THE EFFECT OF LABORATORY BASED TEACHING AND TRADITIONAL BASED TEACHING ON STUDENTS' CONCEPTUAL UNDERSTANDING OF CHEMICAL EQUILIBRIUM

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The Effect of Laboratory Based Teaching and Traditional Based Teaching on Students' Conceptual Understanding of Chemical Equilibrium

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DECLARATION

I hereby declare that this dissertation is the result of my own investigation and has not been submitted previously for any degree at any University, except where acknowledged.

S S Mathabatha

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DEDICATION

This dissertation is dedicated to my late wife, Maupe Endy Mathabatha.

ABSTRACT

The purpose of this abstract is to report on the results of the study conducted to identify misconceptions concerning chemical equilibrium concepts, and to investigate the effectiveness of Laboratory Based Teaching (LBT) compared to Traditional Based Teaching (TBT) on University of Limpopo Foundation Year (UNIFY) students' understanding of chemical equilibrium concepts. The subjects of this study consisted of 53 UNIFY students from two chemistry classes. The data were obtained from 27 students receiving LBT and 26 students in the TBT. The validated Misconception Identification Test (MIT) was administered to diagnose students’ misconceptions in different areas of chemical equilibrium. Analysis of the Pre-MIT and open-ended responses revealed widespread misconceptions such as:

- Left – and right – sidedness: Students perceive each side of a chemical equation as a separate physical quantity.
- The constancy of the equilibrium constant: This includes the ability to judge when and how the chemical equilibrium constant changes. This possible misconception refers to the changes in concentration, pressure and temperature as well as the addition of a catalyst. For example, students fail to grasp the influence of the catalyst on a chemical system, viz., that it has an effect on the reaction rates but not on the equilibrium as such. They perceive the catalysts as leading to a higher yield of the product.
- Rate versus extent: Inability to distinguish how fast the reaction proceed (rate) and how far (extent) the reaction goes.
- Definition of equilibrium constant expression: Inability to relate the equilibrium concentrations of reactants and products using the equilibrium law.
- Misuse of Le Chaterlier’s principle: The application of Le Chaterlier’s type reasoning in inappropriate situations.

To address the identified misconceptions, practical based activities on certain aspects of chemical equilibrium were developed as resource material for one group of students (Laboratory Based Teaching - LBT) and similar activities having the same chemistry content consisting of tutorial questions, theoretical background of some aspects and some experiments were used as resource material for the other group (Traditional Based Teaching - TBT). After both instructions, analysis of the Pre MIT and Post MIT results using t – test statistic for each group revealed significant difference between the means of the sample. This implied that both instructions have contributed significantly to the students' improvement in their misconceptions. Again after both instructions, analysis of the Post MIT results for the two groups using the t-test revealed a significant difference between the two group's sample means. This implied that the misconceptions in the LBT group were reduced significantly as compared to misconceptions held by students in the TBT group. After both instructions, more students in the LBT group had correct representation of mental models of reactions in equilibrium than the students in the TBT group. Implications for science education classroom practice are also discussed.

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CHAPTER 1

INTRODUCTION

1.1 Rationale for the Study

The rationale for the study was influenced by the way I positioned myself as a reflective chemistry teacher. I wanted to find out whether students entering the University of Limpopo Foundation Year Programme (UNIFY) have conceptual difficulties regarding the topic ‘chemical equilibrium’ and whether the Chemistry teaching of that topic within UNIFY can address those misconceptions. A reflective teacher would ask himself/herself the following sorts of questions: Why do I teach what I teach? How do I teach what I teach? What is the science background of the learners I teach? What kinds of assessment methods are suitable for the objectives of the curriculum? What kind of learning environment must be created for conducive teaching and learning? What are the social interactions that will produce appreciable learning conditions for students? Being critical of our actions and documenting them can answer these questions. These kinds of questions recurring in reflective teaching and learning motivated me to formulate some questions on the types of foundation year students’ mental models, conceptual difficulties in chemical equilibrium, and the effectiveness of the teaching and learning strategies used in UNIFY Chemistry.

