero to give us 0,8 is the same as 0,8 mol.
6. So...here we have our concentration at equilibrium. To get our concentration is $c = n/v$ and the volume that we are given is in cubic centimeter, that means we have to change it to cubic decimeter. $V = 200/1000$ and then $200 \div 1000$...we get $0,2\text{dm}^3$. So we will have to calculate the concentration of A_2 ...the concentration which is n/v , 2,0, we take mole that are in equilibrium for the A_2 and divide it by 0,2 to get $2,0/0,2$...[punching the calculator] which means this is $10\text{ mol}\cdot\text{dm}^{-3}$. And we go for the B_2 . B_2 we use the same formula and it is 1,2, this is our number of mole divided by the volume which is...0,2 and you get $1,2/0,2$...you get $6\text{ mol}\cdot\text{dm}^{-3}$...and we go to our product and use the mole at equilibrium, which is 0,8 divided by 0,2... $0,8 \div 0,2$ we get $4\text{ mol}\cdot\text{dm}^{-3}$.
7. So to get our equilibrium constant, we have to use the concentration at equilibrium. And the K_c = the concentration of the product which is AB_2 , because of the two here we have to make it a square and put it here divided by the concentration of the reactants A_2 ...the reactant, we have to multiply by B_2 square...[writing $K_c = [AB_2]^2/[A_2][B_2]^2$.
8. Then the concentration for the product is $= (4)^2 / (10)(6)^2$

9. which is $4^2 \div 10 \times 6^2 = 0,044$.

Task 2

1. The questions says at 10 minutes, 10 minutes is here, the temperature was increased, meaning the temperature is being increased so determine if the production of AB_2 is exothermic or endothermic.
2. When you look at this graph, this temperature is being increased and the number of moles of AB_2 has increased also
3. so an increase in temperatures favours the endothermic reaction...
4. so when we look at this graph, the forward reaction is being favoured so we have to include it...which is the forward reaction.
5. Therefore the production of AB_2 is endothermic.

Task 3

1. Ok, I will have to draw my table again, the table...so here I put my reactants which is Fe^{3+} ...and SCN^- ... to form... $Fe(SCN)^{2+}$...so...
2. initially, er start...there was...0,1mol of Fe^{3+} which we put it here $0,1 \text{ mol.dm}^{-3}$ and is added to 30cm^3 of $0,2 \text{ mol.dm}^{-3}$ of SCN^- which is $0,2\text{mol.dm}^{-3}$ and at equilibrium...meaning here is zero. At equilibrium, the concentration of $Fe(SCN)^{2+}$ is found to be 0,05 mol. The table continues here, here is either used or produced...
3. then we go to the equilibrium...so at equilibrium they say is 0,05mol of $Fe(SCN)^{2+}$, so we put it here...[here referring to the cell corresponding to equilibrium concentration of $Fe(SCN)^{2+}$] $0,05\text{mol.dm}^{-3}$...so here if it is $0,05\text{mol.dm}^{-3}$ plus zero, here it will also be $0,05\text{mol.dm}^{-3}$.
4. So to get the moles used for the reactants we will use the ratio and the ratio is 1:1:1 meaning it will be the same for the...for the concentration that was being used. Since the ratio is 1:1:1 is also $0,05\text{mol.dm}^{-3}$, and $0,05\text{mol.dm}^{-3}$.
5. So to get the equilibrium mole we say $0,1 - 0,05$ and it is $0,05 \text{ mol.dm}^{-3}$. Again, $0,2 - 0,05$ is $0,15\text{mol.dm}^{-3}$.
6. And we have it here, so this one is the same as the concentration at equilibrium so there is no need for me to add the column for concentration at equilibrium since it is the same.
7. So I go straight to my Kc formula which is the product...which is $Fe(SCN)^{2+}$ divided by...the reactant which is Fe^{3+} multiply by Oh! Concentration of eish! I'm making a mistake again, concentration of SCN^- .

8. So I take this concentration, it is in concentration, all of it here; I use this concentration...0,05 over 0,05 multiply by 0,15...
9. then I punch the calculator, $0,05 \div 0,05 \times 0,15$...my Kc value is 6,67 and it doesn't have a unit, then the question was looking for equilibrium constant which is Kc then I'm done with question number two.

Task 4

1. So... I introduce my table again...table in a start for the reactant is SO₂...which is in gaseous phase plus O₂...which is also in gaseous phase to produce 2SO₃ in gaseous phase...I divide my table...
2. so they say that it was 1,5 mol of SO₂ in the start so I write 1,59moles of SO₂ and 0,855mol of oxygen, which is 0,855mol of oxygen. So for the product, it is 0mol during the start.
3. Then we go to moles used or produced...the moles used or produced we don't know, we skip this one and then go to at equilibrium...equilibrium. So they said that when equilibrium is reached, it is found that 94,3% of Sulphur dioxide is converted to Sulphur trioxide meaning 94,3% is converted to 2SO₃...and it is at equilibrium, so we say $94,3/100$ because every percent means divided by hundred, then multiply by 1,59 of the Sulphur dioxide ... $94,3 \div 100 \times 1,59 = 1,49937$,
4. so since we have the number of moles for the product, we can use it to find for the reactant. So this one will go here like this...1,49937 Oh! I have to round off this one...yea, let me write 1,5...1,5, I can also write 1,5 because this number is big and it is going to complicate things. So to get the number of moles used for the reactant, we use the ratio, the ratio says 2:1:2 meaning 2 of the SO₃ to get this one 2 divided by 2 time 1 and you get 1, meaning you have to say 1,5 divided by 2 and multiply by this ratio here which is $1 \dots 1,5 \div 2 \times 1$ is 0,75...and since here is 2:2 I can also write 1,5...which is the same,
5. so to get the equilibrium mol, $1,59 - 1,5$...which is 0,09...and then here is $0,855 - 0,75$ which is 0,105...
6. so since Kc...to calculate we need the concentration, so the concentration...at equilibrium...we are given that...the volume is 30dm³ and the formula for concentration is $c = n/v$, so I will say $0,09/30$ and then $0,105/30$, and then $1,5/30$... $0,09 \div 30$ is 3×10^{-3} and $0,105 \div 30 = 3,5 \times 10^{-3}$...and $1,5 \div 30$ is 0,05...I have my concentration at equilibrium
7. then I can be able to calculate my Kc...is equal to...product...concentration of the product, SO₃...squared...because of this 2 in front and then divided by concentration of the reactant

which is SO_2 square... and O_2 ...eish! I will have to write the unit...I forgot to write this one and I'm totally wrong if I leave it like this...mol...mol...

8. so I use this concentration...which is $0,05$...squared over 3×10^{-3} squared multiply by $3,5 \times 10^{-3}$...
9. I will use my calculator to find $K_c = 0,05^2 \div (3 \times 10^{-3})^2 \times (3,5 \times 10^{-3})$, then I get $79365,08$. This is my K_c and I'm done with question number three.

MSHELE (High achiever)

Task 1

1. from the graph, I have the initial moles and the equilibrium moles so
2. I will first draw the table...first I will have to start with the start moles...then the used moles, the equilibrium moles...and the concentration...then I have A_2 gas...plus... 2B_2 which produces 2AB_2 .
3. Then initially, I have $2,4$ mol of A_2 ...then I have $2,0$ mol of B_2 ...and 0 mol of AB_2 ...
4. then I was given the equilibrium mole.. of A_2 which is...I have to read from the graph, $2,0$...then B_2 is... $1,2$...then AB_2 $0,8$...
5. to get the used moles, because here I have zero, then I have to add this one to get the used, I will say zero plus $0,8$ will give me $0,8$. And then this one initially it is $1,8$ and at equilibrium it is $1,2$ then I have to say $2,0 - 1,2$ which will give me $0,8$ mol...then here I have $2,4$...as start mole and at equilibrium it is $2,4$, I have to say $2,4 - 2,0$ which will give me $0,4$ mol...
6. then the concentration is $c = n/v$... then I have to see if I'm given the volume...Oh! The volume is 200cm^3 . I have to convert it to dm^3 ...it's $200 \div 1000$; it will give me $0,2\text{dm}^3$ Then here it will be number of moles which is $2,0$ divided by the volume, 2 , it will give me $1\text{mol}\cdot\text{dm}^{-3}$. And then here I will have $1,2$ divided by the volume ...Ooh! Sorry I made a mistake, $2,0 \div 0,2$ it will give me 10 , and then $1,2 \div 0,2$ it will give me $6\text{mol}\cdot\text{dm}^{-3}$...and then $0,8$ divided by $0,2$... $0,8 \div 0,2$...it will give me $4\text{mol}\cdot\text{dm}^{-3}$... then I have the equilibrium concentration,
7. then it means I can calculate the K_c ...the formula for K_c is K_c is equal to the product which is ...the concentration of the product is $[\text{AB}_2]$, because the ratio here is 2 , then I will have to square this numbers...divided by the concentration of the reactants is $[\text{A}_2]$ times the concentration of $[\text{B}_2]$ squared, the ratio here is also 2 ...
8. then I substitute the product is 4^2 divide by A_2 is 10 and then B_2 is 6^2

9. then I will punch the calculator $4^2 \div 10 \times 6^2$ is 0,04. The K_c has no unit so I will leave it like this.

Task 2

5. At 10 minutes, the temperature of the flask was increased. Determine whether the production of AB_2 is exothermic or endothermic.
6. When reading from the graph... AB_2 is increasing and the temperature was increased.
7. Increase in temperature favours the endothermic reaction
8. which in this case is the forward reaction because products are increasing.
9. That means the production of AB_2 is endothermic.

Task 3

1. I will first draw my table... before I start. It is one, two, three (counting the number of reactants and products). I have Fe^{3+} ...plus... SCN^- ...which produces $Fe(SCN)^{2+}$ ion...because I'm given the concentration there is no need for me to write the moles...I will just say start...concentration...and the used...concentration...
2. Initially from the statement I have $0,1\text{mol}\cdot\text{dm}^{-3}$ of Fe^{3+} ...[writing $0,1\text{mol}\cdot\text{dm}^{-3}$] I also have $0,2\text{mol}\cdot\text{dm}^{-3}$ of this...[writing $0,2\text{mol}\cdot\text{dm}^{-3}$], and initially I have $0\text{mol}\cdot\text{dm}^{-3}$ of the product.
3. And then I was given the equilibrium concentration of the product...which is $0,05\text{mol}\cdot\text{dm}^{-3}$...[writing $0,05\text{mol}\cdot\text{dm}^{-3}$ in the appropriate cell]. To get this I have to add because here we are adding it is 0 plus 0,05, and it give me $0,05\text{mol}\cdot\text{dm}^{-3}$.
4. The ratio here is 1:1:1, that means this times 1 divided by 1, it will give me $0,05\text{mol}\cdot\text{dm}^{-3}$ and here the ratio is 1:1, it will also give me the same answer which is $0,05\text{mol}\cdot\text{dm}^{-3}$...
5. To get the equilibrium concentration, I will just say 0,1 minus the used concentration which is $0,01 - 0,05$...which will give me Ooh! $0,1 - 0,05$ will give me 0,04...and then $0,2 - 0,...$ Ooh!... $0,01, 0,04$ it is 0,05. Then $0,2 - 0,05$...it will give me 0,15...
6. Then I have the concentration, I can calculate the K_c K_c is equals to product which is $Fe(SCN)^{2+}$...the ratio is 1:1 so...divided by the reactants which is $[Fe^{3+}]$ times the concentration of $[SCN]$
7. It will be equal to 0,05 divided by 0,05 times 0,15.
8. Then I will press the calculator... $0,05 \div 0,05 \times 0,15$...it will give me 6,67...

Task 4

1. I will draw my table first...and then I'm given... 2SO_2 plus oxygen which produces 2 sulphur trioxide...I have the start mol...the used mol...the equilibrium mol and the equilibrium concentration.
2. Form the statement, I was given the initial moles of sulphur dioxide which is 1.59mol...and then I was also given the initial moles of oxygen which is 0,855mol...then the product is 0mol.
3. From the statement, they said when equilibrium is reached it is found that 94,3% of sulphur dioxide is converted to sulphur trioxide. That means to get the equilibrium concentration for the sulphur trioxide...I will say 94,3 over 100 times the initial moles of sulphur dioxide which is 1,59mol...1,59...and I press the calculator, $94,3 \div 100 \times 1,59$...it will give me 1,5mol. At equilibrium, the sulphur trioxide mol is 1,5
4. Then I add this one, it will give 1,5mol. Because the ratio is 2:1 to get the used moles I have to divide this, or I can simply say 1,5 times 1 divided by this... then it is... $1,5 \times 1 \div 2$ which is 0,75. The ratio here is 2:1 but then from here I have the ratio which is 2:2, that means the used moles of this is equals to this, I will say 1,5.
5. Then to get the equilibrium moles, it is 1,59 minus the used moles...is $1,59 - 1,5$... it will give me 0,09 and then $0,855 - 0,75$, it will give me 0,105, and
6. Then I have to find the concentration, I was given the volume which is 30dm^3 , then I will say 0,09 divided by 30 ($0,09 \div 30$) it will give me $3 \times 10^{-3}\text{mol}\cdot\text{dm}^{-3}$. And then 0,105 divided by 30 ($0,105 \div 30$), it will give me $3,5 \times 10^{-3}\text{mol}\cdot\text{dm}^{-3}$. And then 1,5...we divide by 30...it will give me 5×10^{-2} , then I have my concentration,
7. Then I can write K_c is equal to the concentration of Sulphur trioxide square divided by Sulphur dioxide square times concentration of oxygen
8. which will be equal to $(5 \times 10^{-2})^2$ divided by $(3 \times 10^{-3})^2$ times $3,5 \times 10^{-3}$
9. equals to 5 times 10 to the power negative 2 square $(5 \times 10^{-2})^2$ divided by 3 times 10 to the power negative 3 square $(3 \times 10^{-3})^2$ times...oh! It's [repeating the operation on the calculator after pressing a wrong key on the calculator] 5 times 10 to the power negative 2 square divided by...3 times 10 to the power negative 3 square times 3.5 times 10 to the power negative 3 equals to 79 365,78 then the K_c is found