Lack of a research database on the actual classroom and laboratory practices within the UNIFY Chemistry section also prompted me to undertake this study. As an educator, I felt very responsible for the activities (actions) that I do as my daily work, and teaching chemistry has always been my first priority. So I saw the need to conduct the present study so that I can have documented evidence on the research that is taking place within the Chemistry section. Having documented research will help not only the researcher, but also other colleagues within and outside the UNIFY programme. New educators joining the UNIFY programme will be in a position to see what was done before within the Chemistry section and what were the recommendations for further research within that area or field. A research database can also serve as a motivation for these new teachers as it will challenge them to do more research that might be similar or different to that done before, so that they can also leave some legacy for other new teachers.

In the past years, researchers have described the state of science in the South African schools as being characterized by inadequacy and under-preparedness of students in various aspects of knowledge and skills (Craig, 1989; Moll & Slonimsky, 1989; and Gray, 1995). In particular, practical based sciences in schools have suffered the most, because of large class sizes, inadequate laboratory equipment and shortage of qualified teachers. These pervasive difficulties in schools have resulted in what Nyagura (1996) describes as an inadequate teaching and learning environment, one that does not expose students to scientific skills and processes that are important in revealing the nature and genesis of scientific knowledge. Similar factors depicting inadequacy and under-preparedness in practical science have been reported in research from other parts of the Southern African region (Ogunniyi, 1993; and Nyagura, 1996). This state of affairs is unacceptable given the crucial role of practical science in promoting the development of students' understanding and application of scientific concepts, skills and processes. It also runs contrary to the perceived centrality of practical science in developing an appropriate culture of scientific thinking and practice at school level as shown by science education researchers in the UK (Yager, 1991; Tamir, 1991; and Millar, 1991).

It is a fact that science teaching and learning in the Limpopo Province of South Africa is given a priority by the provincial government. This is because despite many science education interventions such as Science and Mathematics Enrichment Programme which targeted in-service mathematics and science teachers, and numerous winter schools for science students at Grade 12 level, the pass rate of the Grade 12 Physical Science is low. So it was very important for me as a science teacher to look at some problems or conditions that result in the poor performance of our Grade 12 Science students. One such problem was the misconceptions possessed or held by entering foundation chemistry students coming directly from Grade 12.

1.2 The UNIFY programme

UNIFY is a University Foundation Year Programme in Maths and Science at the University of Limpopo. The overall aim of having UNIFY is to increase the quality and quantity of qualified science and technology manpower in South Africa (Zaaiman, 1998).

1.2.1 The UNIFY objectives

Given the starting position of the students entering the programme, and where the students should be after UNIFY so that they will be successful in Year 1(mainstream), UNIFY formulated the following objectives:

- To improve students' cognitive and practical skills. This includes thinking critically and logically, appreciation of the role of models in explaining concepts and limitations thereof, manipulation of equipment, experimental design, laboratory practice and safety, and the handling of information;

- To develop attitudes that are conducive to learning. This includes realization that rote learning must be replaced by learning for understanding, realization of whether something is understood or not, realization that the learner is responsible for learning – that the learner generates knowledge instead of merely receiving knowledge, development of a positive self-esteem and confidence, active participation in the learning process and developing ownership of the learning process, preparedness to put in a lot of effort, and the readiness to seek assistance from peers and/or staff if need be; and

- For students to achieve a better understanding of the fundamental aspects of mathematics and science and a mastery of the English language in as far as it is needed for further science studies.

These objectives serve as a guideline for the activities undertaken within the UNIFY project. Although every section of the UNIFY programme has its own focussed course objectives, those objectives are derived from these main ones given above.

1.2.2 The UNIFY Teaching Strategies

UNIFY follows a student centred approach. This translates to several teaching strategies. To name a few;

- Group organisation. Teaching and learning is conducted in small groups of 30 students;

- A purposeful selection of content. Content is selected such that it provides an opportunity to develop cognitive and practical skills. Hence content is basic but rich in conceptual ideas. Topics that allow generation of knowledge by means of simple experiments are preferred;
- Focus on practical work. Theory and practical work are strongly interrelated. Experiments and worksheets are designed such that conceptual understanding is enhanced. Most teaching occurs within tutorial settings; very little time is allocated for formal lectures;
- English and role of language. The teaching of English and study skills aims at mastery of English within the context of science and mathematics. Emphasis is placed on the specific type of English used in these subjects and the needed skills such as report writing and note taking;
- Cooperative learning is strongly encouraged. Practical work is executed in pairs and students are encouraged to work together in tutorials and in some assignments;
- Counselling and guidance form a very strong integral part of the programme. Each group of 30 students is assigned a mentor or group advisor who is a member of staff. His/her role is to discuss progress with students individually. Advisors also assist with personal problems.

These strategies serve as a guideline for the teaching and learning activities undertaken within the UNIFY project. Although every section of the UNIFY programme has its own focussed teaching and learning strategies, those are derived from these main ones given above.

1.2.3 The UNIFY courses

The UNIFY programme consists of five courses, namely, Foundation Mathematics, Foundation English and Study Skills, Foundation Biology, Foundation Physics and Foundation Chemistry. There is a close relationship between topics taught in these courses, for example, in Foundation English, the lecturers use chemistry, biology and physics topics to teach students scientific writing or reporting. The concept of proportion is taught by Foundation Mathematics lecturers, but is widely applied in all other UNIFY science courses.

1.2.4 Chemistry in UNIFY

1.2.4.1 Background

Chemistry is a practical science. In UNIFY Chemistry, we believe that both observations and experiments build up adequate knowledge in the study of chemistry. In every chemistry topic that we teach, there are related practicals. We believe that practical work in UNIFY chemistry helps to make the understanding of concepts easier for the students. It helps students to develop a scientific way of thinking. We have a significant number of practicals and theory content that incorporate daily life applications and as such accommodates the variety of experiences that students have accumulated before studying chemistry. Most of the theory and experimental work are intertwined where possible. Experiments have been carefully selected such that they enhance the understanding of concepts. In some cases, we find it suitable to start a topic using a suitable experiment to arouse the students' interest and clear some misconceptions. This approach does not work for all the topics because some are more abstract in nature. To enhance collaborative learning, practical work is executed in pairs.

The UNIFY Chemistry students are given student material that comprises, among other things, the introduction to chemistry, the Year Programme, contents and assessment strategies, some theory work for all the topics, all practicals related to theory topics, homework and project activities, and a sample of the Exam Paper. The topics that are taught in the UNIFY chemistry course and are included in the UNIFY Chemistry Student Manual are, chemical awareness, stoichiometry, periodicity, thermochemistry, reaction kinetics, equilibrium, and introduction to organic chemistry. The Vrije Universiteit Amsterdam chemistry staff, in collaboration with the University of Limpopo (UL) and UNIFY chemistry staff, developed the chemistry student materials. The materials have been used since the inception of UNIFY, and every year they are reviewed. The students are also given a Book of Data, which consists of important information such as constants, units, physical and thermochemical data of substances, etc., and a prescribed textbook which they use for further reference where necessary. The textbook given is the same as the one used by the Year 1 (mainstream) chemistry students.

From the year 1999 to the year 2001 the Chemistry Laboratory Learning Environment (CLLE) questionnaire is administered. This study is done so that we are in a position to know the needs of our students in relation to the laboratory environment that must be created. These needs are captured by the administration of the CLLE questionnaire developed and validated by Fraser and Giddings (1995). The CLLE questionnaire has five scales. These are (1) Student Cohesiveness – this is the extent to which students know, help, and are supportive of each other, (2) Open-Endedness – this is the extent to which laboratory activities emphasize an open-ended, divergent approach, (3) Integration – this is the extent to which laboratory activities are integrated with non-laboratory and theory classes, (4) Rule Clarity – this is the extent to which behaviour in the laboratory is guided by formal rules, and (5) Material Environment – this is the extent to which the laboratory equipment and materials are adequate. Each of these scales has seven items. The CLLE questionnaire has the preferred and actual version for both themselves and the class. Valuable information that guides the laboratory practice is gathered through the administration and analysis of the questionnaire.

Since 2001, the UNIFY Chemistry staff also administer the Laboratory Experience Survey. The purpose of this survey is to find out from the entering foundation year students how much laboratory exposure they received before entering the institution of higher learning. The survey also attempts to establish whether the students remember or know some basic science laboratory equipment. The instrument used for the survey was developed by Rollnick et al. (1999) and was used by Lubben et al. (2000) in similar surveys. The results of the surveys indicated that many students did not have much exposure to physical science practicals.