APPENDIX 5.3: RUBRIC FOR EVALUATING STUDENTS' METACOGNITIVE ACTIVITIES

Behavior	1 = Unacceptable	2 = Low	3 = High
Task 1			
Interpreting graph	No evidence of graph interpretation	Interpretation of graph with reference to initial moles only	Interpretation of graph with reference to initial and equilibrium moles
Justifying choice of strategy	No evidence of justification of choice of strategy	Comments indicating a strategy is selected	Comments indicating a strategy is selected with reasons
Reading equilibrium moles from graph	Failure to read equilibrium moles from graph	Equilibrium moles read from graph with some errors	Equilibrium moles read from graph accurately
Calculating equilibrium concentration	No calculation of equilibrium concentrations	Equilibrium concentrations calculated with some errors	Equilibrium concentration calculated accurately
Setting up Kc expression	No Kc expression	Kc expression given with some errors	Kc expression given accurately
Substitution of values into Kc expressions	No substitution into Kc expression	Substitution into Kc expression with some errors	Substitution into Kc expression accurately
Calculating Kc value	No calculation of Kc value	Kc value calculated with errors	Kc value calculated accurately

Task 2			
Activating prior knowledge	No prior knowledge activated	Attempted activation of prior knowledge	Successful activation of prior knowledge
Interpretation of graph	No evidence of graph interpretation	Attempted interpretation of graph without success	Complete interpretation of graph with reference to changes in moles of substances
Task 3			
Justifying choice of strategy	No evidence of justification of choice of strategy	Comments indicating a strategy is selected	Comments indicating a strategy is selected with reasons
Determination of initial moles	No evidence of determining initial moles	Initial moles determined with errors	Initial moles determined accurately
Using mole ratios to deduce change moles	Failure to use mole ratio to determine change moles	Mole ratios used to determine change moles with errors	Mole ratios used to determine change moles accurately
Determining equilibrium moles	No determination of equilibrium moles	Determination of equilibrium moles with errors	Determination of equilibrium moles with errors
Calculating equilibrium concentration	No calculation of equilibrium concentrations	Equilibrium concentration calculated with some errors	Equilibrium concentration calculated accurately

Setting up Kc expression	No Kc expression	Kc expression given with some errors	Kc expression given accurately
Substitution of values into Kc expressions	No substitution into Kc expression	Substitution into Kc expression with errors	Substitution into Kc expression accurately
Calculating Kc value	No calculation of Kc value	Kc value calculated with errors	Kc value calculated accurately
Task 4			
Justifying choice of strategy	No evidence of justification of choice of strategy	Comments indicating a strategy is selected	Comments indicating a strategy is selected with reasons
Using mole ratios to deduce change moles	Failure to use mole ratio to determine change moles	Mole ratios used to determine change moles with errors	Mole ratios used to determine change moles accurately
Determining equilibrium moles	No determination of equilibrium moles	Determination of equilibrium moles with errors	Determination of equilibrium moles with errors
Calculating equilibrium concentration	No calculation of equilibrium concentrations	Equilibrium concentration calculated with some errors	Equilibrium concentration calculated accurately
Setting up Kc expression	No Kc expression	Kc expression given with some errors	Kc expression given accurately
Substitution of values	No substitution into Kc	Substitution into	Substitution into

into Kc expressions	expression	Kc expression with some errors	Kc expression accurately
Calculating Kc value	No calculation of Kc value	Kc value calculated with errors	Kc value calculated accurately



Private Bag X6001, Potchefstroom
South Africa 2520

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

Faculty of Education Sciences

APPENDIX 5.4: CHEMICAL EQUILIBRIUM METACOGNITIVE SKILLS QUESTIONNAIRE

This questionnaire has a number of questions about your usual way of solving chemical equilibrium problems. There is ***NO RIGHT*** way of solving chemical equilibrium problems. It depends on what suits your own style and the chemical equilibrium concept you are studying. It is accordingly important that you answer each question as **HONESTLY** as you can. The letters alongside each number stand for the following response:

- A—this item is *never* or *only rarely* true of me
- B—this item is *sometimes* true of me
- C—this item is true of me about *half the time*
- D—this item is *frequently* true of me
- E—this item is *always* or *almost always* true of me

Please choose the *one* most appropriate response to each question by making a [×] mark on the letter that corresponds to it.

Do not spend a long time on each item: Your first reaction is probably the best one. Please answer each item. Do not worry about projecting a good image. Your answers are **CONFIDENTIAL**.

Surname..... Name

Age Gender: Male [] Female []

1	When I solve problems in chemical equilibrium, I try to relate the problems that are new to me with problems I have previously solved.	A	B	C	D	E
2	When I solve chemical equilibrium problems, I think deeply upon ideas or skills and the methods I know that are in connection with the problem.	A	B	C	D	E
3	When I solve chemical equilibrium problem I read the problem statement carefully several times until I understand what the problem requires me to do	A	B	C	D	E
4	When I solve chemical equilibrium problems, I identify key words in the problem statement and make sure I understand them	A	B	C	D	E
5	When I solve assigned questions in chemical equilibrium, I try to make sure I understand the ideas behind so that I can apply this ideas to test questions.	A	B	C	D	E
6	When I solve chemical equilibrium problems, I clearly identify the goal of a problem (unknown variable to solve for or the concept to be defined) before attempting a solution.	A	B	C	D	E
7	When I solve problems in chemical equilibrium, I sort out the information in the problem statement and determine what	A	B	C	D	E

	information is useful for solving the problem.					
8	When I solve chemical equilibrium problems, I consider what information is needed that might not be given in the statement of the problem.	A	B	C	D	E
9	When I solve chemical equilibrium problems, I plan how to solve a problem before I actually start solving it (even if it is a brief mental plan).	A	B	C	D	E
10	When I solve chemical equilibrium problems, I experience moments of insight and creativity (for example feeling of 'Ahaa!! ok I got it now, I was messing up at first!')	A	B	C	D	E
11	When I solve chemical equilibrium problems, I find important relations among the quantities, variables, or concepts involved before trying a solution	A	B	C	D	E
12	When I solve chemical equilibrium problems, I experience a feeling of anxiety	A	B	C	D	E
13	When I solve chemical equilibrium problems, I experience a feeling of being not sure with my solution to the problem	A	B	C	D	E
14	When I solve chemical equilibrium problems, I experience a feeling of frustration with the problem.	A	B	C	D	E
15	When I solve chemical equilibrium problems, I experience a feeling of difficulty with the problem	A	B	C	D	E
16	When I solve chemical equilibrium problems, I use diagrams or flow-charts or sketches or tables to better understand problems.	A	B	C	D	E
17	When I solve a chemical equilibrium problem, I think about different approaches and then select the best approach for that problem	A	B	C	D	E
18	When I solve chemical equilibrium problems, I make a sketch of	A	B	C	D	E

	the problem in order to represent the problem					
19	When I solve chemical equilibrium problems, I think about misconceptions or the wrong ideas people have about the concepts in the problem	A	B	C	D	E
20	When practicing how to solve chemical equilibrium problems, if a problem takes several attempts and I cannot get it right, I show it to my friends and we solve it together	A	B	C	D	E
21	When I solve chemical equilibrium problems, I organize the solution into several steps.	A	B	C	D	E
22	If a chemical equilibrium problem involves several calculations, I make those calculations separately and check the intermediate answers to see if they are correct.	A	B	C	D	E
23	When I solve problems in chemical equilibrium, I check my answers by reworking the problem	A	B	C	D	E
24	When I solve problems in chemical equilibrium which involves calculations, I try to make a rough estimate of the answer first before proceeding with the calculation.	A	B	C	D	E
25	When I solve chemical equilibrium problems, I make sure that my solution actually answer the question by checking through and cross-checking for mistakes I might have made.	A	B	C	D	E
26	If I do not know exactly how to solve a chemical equilibrium problem, I immediately try to guess the answer.	A	B	C	D	E
27	When I solve chemical equilibrium problems, I do not check that the answer makes sense.	A	B	C	D	E
28	Once I know how to solve a type of chemical, equilibrium problem, I do not spend time in understanding the concepts involved.	A	B	C	D	E

29	When I solve chemical equilibrium problems, I do not think of concepts involved before attempting a solution.	A	B	C	D	E
30	When practicing how to solve chemical equilibrium problems, if a problem takes several attempts and I cannot get it right, I leave it.	A	B	C	D	E
31	Once I start solving a chemical equilibrium problem, I continue straight to the end without going back to the problem statement to verify whether I have made a mistake	A	B	C	D	E
32	I start solving chemical equilibrium problems without reading all the details of the question.	A	B	C	D	E



NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

Private Bag X6001, Potchefstroom
South Africa 2520

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

Faculty of Education Sciences

APPENDIX 5.5: CHEMICAL EQUILIBRIUM ACHIEVEMENT TEST

DURATION

2 HOURS

INSTRUCTIONS

Question 1.1 – 1.22 consist of **TWO -TIE** multiple choice questions. Each question is followed by **FOUR** or **FIVE** options labelled A, B, C D and E. An option 'I don't know the answer' has been included in order to avoid **GUESSING**. For each question, choose the

CORRECT answer and give a reason for your choice in the spaces provided on your answer sheet. Circle the appropriate letters on your answer sheets

1.1 The following hypothetical reaction reaches equilibrium at 25°C: (2)

A(g) + B(g) ⇌ C(g) + D(g) . Once equilibrium has been reached, the concentration of C is increased by the addition of more C. Assume that the **temperature remains constant**. Which of the following can be said about the value of the equilibrium constant, K_c ? It will:

- A Decrease
- B Increase
- C Remain the same
- D I don't know

Reason.....

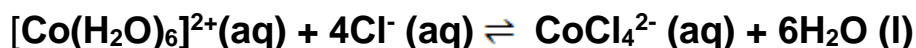
1.2 Limestone decomposes to form quicklime and carbon dioxide as follows: (2)

CaCO₃(s) ⇌ CaO(s) + CO₂(g). Which reaction will be favoured after removing some solid CaCO₃ from the equilibrium mixture?

- A Forward reaction
- B Reverse reaction
- C None of them is favoured
- D I don't know

Reason.....

1.3 Consider the following reversible reaction that is in a state of equilibrium in a blue solution: (2)



pink

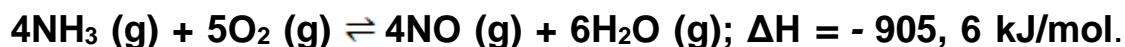
blue

What will be observed if water is added to this system?

- A the solution turns pink
- B the solution becomes more blue
- C the solution remains unchanged
- D I don't know

Reason.....

- 1.4 In the first step of the Ostwald process for the synthesis of nitric acid, (2)
ammonia is oxidized to nitric oxide by the reaction:



How does the equilibrium constant vary with an **INCREASE** in temperature?

- A Decreases
- B Increases
- C Remains unchanged
- D I don't know

Reason

- 1.5 Sulphur dioxide and oxygen react to form sulphur trioxide in the following (2)
reaction: $2\text{SO}_2 (\text{g}) + \text{O}_2 (\text{g}) \rightleftharpoons 2\text{SO}_3 (\text{g}); \Delta H = - 197, 78 \text{ kJ/mol.}$

What can we say about the forward reaction rate compared with the reverse reaction rate if a **catalyst** is added to system?

- A Higher
- B Lower
- C The same

D I don't know

Reason.....

- 1.6 Suppose that **0,30mol PCl₅** is placed in a reaction vessel of volume **1dm³** and (2)
allowed to reach equilibrium with its decomposition products: phosphorus
trichloride and chlorine at **250°C**, when **K_c = 1.8** for



What can we say about the concentration of the **PCl₃** gas and **Cl₂** gas at
equilibrium?

- A higher than 0.30mol/dm⁻³
B lower than 0.30mol/dm⁻³
C equal to 0.30mol/dm⁻³
D I don't know

Reason

- 1.7 Calcium carbonate decomposes to form calcium oxide and carbon dioxide (2)
according to the equation: **CaCO₃(s) + heat** \rightleftharpoons **CaO(s) + CO₂(g)** After
the system reaches equilibrium in a closed container, extra **solid CaCO₃** is
added to the equilibrium mixture. What will happen to the concentration of
carbon dioxide after addition?

- A Increase
B Decrease
C Remains unchanged
D I don't know

Reason.....

- 1.8 Carbon monoxide reacts with oxygen to form carbon dioxide in accordance (2)

with following reaction.

$2\text{CO}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{CO}_2(\text{g}); \Delta H = - 566 \text{ kJ/mol}$. Suppose that you have a reaction vessel containing an equilibrium mixture of **$[\text{CO}] = 0,30 \text{ mol/dm}^{-3}$** , **$[\text{O}_2] = 0,20 \text{ mol/dm}^{-3}$** and **$[\text{CO}_2] = 0,25 \text{ mol/dm}^{-3}$** . What will happen to the concentration of CO_2 if a **catalyst** is added while the system is at equilibrium?

- A will be higher than 0,25
- B will be lower than 0,25
- C will be equal to 0,25
- D I don't know

Reason.....

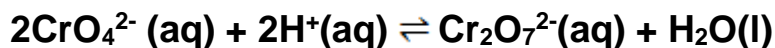
1.9 Consider the gaseous reaction of hydrogen with iodine; (2)

$\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$. Suppose that we have a mixture of **$\text{H}_2(\text{g})$** and **$\text{I}_2(\text{g})$** at 700°C with the initial concentrations **$[\text{H}_2] = 0,1 \text{ mol/dm}^{-3}$** and **$[\text{I}_2] = 0, 2 \text{ mol/dm}^{-3}$** . When the system reaches equilibrium, the numerical value of equilibrium constant equals, **$K_c = 57.0$** . If the initial concentrations is changed to **$0, 3 \text{ mol/dm}^{-3} \text{ H}_2$** and **$0, 3 \text{ mol/dm}^{-3} \text{ I}_2$** , what would you say about the value of K_c when the system reaches equilibrium at the same temperature?

- A Increases
- B decreases
- C Remain the same
- D I don't know

Reason.....

- 1.10 If you have a **0,5mol/dm⁻³** solution of sodium dichromate (**Na₂Cr₂O₇**) in which (2)
the following equilibrium is established



yellow

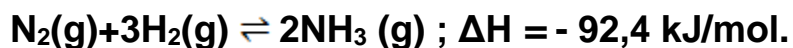
orange

and you add **10cm³ of 0,5mol/dm⁻³** solution of sodium dichromate to the original solution, what would you observe?

- A the solution becomes yellow
- B the solution becomes deeper orange
- C the solution remains unchanged
- D I don't know

Reason

- 1.11 Consider the following reversible reaction that is in a state of equilibrium. (2)

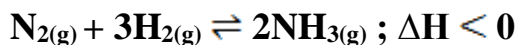


If the temperature of the system is increased, which reaction will be favoured?

- A Reverse
- B Forward
- C None of them is favoured
- D I don't know

Reason

- 1.12 The Haber process represented by the balanced equation below reaches equilibrium (2)
at **300°C**.



What will happen to the mass of **NH₃** if the temperature is **INCREASED** to **500°C**?

- A Increase
- B Decrease
- C Remain the same
- D I don't know

Reason

1.13 The equation below represents a chemical reaction at equilibrium in a closed (2) container. $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$; $\Delta\text{H} < 0$. Which ONE of the following changes will increase the mass of $\text{HI}(\text{g})$ in the above reaction?

- A Add a catalyst
- B Decrease the temperature
- C Increase the temperature
- D I don't know

Reason.....

1.14 Consider the following hypothetical reaction that reached equilibrium in a closed (2) container at 450°C : $\text{XY}(\text{s}) \rightleftharpoons \text{X}(\text{g}) + \text{Y}(\text{s})$; $\Delta\text{H} > 0$

Which **ONE** of the following changes will **NOT** affect the equilibrium position?

- A Increase in the amount of $\text{Y}(\text{s})$
- B Decrease in pressure at constant volume
- C Increase in the volume of the container
- D I don't know

Reason.....

1.15 H_2 , which is thought as fuel in the future, is obtained through the (2) decomposition of H_2O at a high temperature. The reaction reaches equilibrium as shown in the equation the below:

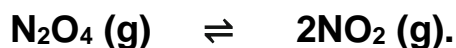


How will the mass of H_2 be affected when helium, an inert gas is added to the equilibrium mixture at constant volume?

- A Addition of an inert gas has no effect on this equilibrium system
- B Increase in pressure will shift the equilibrium to the side with less number of moles
- C Partial pressure of H_2O will increase and shift the equilibrium to the right
- D I don't know

Reason

- 1.16 The decomposition of dinitrogen tetraoxide (N_2O_4) reaches equilibrium in a (2) transparent sealed vessel as shown below:



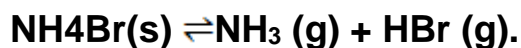
Colourless **Brown**

How will the colour of the system change immediately after the total pressure is increased while keeping the temperature constant?

- A Dark brown
- B Colourless
- C Remain the same
- D I don't know

Reason

- 1.17 Ammonium bromide decomposes to ammonia and hydrogen bromide in a (2) sealed vessel. The reaction reaches equilibrium as shown:

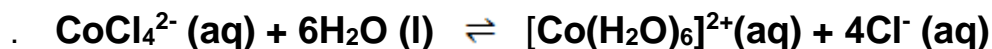


How will the mass of **HBr(g)** change after the adding some **NH₃(g)** while keeping the volume and temperature constant?

- A Increase
- B Decrease
- C Remain the same
- D I don't know

Reason

1.18 Cobalt (II) chloride crystals are dissolved in a water/ alcohol mixture to form a (2) blue solution. As represented by the following equilibrium equation



Blue

Pink

A few drops of concentrated sulphuric acid are added to the above solution. What colour change is observed?

- A No change in colour
- B Pink
- C Deep blue
- D I don't know

Reason

1.19 In a closed system, the following equilibrium can be established: (2)

C₂H₆(g) ⇌ C₂H₄(g) + H₂(g). Initially **8mol of C₂H₆** are present, at this time C₂H₄ and H₂ have not been yet been formed. At equilibrium, **3mol C₂H₄** are present. How many mol of C₂H₆ and H₂ exist at equilibrium?

- A 2mol C₂H₆ and 3mol H₂
- B 3mol C₂H₆ and 3mol H₂

C 4mol C₂H₆ and 1mol H₂

D 5mol C₂H₆ and 3mol H₂

E I do not know

Reason

1.20 The following equilibrium can be found between the compounds NO₂ and N₂O₄: (2)

2 NO_{2(g)} ⇌ N₂O_{4(g)}. Initially **7 mol NO₂** were placed in a closed vessel. At equilibrium, **2 mol N₂O₄** are formed. How many mol of NO₂ exist at equilibrium?

A 2 mol NO₂

B 3 mol NO₂

C 5 mol NO₂

D 6 mol NO₂

E I don't know

Reason

1.21 In a closed vessel, the following equilibrium is established between hydrogen (H₂), iodine (I₂) and hydrogen iodide (HI) : **2HI(g) ⇌ H_{2(g)} + I_{2(g)}**. Initially **6 mol HI** are present. At this time H₂ and I₂ have not yet been formed. At equilibrium, **1 mol of H₂** exist. How much HI and I₂ exist at equilibrium? (2)

2HI(g) ⇌ H_{2(g)} + I_{2(g)}. Initially **6 mol HI** are present. At this time H₂ and I₂ have not yet been formed. At equilibrium, **1 mol of H₂** exist. How much HI and I₂ exist at equilibrium?

A 1 mol HI and 1 mol I₂

B 2 mol HI and 1 mol I₂

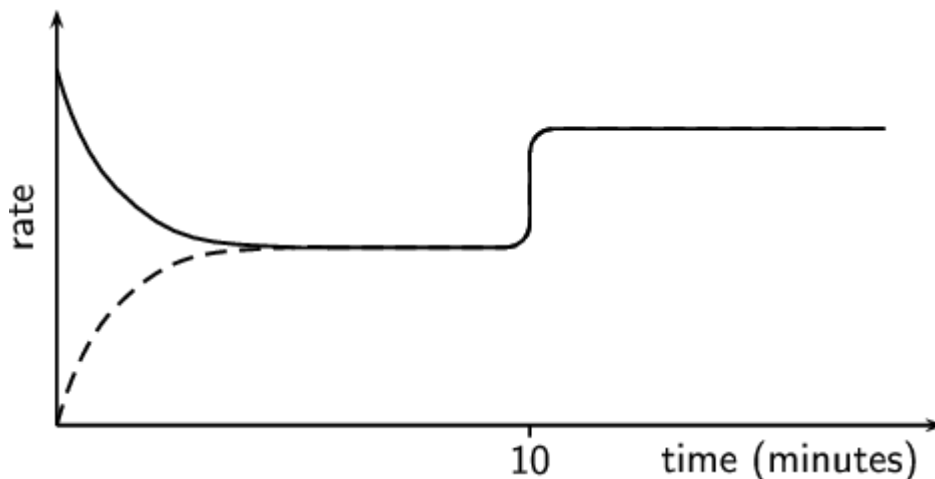
C 3 mol HI and 2 mol I₂

D 4 mol HI and 1 mol I₂

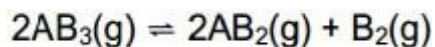
E I do not know

Reason

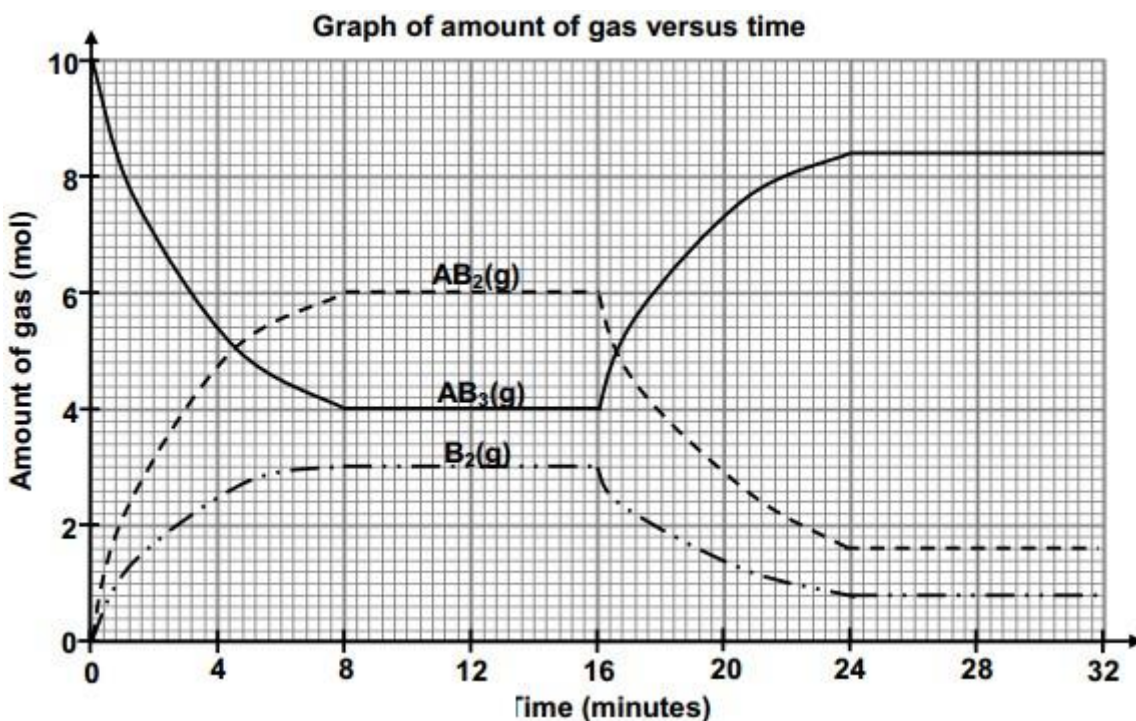
- 2 Consider the rate – time graph for the reversible reaction below: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$ (2)



- 2.1 Which reaction does the broken line represent? (2)
- 2.2 What is responsible for the change at $t = 10$ minutes? Explain your answer fully (3)
- 3 The following equation represents a hypothetical reaction that reaches equilibrium in a 2 dm^3 closed container at 500°C after 8 minutes.



The course of the reaction is illustrated in the graph below.



3.1.1 At what time was equilibrium reached for the: (2)

(a) first time

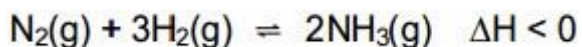
(b) second time

3.1.2 Use the information in the graph to calculate the value of the (7)
equilibrium constant at 500°C.

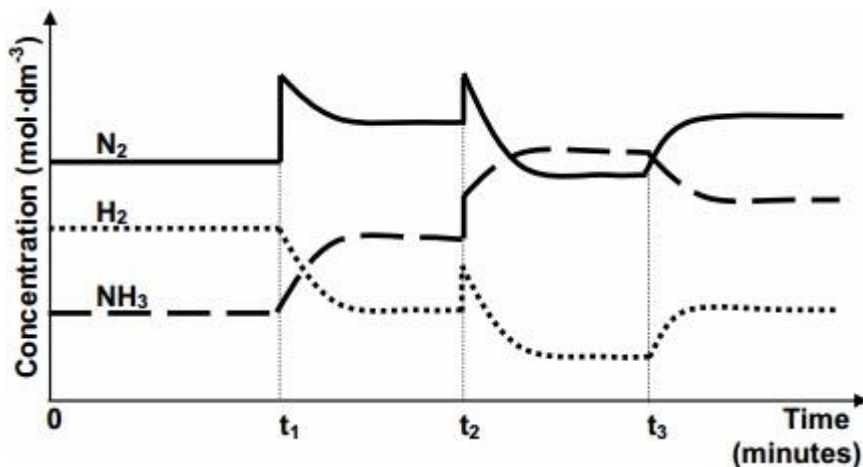
3.1.3 What does the K_c value you calculated in QUESTION 3.1.3 show (2)
about the relative amount of reactants and products in the
equilibrium mixture?

3.2 The temperature is increased to 600°C at the 16th minute. (4)
Is the forward reaction endothermic or exothermic? Explain your
answer.

4 A fertiliser company produces ammonia on a large scale at a temperature of 450°C.
The balanced equation below represents the reaction that takes place in a sealed
container.



To meet an increased demand for fertiliser, the management of the company instructs their engineer to make the necessary adjustments to increase the yield of ammonia. In a trial run on a small scale in the laboratory, the engineer makes adjustments to the **TEMPERATURE, PRESSURE and CONCENTRATION** of the equilibrium mixture. The graphs below represent the results obtained.



What change was made to the system at:

4.1.1 t_1 (2)

4.1.2 t_2 (2)

4.1.3 t_3 (2)

4.2 At which of the above time(s) did the change made to the reaction mixture lead to a higher yield of ammonia? (2)

5 Sulphuric acid is an important substance used in the manufacture of fertilisers. The equation below represents one of the steps in the industrial preparation of sulphuric acid. $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g}) \Delta H < 0$

5.1 Is the forward reaction exothermic or endothermic? Give a reason for the answer. (2)

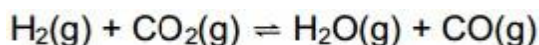
5.2 The reaction, represented by the equation in QUESTION 5, reaches equilibrium at a certain temperature in a 2 dm^3 closed container for the first time. (9)

On analysis of the equilibrium mixture, it is found that **0,6 mol of SO₂(g), 0,5 mol of O₂(g) and 0,4 mol of SO₃(g)** are present in the container.

The temperature is THEN increased and the reaction is allowed to reach equilibrium for the second time at the new temperature. On analysis of this new equilibrium mixture, it is found that **0,2 mole of SO₃(g)** is present in the container. Calculate the K_c at the new temperature

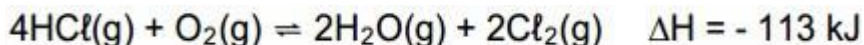
- 5.3 What does the K_c you calculated indicate about the relative amount of reactants and products in the equilibrium mixture? (2)

- 6 Study the reversible reaction represented by the balanced equation below.



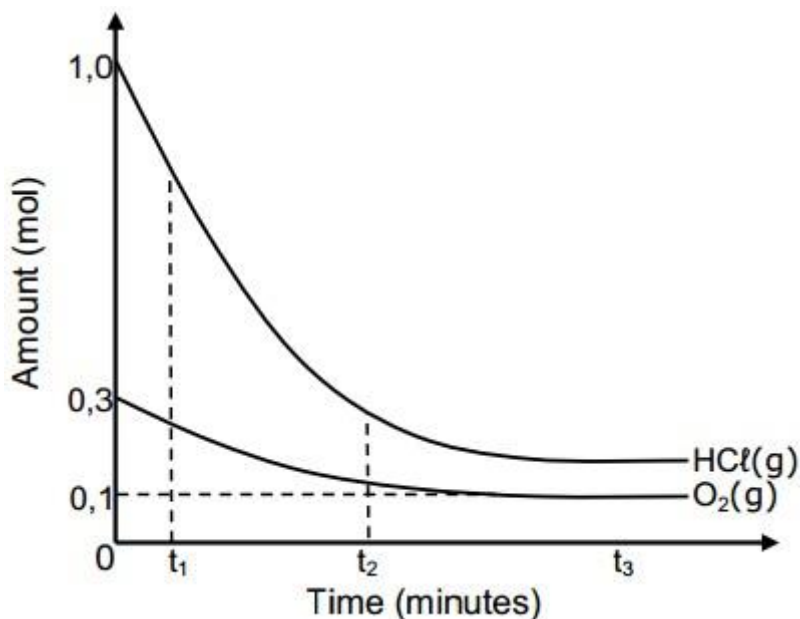
Initially x moles of H₂(g) is mixed with 0,3 moles of CO₂(g) in a sealed 10 dm³ container. When equilibrium is reached at a certain temperature, it is found that 0,2 moles of H₂O(g) is present. The equilibrium constant (K_c) for the reaction at this temperature is 4.

- 6.1 Calculate the initial number of moles of H₂(g), x, that was in the container. (8)
- 6.2 The reaction is now carried out at a much higher temperature. It is found that K_c decreases at this higher temperature. Is this reaction exothermic or endothermic? Explain the answer. (4)
- 7 The reaction between hydrogen chloride and oxygen reaches equilibrium in a closed container according to the following balanced equation:



- 7.1 Is this reaction exothermic or endothermic? Give a reason for the answer. (2)
- 7.2 The graphs below, not drawn to scale, show how the amounts of reactants present in the container change with time at a specific

temperature. The volume of the container is 5 dm^3 .



- 7.2.1 How does the rate of the forward reaction at time t_1 compare to that at time t_2 ? Write down GREATER THAN, SMALLER THAN or EQUAL TO. Use the graphs to give a reason for the answer (2)
- 7.2.2 How does the rate of the forward and the reverse reactions compare at time t_3 ? Write down only GREATER THAN, SMALLER THAN or EQUAL TO. Give a reason for your answer (2)
- 7.2.3 Calculate the equilibrium constant (K_c) for this reaction at this temperature (8)
- 7.3 The temperature is NOW increased. How will this change affect the value of the equilibrium constant? Write down INCREASES, DECREASES or REMAINS THE SAME. Explain your answer. (4)

TOTAL

113 MARKS

APPENDIX 5.6: MARKING GUIDELINE FOR THE CHEMICAL EQUILIBRIUM ACHIEVEMENT TEST

1.1	C✓	The value of K_c will change only when temperature changes ✓	(2)
1.2	C✓	Concentration of pure solid is constant, therefore equilibrium will not be disturbed ✓	(2)
1.3	A✓	Equilibrium position will shift to the left to produce more $[\text{Co}(\text{H}_2\text{O})]^{2+}$ ions ✓	(2)
1.4	C✓	The reverse reaction will be favoured and the concentration of reactants will increase, K_c is inversely proportional to reactant concentration ✓	(2)
1.5	C✓	Catalyst increases the rate of both forward and reverse reaction to the same extent, therefore the net effect is zero ✓	(2)
1.6	B✓	In a sealed vessel, the decomposition of PCl_5 is less than 100% because as reactants decompose, products form back the reactants until equilibrium is established ✓	(2)
1.7	C✓	Concentration of pure solid is constant, therefore equilibrium will not be disturbed ✓	(2)
1.8	C✓	Catalyst increases the rate of both forward and reverse reaction to the same extent, therefore the net effect is zero ✓	(2)

1.9	C✓	The value of K_c will change only when temperature changes ✓	(2)
1.10	C✓	The concentration of dichromate ions will not change therefore equilibrium will not be disturbed ✓	(2)
1.11	A✓	Increase in temperature favours endothermic reaction which in this case is the reverse reaction ✓	(2)
1.12	B✓	Increase in temperature favours endothermic reaction which in this case is the reverse reaction ✓	(2)
1.13	B✓	Decrease in temperature favours the exothermic reaction which in this case is the forward reactions ✓	(2)
1.14	A✓	Concentration of a pure solid is constant therefore adding a pure solid will not disturb equilibrium position ✓	(2)
1.15	A✓	Adding an inert gas at constant volume increases total pressure but does not affect the concentration of substances so no disturbance of equilibrium occurs ✓	(2)
1.16	A✓	Increase in pressure causes a decrease in volume and an increase in concentration making the brown colour more conspicuous ✓	(2)
1.17	B✓	The reverse reaction will be favoured, therefore some of the HBr will be used alongside with NH_3 to form the reactants ✓	(2)
1.18	C✓	H_2SO_4 is a strong dehydrating agent, it will decrease the concentration of water by forming H_3O^+ . This favours the reverse reaction which produces more CoCl_4^{2-} ions ✓	(2)

		✓	
1.19	D✓	Equilibrium moles of C ₂ H ₆ : 8-3 = 5 Equilibrium mole of C ₂ H ₄ : 0+3 = 3 ✓ Equilibrium moles of H ₂ : 0+3 = 3	(2)
1.20	B✓	Equilibrium moles of NO ₂ : 7-2(2) = 3 ✓	(2)
1.21	D✓	Equilibrium moles of HI: 6-2(1) = 4 ✓ Equilibrium moles of I ₂ : 1(1) = 1	(2)
TOTAL MARKS FOR QUESTION 1			42
2.1	Reverse/product (reaction)✓✓		(2)
2.2	Catalyst✓ the rate of the forward and reverse reactions increased✓ to the same extent✓		(3)
TOTAL MARKS FOR QUESTION 2			5

3.1.1	(a) 8 minutes✓ (b) 24 minutes✓	(2)
3.1.2	$c = \frac{n}{v} \checkmark [AB_2] = \frac{6}{2} = 3 \text{ mol. dm}^3 \checkmark [AB_3] = \frac{4}{2} = 2 \text{ mol. dm}^3 \checkmark$ $[B_2] = \frac{3}{2} = 1.5 \text{ mol. dm}^3 \checkmark$ $K_c = \frac{[AB_2]^2[B_2]}{[AB_3]^2} \checkmark$ $K_c = \frac{(3^2)(1.5)}{(2)^2} \checkmark = 3.38 \checkmark$	(7)
3.1.3	There are more products than reactants✓	(2)
3.2	(From the graph, moles of) reactants have increased✓ which implies the reverse reaction is favoured.✓ Since increase in temperature favours endothermic reaction✓, it implies the reverse reaction is endothermic and therefore forward	(4)

	reaction is exothermic✓	
	TOTAL MARKS FOR QUESTION 3	15
4.1.1	(More) N _{2(g)} /nitrogen✓ was added✓	(2)
4.1.2	Pressure✓ was increased	(2)
4.1.3	Temperature✓ was increased✓	(2)
4.2	t ₁ ✓ and t ₂ ✓	(2)
	TOTAL MARKS FOR QUESTION 4	8

5.1 Exothermic✓ $\Delta H < 0$ / ΔH is negative/energy is released✓

(2)

5.2

Reaction	2SO _{2(g)}	O _{2(g)}	2SO _{3(g)}	Remark
Initial mol.	0.6mol	0.5mol	0.4mol	
Change mol.	+0.2mol	+0.1mol	-0.2mol ✓	✓ mole ratios
Equilibrium mol.	0.8mol✓	0.6mol✓	0.2mol	✓✓ equilibrium mole of reactant
Equilibrium concentration	0.4 mol.dm ⁻³ ✓	0.3 mol.dm ⁻³ ✓	0.1 mol.dm ⁻³ ✓	✓✓✓ equilibrium concentrations
$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$ $K_c = \frac{(0.1)^2}{(0.4)^2(0.3)} \checkmark = 0.21 \checkmark$				✓ Kc expression ✓ Substitution ✓ Answer (9)

5.3 There are more reactants than products✓✓ (at equilibrium)

(2)

TOTAL MARKS FOR QUESTION 5

13

6.1

Reaction	H _{2(g)}	CO _{2(g)}	H _{2O(g)}	CO(g)	Remarks
Initial mol.	x	0.3	0	0	
Change mol.	-0.2	-0.2	+0.2	+0.2✓	✓mole ratio
Equilibrium mol.	$x - 0.2$	0.1	0.2	0.2	
Equilibrium concentration	$\frac{x - 0.2}{10}$ ✓	0.01✓	0.02	0.02✓	✓✓✓equilibrium concentrations
$K_c = \frac{[H_2O][CO]}{[H_2][O_2]}$ $4 \checkmark = \frac{(0.02)(0.02)}{(\frac{x-2}{10})(0.01)}$ $x = 0.3 \text{ mol} \checkmark$					✓Kc expression ✓✓Substitution ✓Answer (8)
6.2 Exothermic✓ Kc has decreased meaning that reactants have increased.✓ Reverse reaction is favoured✓ therefore it is the endothermic reaction.✓					(4)
TOTAL MARKS FOR QUESTION 6					12

7.1 Exothermic✓ $\Delta H < 0/\Delta H$ is negative/energy is released✓ (2)

7.2.1 Greater than✓, the slope (of the graph) is steeper at t_1 than t_2 ✓ (2)

7.2.2 Equal to✓ concentrations remain constant✓ (2)

7.2.3

Reaction	4HCl(g)	O _{2(g)}	2H _{2O(g)}	2Cl _{2(g)}	Remarks
Initial mol.	1.0	0.3✓	0	0	✓initial mole of reactants
Change mol.	-0.8	-0.2	+0.4	+0.4	
Equilibrium mol.	0.2	0.1✓	0.4	0.4	✓equilibrium mole of

					O ₂
Equilibrium concentration	0.04✓	0.02✓	0.08	0.08✓	✓✓✓ equilibrium concentrations
$K_c = \frac{[H_2O]^2 [Cl_2]^2}{[HCl]^4 [O_2]}$ $K_c = \frac{(0.08)^2 (0.08)^2}{(0.04)^4 (0.02)} = 800$					✓ Kc expression ✓ Substitution ✓ Answer (8)
7.3 Decrease✓ increase in temperature favours endothermic reaction✓ which, in this case, is the reverse reaction✓ more reactants are formed which decreases the Kc value✓					(4)
TOTAL MARKS FOR QUESTION 7					(18)

TOTAL

113 MARKS



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 YUNIBESITHI YA BOKONE-BOPHIRIMA
 NOORDWES-UNIVERSITEIT
 POTCHEFSTROOM CAMPUS

Private Bag X6001, Potchefstroom
 South Africa 2520

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

Faculty of Education Sciences

APPENDIX 5.7: THE REVISED TWO-FACTOR STUDY PROCESS QUESTIONNAIRE

This questionnaire has a number of questions about your usual way of studying chemical equilibrium. There is **NO RIGHT** way of studying chemical equilibrium. It depends on what suits your own style and the chemical equilibrium concept you are studying. It is accordingly important that you answer each question as **HONESTLY** as you can. The letters alongside each number stand for the following response:

A—this item is *never* or *only rarely* true of me

B—this item is *sometimes* true of me

C—this item is true of me about *half the time*

D—this item is *frequently* true of me

E—this item is *always* or *almost always* true of me

Please choose the **ONE** most appropriate response to each question by making a [**×**] mark on the letter that corresponds to it.

Do not spend a long time on each item: Your first reaction is probably the best one. Please answer each item. Do not worry about projecting a good image. Your answers are **CONFIDENTIAL**.

Surname..... Name

Age Gender: Male [] Female []

1	I find that at times studying chemical equilibrium gives me a feeling of deep personal satisfaction.	A	B	C	D	E
2	I find that I have to do enough work on chemical equilibrium so that I can form my own conclusions before I am satisfied.	A	B	C	D	E
3	My aim for studying chemical equilibrium is to pass the exams while doing as little work as possible.	A	B	C	D	E
4	I only study seriously what is given out in class or in the examination guideline concerning chemical equilibrium.	A	B	C	D	E

5	I feel that virtually any aspect about chemical equilibrium can be highly interesting once I get into it.	A	B	C	D	E
6	I find most new concepts about chemical equilibrium interesting and often spend extra time trying to obtain more information about them.	A	B	C	D	E
7	I do not find my chemical equilibrium very interesting so I keep my work on this topic to the minimum.	A	B	C	D	E
8	I learn chemical equilibrium by rote, going over and over them until I know them by heart even if I do not understand them.	A	B	C	D	E
9	I find that studying chemical equilibrium can at times be as exciting as a good novel or movie.	A	B	C	D	E
10	I test myself on important topics in chemical equilibrium until I understand them completely.	A	B	C	D	E
11	I find I can get a pass mark in most assessments in chemical equilibrium by memorising key sections rather than trying to understand them	A	B	C	D	E
12	I generally restrict my study of chemical equilibrium to what is specifically set in exams as I think it is unnecessary to do anything extra.	A	B	C	D	E
13	I work hard at my study of chemical equilibrium because I find the material interesting.	A	B	C	D	E
14	I spend a lot of my free time finding out more about interesting concepts in chemical equilibrium which have been discussed in the different lessons.	A	B	C	D	E
15	I find it is not helpful to study chemical equilibrium in depth. It confuses and wastes time, when all you need is a passing	A	B	C	D	E

	acquaintance with chemical equilibrium.					
16	I believe that teachers shouldn't expect students to spend significant amounts of time studying aspects of chemical equilibrium everyone knows won't be examined.	A	B	C	D	E
17	I come to most chemical equilibrium classes with questions in mind that I want answering.	A	B	C	D	E
18	I make a point of looking at most of the suggested textbooks that go with the lessons on chemical equilibrium.	A	B	C	D	E
19	I see no point in learning aspects of chemical equilibrium which is not likely to be in the examination.	A	B	C	D	E
20	I find the best way to pass tests in chemical equilibrium is to try to remember answers to likely questions.	A	B	C	D	E

APPENDIX 5.8: PERMISSION FROM MPUMALANGA DEPARTMENT OF EDUCATION



Building No. 5, Government Boulevard, Riverside Park, Mpumalanga Province
Private Bag X11341, Mbombela, 1200.
Tel: 013 766 5552/5 115, Toll Free Line: 0800 203 116

Litiko le Temfundvo, Umnyango we Funda

Departement van Ondervys

Ndzawulo ya Dyondzo

Mr. Alfred Mensah
PO BOX 235
Hazy view
1242

RE: APPLICATION TO CONDUCT RESEARCH: MR. ALFRED MENSAH

Your application to conduct research was received. I trust that the aims and the objectives of the study will benefit schools and improve our education. It therefore gives me pleasure to approve your application subject to you observing the provisions of the departmental draft research policy which is attached. You are also further requested to adhere to your University's research ethics as spelt out in your research ethics document.

In terms of the draft research policy data or any research activity can only be conducted after school hours as per appointment. You are also requested to share your findings with the relevant sections of the department so that we may consider implementing your findings if that will be in the best interest of the department. To this effect, your final approved research report (both soft and hard copy) should be submitted to the department so that your recommendations could be implemented. You may be required to prepare a presentation and present at the department's annual research dialogue.

For more information kindly liaise with the department's research unit @ 013 766 5476 or a.baloyi@education.mpu.gov.za.

The department wishes you well in this important project and pledges to give you the necessary support you may

need.


MRS MOC MHLABANE
HEAD OF DEPARTMENT

16 9, 15
DATE

APPENDIX 5.9 PERMISSION FROM THE SCHOOL GOVERNING BOARD



EMIS NO: 800035169
Tel/Fax: 015 773 0330

**ORHOVELANI
High School**

Orhovelandi High School
Private Bag X1409
Thulamahashe
1365

email: orhovelandihighschool@gmail.com

TO : MR MENSEH A

DEAR SIR

PERMISSION TO CONDUCT RESEARCH

As the principal of the above named institution I hereby wish to let you know that permission is granted to you to conduct the research you intend t

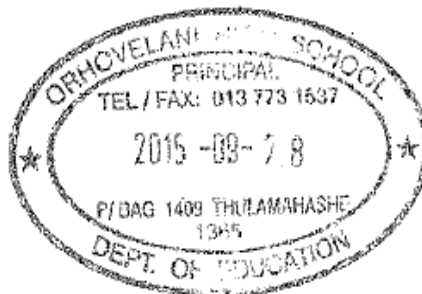
After consulting my colleagues and notifying the S.G.B and S.M.T I was mandated to inform you of this kindly feel energetic and free to utilise our resources during the duration of your research.

On behalf of the entire school we wish you all the best

Yours faithfully



KHOZA M.P



APPENDIX 5.10: PARENTAL AND STUDENT CONCENT FORMS



NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

Private Bag X6001, Potchefstroom
South Africa 2520

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

Faculty of Education Sciences

PARENTAL INFORMED CONSENT

I hereby confirm that I have been adequately informed by the researcher about the nature, conduct, benefits and risks of the study. I am aware that the results of the study, including personal details regarding my child, will be anonymously processed into a research report. I understand that his/her participation is voluntary, and that he/she may at any stage, without prejudice, withdraw his/her assent and participation from the study. He/she has had sufficient opportunity to ask questions and I, of my own free will declare that my child can participate in the study.

Researcher-participant's name GARY BONGI MARULE(Please print)

Research participant's signature: [Signature]

Date: 20th July 2016

Researcher's name: Alfred Mensah(Please print)

Researcher's signature: [Signature]

Date: 25th July 2016



NORTH-WEST UNIVERSITY
 YUNIBESITHI YA BOKONE-BOPHIRIMA
 NOORDWES-UNIVERSITEIT
 POTCHEFSTROOM CAMPUS

Private Bag X6001, Potchefstroom
 South Africa 2520

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

Faculty of Education Sciences

LEARNER CONSENT FORM

I hereby confirm that I have been adequately informed by the researcher about the nature, conduct, benefits and risks of the study. I am aware the study will be anonymously processed into a research report. I understand that my participation is voluntary, and that I may at any stage, without prejudice, withdraw my consent and participation from the study. I had sufficient opportunity to ask questions and of my own free will declare myself prepared to participate in the study.

Researcher participant's name : ... GARY BONSI MARUCE(Please print)

Research participant's signature: ... G.B. Marule

Date: ... 20th July 2016

Researcher's name: ... Alfred Mensah(Please print)

Researcher's signature: ... [Signature]

Date: ... 20th July, 2016

APPENDIX 5.11: WORKSHEETS

LESSON 1: NATURE OF CHEMICAL EQUILIBRIUM

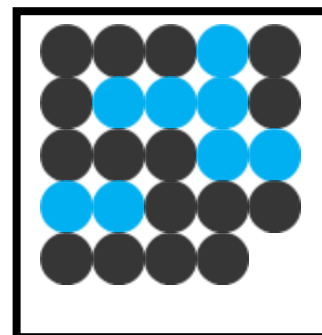
Consider the equilibrium reaction. $A(g) \rightleftharpoons B(g)$. Assume the rate of the forward reaction is $\frac{1}{2}$ while the rate of the reverse reaction is $\frac{1}{4}$. Your teacher will demonstrate how the reaction proceeds from the start to equilibrium. Listen carefully and answer the questions that follow.

Time (min)	A mol.dm ⁻³ / min	B mol.dm ⁻³ / min	[A]	[B]
0			24	0

Time (min)	A mol.dm ⁻³ / min	B mol.dm ⁻³ / min	[A]	[B]
0			24	0
1	12	0	12	12
Time	A	B	[A]	[B]

(min)	mol.dm ⁻³ / min	mol.dm ⁻³ / min		
0			24	0
1	12	0	12	12
2	6	3	9	15

Time (min)	A mol.dm ⁻³ / min	B mol.dm ⁻³ / min	[A]	[B]
0			24	0
1	12	0	12	12
2	6	3	9	15
3	5	4	8	16
4	12	0	12	12
5	6	3	9	15
6	5	4	8	16



4	4	4	8	16

Time (min)	A mol.dm ⁻³ / min	B mol.dm ⁻³ / min	[A]	[B]
0			24	0
1	12	0	12	12
2	6	3	9	15
3	5	4	8	16
4	4	4	8	16
5	4	4	8	16

Questions

1. What does the blue marbles stand for?
 2. What does the red marbles stand for?
 3. What is the phase of molecules? Solid or Liquid or Gas?
 4. What type of system is housing the molecules? Open or Closed?
 5. What does the unit mol.dm⁻³/min indicate?
 6. Why is it necessary for the system to be closed?
-

7. In the 2nd minute B(g) started to decompose. What does this suggest about reactions in a closed system?
8. Will the reactants in the system ever get finished? Yes or No? What does this suggest about this type of reaction
9. From the 4th minute onwards, the rate of decomposition of A(g) is equal to the rate of decomposition of B(g). What does this suggest about the reaction at this time?
10. From the 4th minute onwards, concentration of reactants and products did not change. What does this mean
11. Before the 4th minute, the number of blue marbles decrease while the number of red marbles increased. What can we say about the reaction before the 4th minute?
12. Before the 4th minute, the number of blue marbles that decompose in one minute decrease while the number of red marbles that decomposed in one minute increased. What can we say about the reaction before the 4th minute?
13. If the system in this activity were a coloured solution, how many colours will be solution have in the fourth minute?
14. Which colour will be visible at the beginning when time is zero.....
15. Which colour will be visible from the 4th minute onwards?
16. What happens to the other colour?
17. Calculate the ratio $\frac{[\text{products}]}{[\text{reactants}]}$ in the 4th minute.....
18. How is this ratio called?

NOTE: Only equilibrium concentrations are used in calculating Kc

19. What does this ratio suggest about the relative amounts of reactant and product in the system from the 4th minute onwards?
20. Suppose a catalyst was used at the start of the reaction.
 - a) Will the yield/ amount of product at equilibrium **increase, decrease or remain the same?** Explain your answer.....

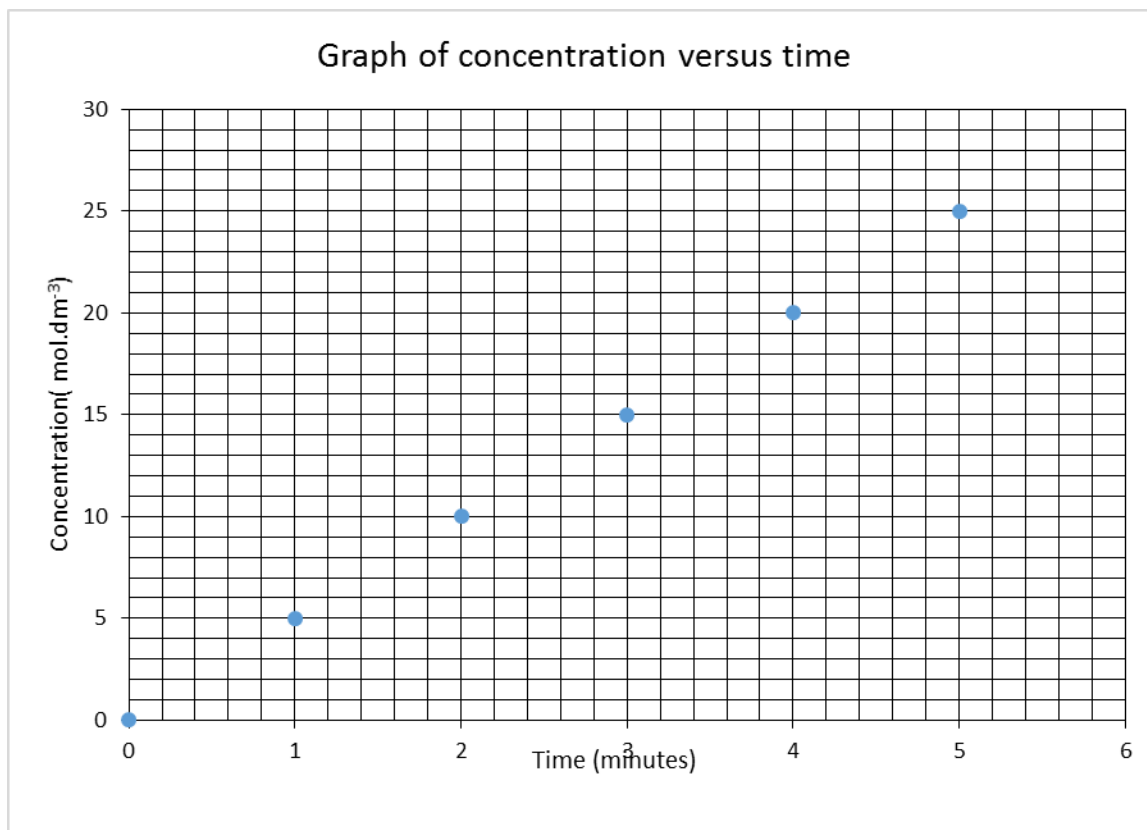
b) How will the time at which equilibrium is reached be affected?

Plot a Concentration – Time curves for A(g) and B(g) on the same graph below using data on the in the last table. Use different colours for A(g) and B(g) in drawing the curves.

- Label the curves. A and B
- Circle the time when equilibrium is reached on the time axis
- Circle the initial concentrations on the concentration axis
- Circle the equilibrium concentration on the concentration axis

Refer to the curves describe changes in concentration of:

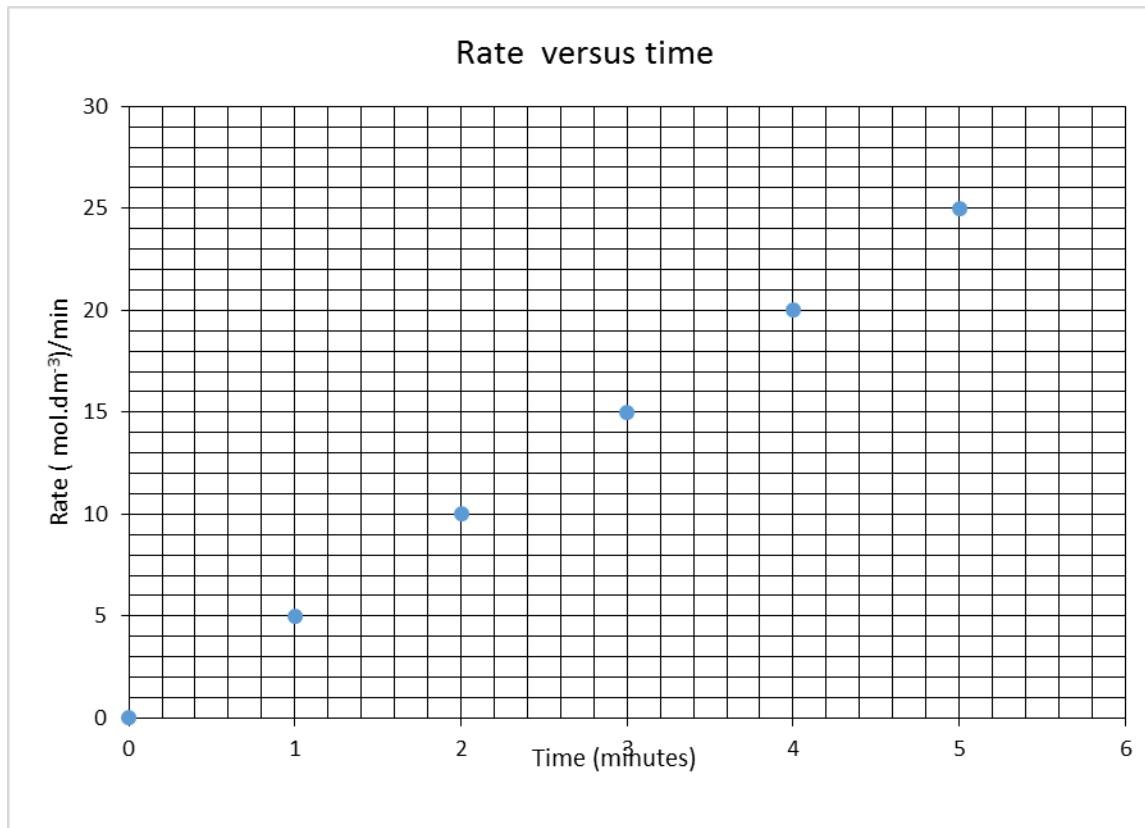
- 1) reactants from the start of the reaction up to equilibrium
- 2) products from the start of the reaction up to equilibrium



Plot the rate – time curves for A(g) and B(g) on the same graph below. Use different colours for A(g) and B(g) in drawing the curves.

- Label the curves. A and B

- Circle the time when equilibrium is reached on the time axis
- Circle the initial rates on the rate axis
- Circle the equilibrium rates on the rate axis



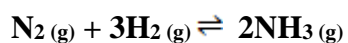
How does the rate-time graph differ from the concentration-time graph?

.....

Refer to the curves describe changes in rate of:

- 1) reactants reaction from the start of the reaction up to equilibrium
- 2) products reaction from the start of the reaction up to equilibrium

The reaction between nitrogen and hydrogen to produce ammonia is given below:

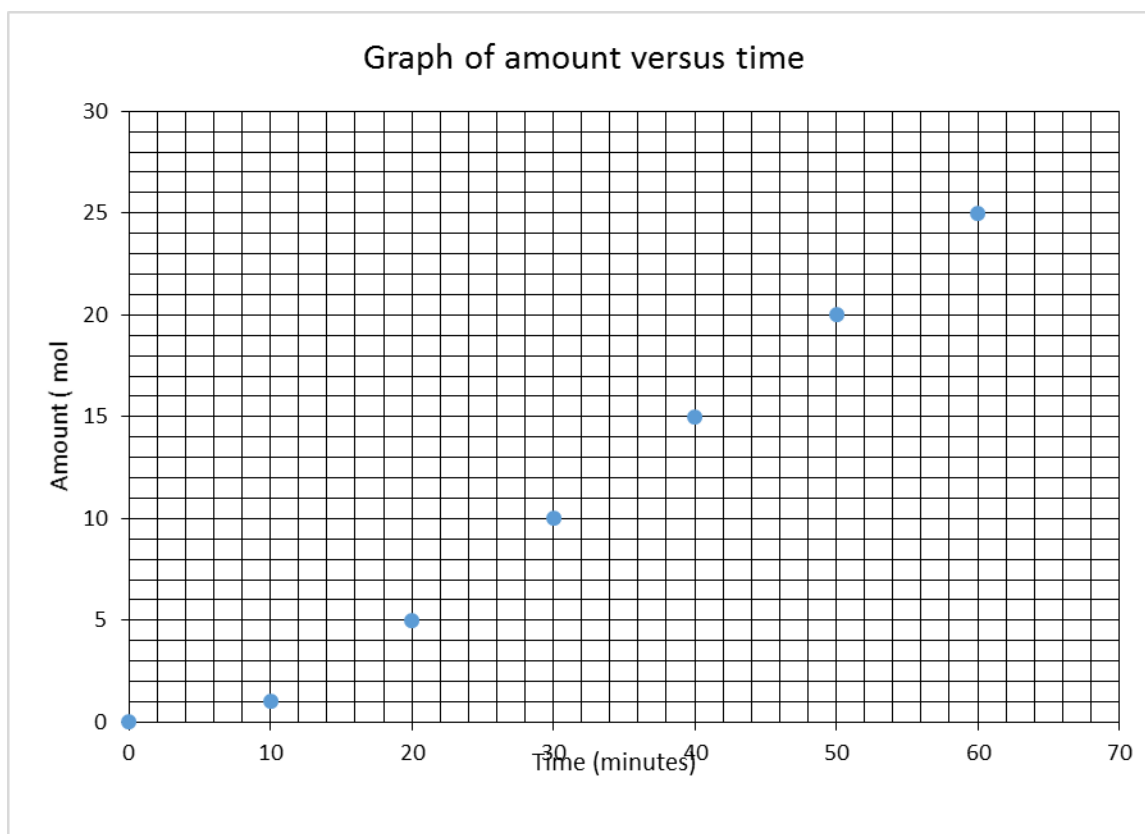


Plot a graph of concentration – time for the reactants and products on the same graph sheet provided below.

- Label the curves as N₂, H₂ and NH₃

- Circle the time when equilibrium is reached on the time axis
- Circle the initial concentrations of N_2 , H_2 and NH_3 on the concentration axis
- Circle the equilibrium concentrations of N_2 , H_2 and NH_3 on the concentration axis

	Amount (mol)		
Time (Min)	$\text{N}_2(\text{g})$	$\text{H}_2(\text{g})$	$\text{NH}_3(\text{g})$
0	10	20	0
10	8	14	4
20	7	11	6
30	7 (Equilibrium)	11	6
40	7	11	6
50	7	11	6
60	7	11	6



Questions

1. From the graphs which substances decreased towards equilibrium? Reactants/Products
2. Which substances increased towards equilibrium? Reactants/Products
3. How does the rate of forward reaction changed from the start toward equilibrium?
Increase/Decrease?
4. How does the rate of reverse reaction changed from the start toward equilibrium?
Increase/Decrease?
5. Does the reaction stop at equilibrium? Yes/ No. Explain.....
.....
6. Before equilibrium is established which reactant has a higher reaction rate? N_2 or H_2 ?
Explain by referring to the graph.....
.....
7. What does the symbol [] stand for?
8. Calculate the equilibrium constant for this reaction [**Hint: in equilibrium constant expressions, stoichiometric coefficients are powers**]

.....

9. What does the equilibrium constant you calculated suggest about the relative amount of reactant and product in the equilibrium mixture?

.....

 ...

EVIDENCE STATEMENTS (1): EFFECT OF CATALYST ON EQUILIBRIUM

- If a catalyst is added to a reaction equilibrium, both the forward and reverse reaction rates will be increased TO THE SAME EXTENT.
- If both rates are increased to the same extent, then the net effect will be zero. This means that a catalyst has no effect on the equilibrium position. However, a catalyst will affect how quickly equilibrium is reached.
 - a) Sketch a graph of rate versus time to show how the rates of the forward and reverse reactions change from the start of reaction to equilibrium. Label this **U** (Unanalyzed reaction)
 - b) On the same set of axes sketch a graph of rate versus time for the catalyzed reaction. Label this **C** (catalyst reaction).
 - c) On another set of axes, sketch a graph of rate versus time to show changes in rates assuming the catalyst when is added while the reaction is at equilibrium

Our Argument

Problem / Question: Suppose while the reaction is at equilibrium, a catalyst is added to the system. What effect will this have the yield of products?

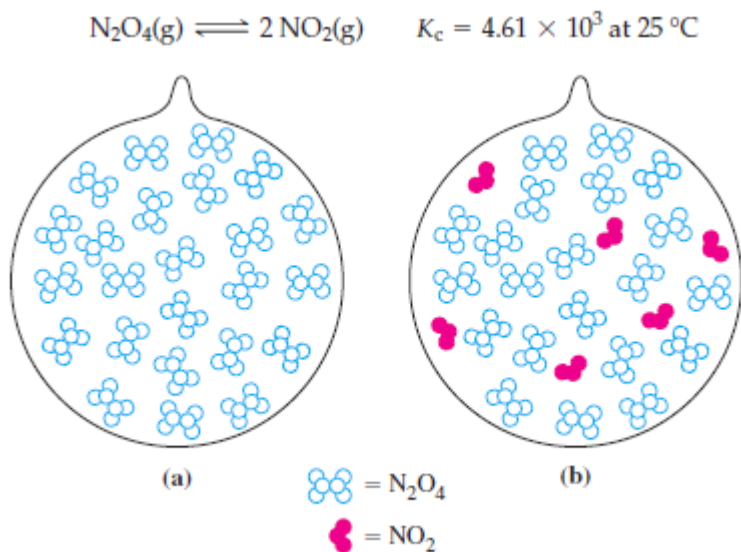
Our claim / belief	We think that
Data / Evidence	Our evidence for this is
Reason	This evidence supports our idea because

Counter-argument	Someone might argue against our idea by saying that the yield of product will increase because adding a catalyst will increase the rate of reaction.
Rebuttal	If someone does not agree with us, we would convince him / her by.....

LESSON 2: CALCULATIONS INVOLVING K_c

8.1. Worked example

Refer to the diagram below:



A 0.5-mol sample of N_2O_4 (g) is allowed to come to equilibrium with NO_2 (g) in a 500cm^3 flask at 25°C .

Calculate

- the amount of N_2O_4 present at equilibrium
- show that the K_c for the reaction at 25°C is 0,071

c) What does the K_c value you calculated suggest about the relative amounts of reactants and products?

Dummy RICEE TABLE

Reaction	$N_2O_4(g)$	$2NO_2(g)$
Initial (mol)	24	0
Used/formed (mol)	-3	+6
Equilibrium(mol)	21	6
Equilibrium conc. $c = \frac{n}{v}$ (mol.dm ⁻³)		

Place initial amounts in this row
Apply m/r in this row
Place equilibrium mol in this row
Place equilibrium concentrations in this row

Reaction	$N_2O_4(g)$	$2NO_2(g)$
Initial (mol)	0.5000	0
Used/formed (mol)	-0.0625	+0.125
Equilibrium(mol)	0.4375	0.125
Equilibrium conc. $c = \frac{n}{v}$ (mol.dm ⁻³)	0.8750	0.250

a) Amount of N_2O_4 present at equilibrium is 0,4375 mol

b) $K_c = \frac{[NO_2]^2}{[N_2O_4]} = \frac{(0,125)^2}{0,8750} = 0,071.$

c) $K_c < 1$, there are more reactants than products.

LESSON 3: EFFCET OF CONCENTRATION ON K_c

The purpose of this activity is to show that for a particular reaction, so long as the temperature remains the same, changing initial centration does not change the equilibrium constant.

Learners investigate the reaction between carbon monoxide and hydrogen to produce methanol. Three experiments were carried out in a 10dm³ flask at 483 K. The table below shows the results of the investigation.

Three Approaches to Equilibrium in the Reaction:			
CO (g) + H₂(g) ⇌ CH₃OH(g)			
	CO (g)	H₂(g)	CH₃OH(g)
Experiment 1			
Initial amounts, (mol)	1.000	1.000	0.000
Equilibrium amounts, (mol)	0.911	0.822	0.0892
Equilibrium concentrations (mol.dm ⁻³)	0.0911	0.0822	0.00892
Experiment 2			
Initial amounts, (mol)	0.000	0.000	1.000
Equilibrium amounts, (mol)	0.753	1.506	0.247
Equilibrium concentrations (mol.dm ⁻³)	0.0753	0.1506	0.0247
Experiment 3			
Initial amounts, (mol)	1.000	1.000	1.000
Equilibrium amounts, (mol)	1.380	1.760	0.620
Equilibrium concentrations (mol.dm ⁻³)	0.1380	0.1760	0.0620

Identify:

1.1 The independent variable.....

1.2 The dependent variable.....

1.3 Two control variables

2.1. Calculate the K_c for each of the three experiments (round your answer to 1dp)

Experiment 1

Experiment 2

Experiment 3

2.2. What conclusion can be drawn from this investigation?

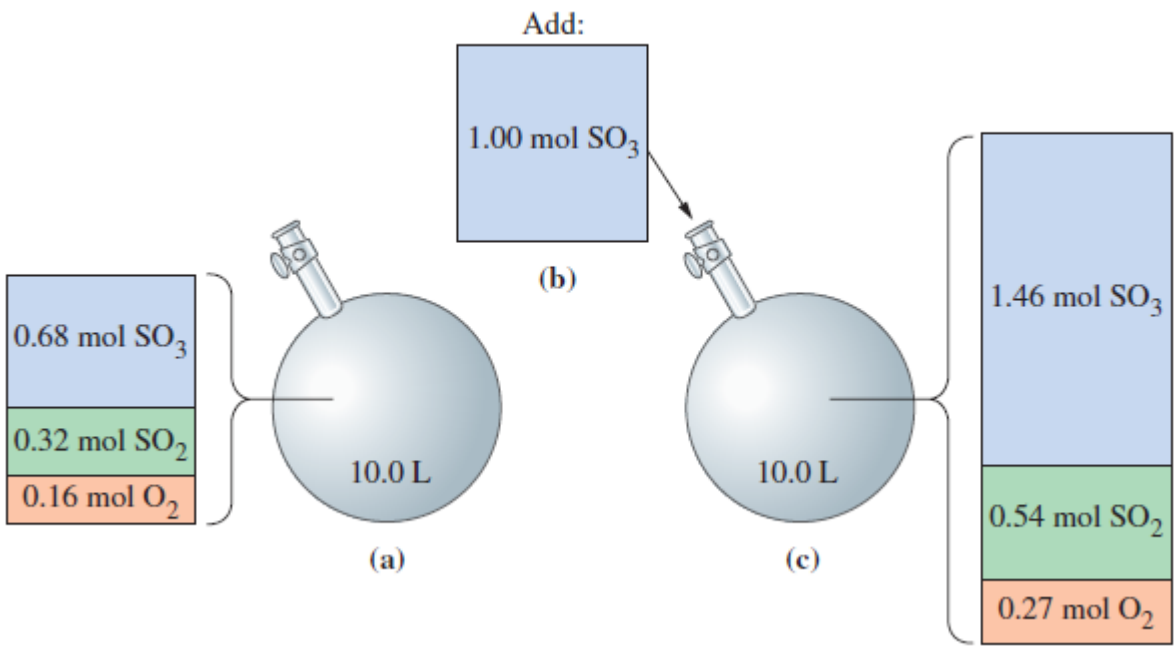
.....

.....

.....

LESSON 4: CHANGING EQUILIBRIUM CONDITION BY CHANGING CONCENTRATION

Consider the reaction: $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$, $K_c = 2.8 \times 10^2$ at 1000 K. The reaction reaches equilibrium in a 10.0 L sealed vessel (a). After equilibrium is reached, 1.00 mol SO_3 was added (b). This change disturbed the equilibrium until a new equilibrium is reached (c).



Questions

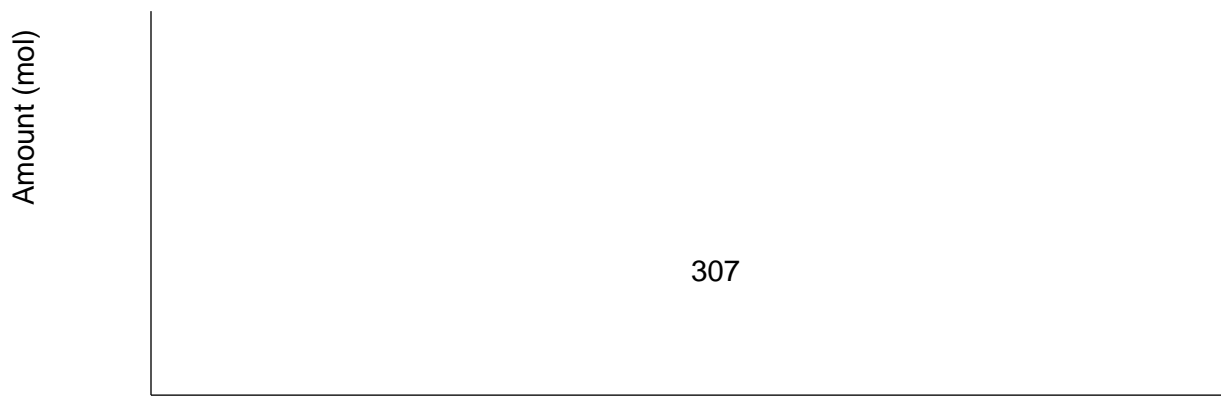
1. When a new equilibrium is established, how does the amount of each substance change?

- a) SO₃
- b) SO₂
- c) O₂

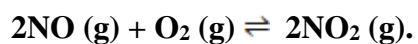
2. In which direction does the equilibrium shift occur? Left/Right?

Reason.....

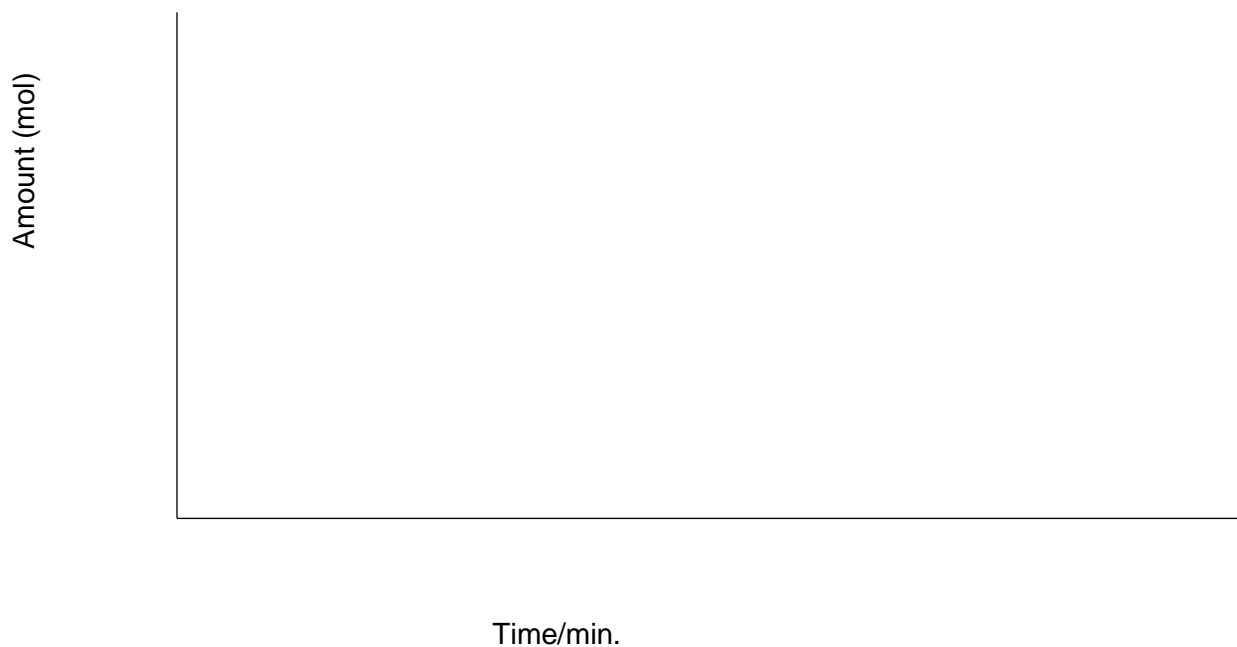
3. Sketch a concentration versus time graph to show the changes that occurred



Time/min.



1. Sketch a concentration – time graph to illustrate the change that takes place. Mark the time when equilibrium was disturbed as t_1 and the time when a new equilibrium is established as t_2



2. Compared to the old equilibrium, the concentration

- a) NO_2 will be higher/lower. Reason
- b) NO will be higher/lower. Reason
- c) O_2 will be higher/lower. Reason

In which direction does equilibrium shift occur? Left/ right. Explain

.....

Argumentative Discussion and Writing

In the problems that follow, you are required to use argument approach to provide answers to the problems. Evidence statements and diagram sheets are provided. You can use them to enhance the quality of argument.

EVIDENCE STATEMENTS (2): EFFECT OF CONCENTRATION ON EQUILIBRIUM

If the concentration of a substance is changed, the equilibrium will shift to minimize the effect of that change.

- If the concentration of a reactant is increased the equilibrium will shift to the right to decrease the concentration of the reactant, so that the reactant. The forward reaction is favoured.
- The forward reaction is also favoured if the concentration of the product is decreased, so that more product is formed.
- If the concentration of a reactant is decreased the equilibrium will shift in the direction of the reaction that produces the reactants, so that the reactant concentration increases. The reverse reaction is favoured. The reverse reaction is also favoured if the concentration of the product is increased, so that product is used.

3.2.1 Our Argument 1

Problem / Question 1: What effect will the addition of more H_2 (g) have on the equilibrium amount of N_2 for the reaction: N_2 (g) + 3H_2 (g) \rightleftharpoons 2NH_3 (g)

Our claim / belief	We think that amount of N_2 will
Data / Evidence	Our evidence for this is

Reason	This evidence supports our idea because.....
Counter-argument	Someone might argue against our idea by saying that amount of N ₂ will not change because its concentration has not been change by addition of more H ₂
Rebuttal	If someone does not agree with us, we would convince him / her by

3.2.2. Our Argument 2

Problem / Question 2: Given the reaction $2\text{CO}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{CO}_2(\text{g})$, what is the effect of adding more CO(g) to the amount of CO₂ present at equilibrium?

Our claim / belief	We think that amount of CO ₂ will
Data / Evidence	Our evidence for this is
Reason	This evidence supports our idea because.....
Counter-argument	Someone might argue against our idea by saying that adding more CO (g) will decrease the amount of CO ₂ (g) present because the

	side of CO (g) will be heavy and equilibrium will shift to the left.
Rebuttal	If someone does not agree with us, we would convince him / her by saying

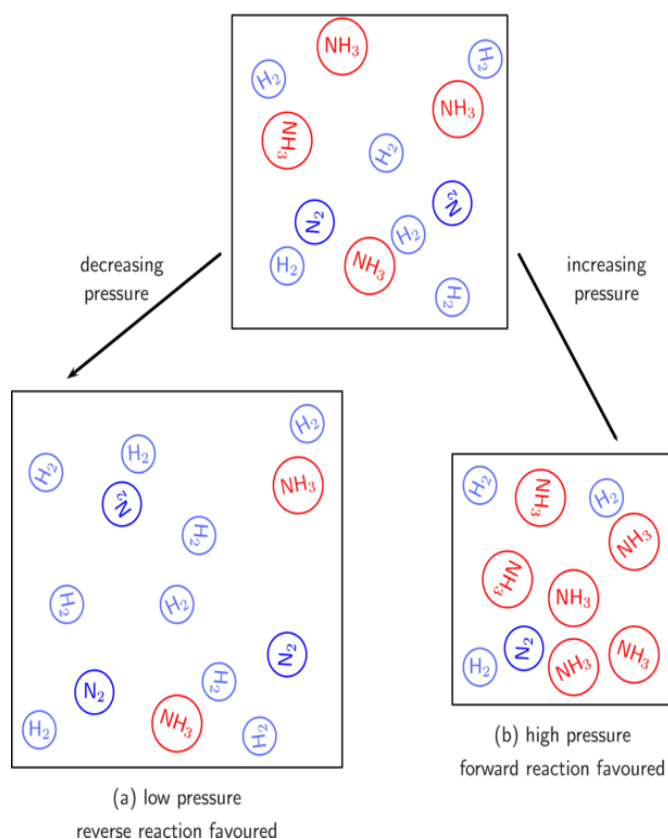
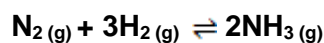


Illustration of effect of pressure on N_2 , H_2 and NH_3 equilibrium systems

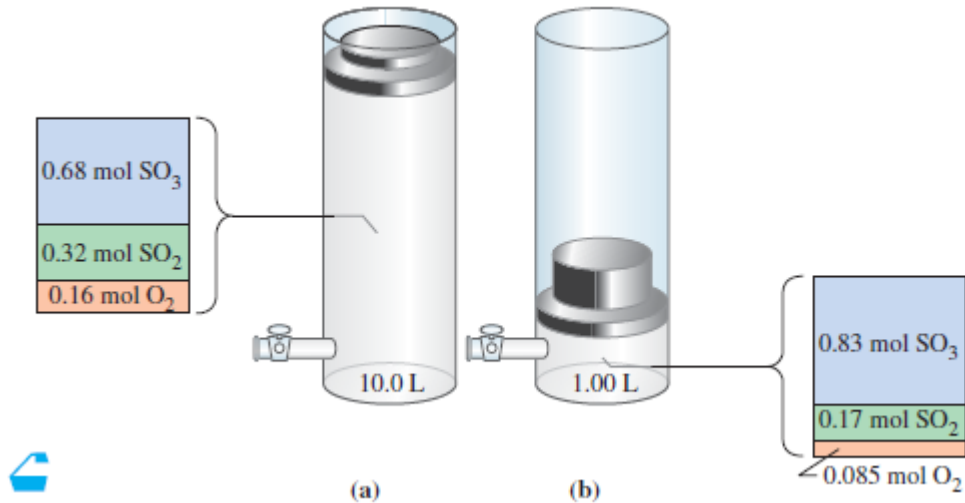


Increasing pressure decreases the volume of the vessel and concentration of all components increase. However, the total number of molecules reduces which shifts the equilibrium position to the side with less number of gas molecules. As can be seen, there are more NH_3 molecules after pressure is increased **(b)**. When pressure is decreased, the vessel expands and volume increases. This causes the total number of molecules to increase. As shown in **(a)**, the side with more number of gas molecules is favoured and we can see more molecules of N_2 and H_2 in the new equilibrium after pressure is decreased. Concentration of substances decrease due increase in volume.

LESSON 5: CHANGING EQUILIBRIUM CONDITION BY CHANGING PRESSURE.

Look at the cylinders (a) and (b) below which contain the equilibrium mixture for the reaction: $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$

Study the diagram and answer the question that follow:



1. What change transformed the equilibrium mixture from state (a) to state (b)?

.....

2. Following the change, how does each of the following changed

a) Amount of SO₃?

b) Amount of SO₂?

c) Amount of O₂?

d) Concentration of SO₃?

e) Concentration of SO₂?

f) Concentration of O₂?

3. Assuming the change from equilibrium state (a) to state (b) occurred very rapidly. Sketch a concentration versus time graph to show the change from equilibrium state (a) to (b).

Concentration (mol/dm³)



Time (minutes)

4. What conclusion can you draw about increasing external pressure (decreasing volume) on

a) Equilibrium position

.....

b) Concentration.....

.....

.....

EVIDENCE STATEMENTS (3) EFFECT OF PRESSURE

4.2 Our Argument 1

Problem / Question: The following reaction is brought to equilibrium at 700 °C in a rigid container $2\text{H}_2\text{S} (\text{g}) + \text{CH}_4 (\text{g}) \rightleftharpoons \text{CS}_2 (\text{g}) + 4\text{H}_2 (\text{g})$. Predict what will happen to the equilibrium mixture in each case:

a) **If the equilibrium mixture is allowed to expand into an evacuated larger container what will happen to the concentration of all substances?**

Our claim / belief	We think that concentration of all substances will
Data / Evidence	Our evidence for this is.....

Reason	This evidence supports our idea because
Counter-argument	Someone might argue against our idea by saying that
Rebuttal	If someone does not agree with us, we would convince him / her by.....

b) If the equilibrium mixture is allowed to expand into an evacuated larger container, what will happen to the moles of CH₄

Our claim / belief	We think that moles of CH ₄ will
Data / Evidence	Our evidence for this is.....
Reason	This evidence supports our idea because

Counter-argument	Someone might argue against our idea by saying that
Rebuttal	If someone does not agree with us, we would convince him / her by.....

c) If the equilibrium mixture is forced into a slightly smaller container, what will happen to the moles of CS₂

Our claim / belief	We think that moles of CS ₂ will
Data / Evidence	Our evidence for this is.....
Reason	This evidence supports our idea because
Counter-argument	Someone might argue against our idea by saying that
Rebuttal	If someone does not agree with us, we would convince him / her by.....

--	-------

d) If several moles of Ar(g) are forced into the reaction container,

Our claim / belief	We think that
Data / Evidence	Our evidence for this is.....
Reason	This evidence supports our idea because
Counter-argument	Someone might argue against our idea by saying that
Rebuttal	If someone does not agree with us, we would convince him / her by.....

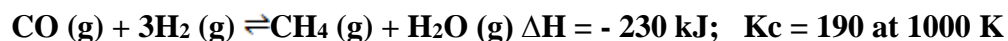
LESSON 6: CHANGING EQUILIBRIUM CONDITIONS BY CHANGING TEMPERATURE

EVIDENCE STATEMENTS: EFFECT OF TEMPERATURE ON EQUILIBRIUM

- *Raising the temperature* of an equilibrium mixture shifts the equilibrium condition in the direction of the *endothermic* reaction OR increasing the temperature of an equilibrium mixture favours the endothermic reaction.
- *Lowering the temperature* causes a shift in the direction of the *exothermic* reaction OR decreasing the temperature of an equilibrium mixture favours the exothermic reaction.
- Raising the temperature raises the rate of both endothermic and exothermic reactions but rate of endothermic reaction is raised more than exothermic reaction
- Lowering the temperature lowers the rates of both endothermic and exothermic reactions but rate of endothermic slows down more than exothermic reaction
- It is ONLY A CHANGE IN TEMPERATURE THAT CHANGES THE VALUE OF K_c
- Generally, $K_c = \frac{[\text{products}]}{[\text{reactants}]}$,
- K_c value will **increase** if a change in temperature causes leads to an **increase** in concentration of **products** , $K_c \propto [\text{products}]$
- K_c value will **decrease** if a change in temperature leads to an **increase** in concentration of **reactants** $K_c \propto \frac{1}{[\text{reactants}]}$

6.1 Worked Example

One of the key reactions in the gasification of coal is the methanation reaction, in which methane is produced from synthesis gas - a mixture of CO and H₂



How will an increase in temperature affect

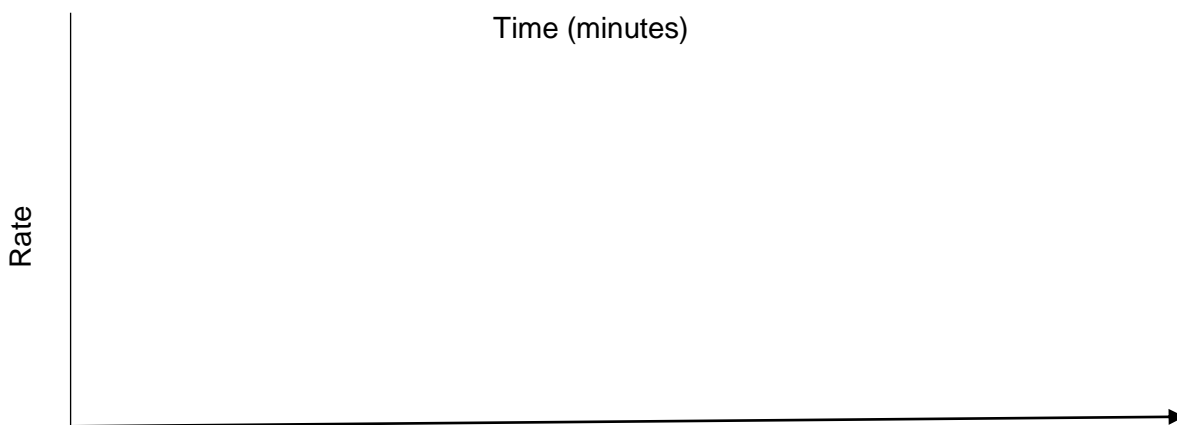
- The amount of CH₄ in the system
- K_c
- Rate of forward reaction
- Rate of reverse reaction
- Sketch the graph of amount verses time to show the changes that occur to the from equilibrium state one to equilibrium state 2
- Sketch the graph of rate versus time to show how the rates of reaction change from equilibrium state 1 to state 2

Answer

- a) The amount of CH_4 will
- b) K_c will because.....

- c) Rate of forward reaction will because.....

- d) Rate of reverse reaction will because.....
 however.....



Time (minutes)

6.2 Argumentative discussions and writing

The following reaction reaches equilibrium in a closed container at 500°C:



5.2.1 Our Argument 1

Problem / Question:

- a) What will happen to the amount of SO_3 formed when the container is heated further to 700°C?
- b) How will this change affect the value of K_c

Our claim / belief	a) We think that heating the container further to 700°C will..... b) We think that heating the container further to 700°C will.....
Data / Evidence	a) Our evidence for this is b) Our evidence for this is.....
Reason	a) This evidence supports our idea because b) This evidence supports our idea because

	<p>.....</p> <p>.....</p> <p>.....</p>
Counter-argument	<p>a) Someone might argue against our idea by saying that increase in temperature increases the rate of reaction and more product (SO₃) will form</p> <p>b) Someone might argue against our idea by saying that increase in temperature will increase K_c because more products will be formed.</p>
Rebuttal	<p>a) If someone does not agree with us, we would convince him / her by</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>b) If someone does not agree with us, we would convince him / her by</p> <p>.....</p> <p>.....</p> <p>.....</p>

6.2.2 Our Argument 2

Problem / Question: The reaction $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2 \text{NO}_2(\text{g}), \Delta H = +57.2\text{kJ}$ occurs in a

Colourless Brown

sealed glass vessel at 100°C.

- a) What will happen to the colour of the vessel if is placed in an ice bath?
- b) How will this change affect the value of K_c?

TAKE NOTE! COLOUR INTENSITY IS AN INDICATION OF CONCENTRATION

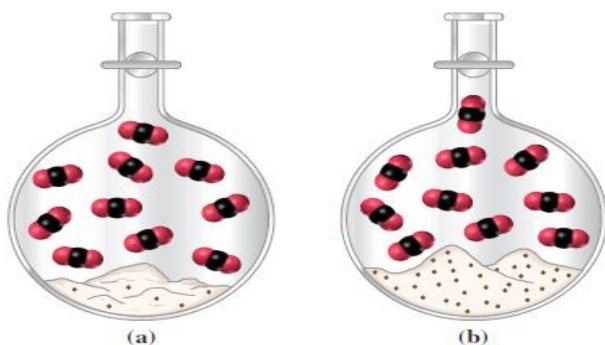
Our claim / belief	<p>a) We think that placing the vessel in an ice bath will</p> <p>.....</p> <p>b) We think that Kc will</p> <p>.....</p>
Data / Evidence	<p>a) Our evidence for this is</p> <p>.....</p> <p>b) Our evidence for this is.....</p> <p>.....</p>
Reason	<p>a) This evidence supports our idea because</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>b) This evidence supports our idea because</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p>
Counter-argument	<p>a) Someone might argue against our idea by saying that placing the vessel in an ice bath will make the vessel colourless because the reverse reaction is favoured at a lower temperature</p> <p>b) Someone might argue against our idea by saying that Kc will decrease because temperature has decreased</p>
Rebuttal	<p>a) If someone does not agree with us, we would convince him / her by the vessel cannot become colourless completely because.....</p> <p>.....</p> <p>.....</p>

	<p>.....</p> <p>b) If someone does not agree with us, we would convince him / her by</p> <p>.....</p> <p>.....</p>
--	--

LESSON 7: HETEROGENEOUS EQUILIBRIUM

The decomposition of CaCO₃(s) on heating reaches equilibrium in a closed container:

CaCO₃(s) ⇌ CaO(s) + CO₂ (g) (a). After equilibrium is established, some CaCO₃(s) is added to the system (b)



Our Argument

Problem / Question: What will the addition of pure CaCO₃(s) have on equilibrium condition?

Our claim / belief	We think that
Data / Evidence	Our evidence for this is
Reason	This evidence supports our idea because
Counter-argument	Someone might argue against our idea by saying that the equilibrium will shift to the right to produce more product because

	according Le Chatelier's principle, when the concentration of a substance is increased the reaction that uses that substance will be favoured
Rebuttal	If someone does not agree with us, we would convince him / her by.....

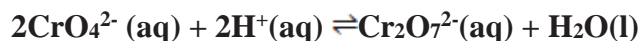
Write the equilibrium constant expression K_c for each of the following reactions. In each case, cross out the reactant or product which should not appear in the K_c expression.

- $\text{H}_2\text{S}(\text{g}) + \text{I}_2(\text{s}) \rightleftharpoons 2\text{HI}(\text{g}) + \text{S}(\text{s})$.
- $\text{C}(\text{s}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + \text{H}_2(\text{g})$
- $\text{Ca}_5(\text{PO}_4)_3\text{OH}(\text{s}) + 4\text{H}^+(\text{aq}) \rightleftharpoons 5\text{Ca}^{2+}(\text{aq}) + 3\text{HPO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l})$.
- $2\text{CO}(\text{g}) + \text{MoO}_2(\text{s}) \rightleftharpoons 2\text{CO}_2(\text{g}) + \text{Mo}(\text{s})$
- $\text{S}(\text{s}) + \text{O}_2(\text{g}) \rightleftharpoons \text{SO}_2(\text{g})$
- $\text{CaCO}_3(\text{s}) \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$

LESSON 8: COMMON-ION EFFECT

TAKE NOTE! COLOUR INTENSITY IS AN INDICATION OF CONCENTRATION

You were given the following materials: potassium dichromate solution, $\text{K}_2\text{Cr}_2\text{O}_7$ (aq) sodium hydroxide solution, NaOH (aq) and nitric acid HNO_3 (aq). Design and conduct an experiment to investigate the effect of pH on the chromate - dichromate equilibrium system. The reaction occurring is:



Yellow

Orange

Problem / Question 1: Your teacher is going to add NaOH (aq) solution to the $K_2Cr_2O_7$ (aq) in which the above equilibrium exists. Before the addition predict what will happen to the colour of the solution and explain why the colour would change that way

Our claim / belief	We think that
Data / Evidence	Our evidence for this is
Reason	This evidence supports our idea because
Counter-argument	Someone might argue against our idea by saying that
Rebuttal	If someone does not agree with us.....

Problem / Question: Your teacher is going to add nitric acid HNO_3 (aq) solution to the $K_2Cr_2O_7$ (aq) in which the above equilibrium exists. Before the addition predict what will happen to the colour of the solution and explain why the colour would change that way

Our claim / belief	We think that
Data / Evidence	Our evidence for this is
Reason	This evidence supports our idea because

Counter-argument	Someone might argue against our idea by saying that
Rebuttal	If someone does not agree with us, we would convince him / her by