1.2.4.2 Objectives of UNIFY Chemistry

The major intentions of the UNIFY chemistry curriculum are (1) to allow students to attain practical skills that are valuable for further studies in the line of chemistry, (2) to allow students to expand their chemistry content knowledge with understanding, (3) to allow students to appreciate the world of chemistry (see chemistry from societal point of view) and its relationship with other courses within or outside UNIN. Specific topics within the Chemistry curriculum have their specific outcomes.

1.2.4.3 Teaching and learning setting in UNIFY Chemistry

The teaching and learning in foundation Chemistry is organized into lecture, tutorial, projects and practical. Fifty percent (50 %) of the teaching and learning done in Chemistry is by practicals. Lecturing, tutorials, and projects constitute the other 50 % of teaching and learning. The teaching arrangement and social context taking place within Chemistry are briefly described below.

One period per week is assigned for the lecture session. The lecture session is semi-formal in the sense that the teacher uses it to introduce new topics and abstract concepts, especially those involving mathematical relationships and graphs. It is however the responsibility of a student to find information relevant to new topics so that at the start and during the lecture the student can actively participate. The teacher always assesses the understanding of concepts involved in a particular topic before teaching it. Although there is interaction between the students and the teacher during the lecture period, that interaction is minimal in the sense that the time given for the lecture is very limited. Interaction between the students as a group is also limited. Interaction occurs only between the students within the same physical neighbourhood. The teacher mostly encourages this kind of interaction during the lecture period. Individually, the students are aware that they must account for whatever they say or write down.

Two successive (continuously one after the other) periods per week are assigned for tutorial sessions. The tutorial sessions are less formal because during these sessions students will be actively involved in discussions of concepts, homework, tutorial tasks, assignments and some practical activities. Some demonstrations are made during tutorial settings to help students understand some concepts. These demonstrations are only those that are easy to carry out in a classroom setting and are not harmful or do not pose any threat to human health. During the tutorial session, the teacher's role is to help learners understand and complete their tasks where necessary. During the tutorial session, a student would interact with small group, whole class and the teacher to a full extent.

Three successive (continuously one after the other) periods per week are assigned for a practical session. The practical periods are formal because students are given structured practicals to perform. Before each practical activity there is a preparatory laboratory session whereby the teacher introduces the practical, checks the students' pre-lab reports and highlights the disciplinary measures and dangers that students might face during the practical. As mentioned before, students perform practicals in pairs. No single student is allowed to scribe throughout the experiment while the other one does the actual work. Students are not allowed to discuss in detail their results in the laboratory except where the teacher has given permission. The interaction between the students as a class is therefore limited. However, more rigorous interactions do occur between each pair of students and also between the pair and the teacher. The students must understand these meanings beyond any reasonable doubt so that they can later communicate them with their peers. The teacher always encourages students to make accurate observations and record results, even if they are unexpected. Students are gradually introduced to scientific report writing in the first and second practicals and thereafter they are expected to know how to write scientific reports. This time span given to students is found to be efficient of report writing activities in other UNIFY courses such as Foundation English and Study Skills, Foundation Biology and Foundation Physics. Independent group projects are also organized within the chemistry section to encourage investigative skills.

1.2.4.4 The choice of chemical equilibrium in UNIFY Chemistry

The choice of the topic was influenced by many factors. I had to look into literature reviews for many topics that are offered in UNIFY, consult other colleagues for interest sake but also not compromising my interests, and consult both students and high school science teachers. Of most important, the choice was informed by the ongoing international research on misconceptions, students' difficulty in understanding the concept itself and remediation strategies in chemical equilibrium.

Chemical equilibrium is an abstract concept demanding the mastery of large number of other concepts, and as has been reported (Finley et al., 1982), it is considered to be one of the most difficult chemistry concepts to teach, involving a high level of student understanding. A lack of understanding or mastery of the principles of chemical equilibrium, or an inability to transfer them to new situations, is one of the sources of difficulties which students encounter with the topics of redox (Allsop and George, 1984), acid and base behavior (Banerjee, 1991; Camacho and Good, 1989), and solubility (Buell and Bradley, 1972).

When students begin studying chemical equilibrium they ordinarily have no preconceived ideas regarding chemical equilibrium. Nevertheless, it has been noted that, as topics related to this important concept are explained on, a number of misconceptions and obstacles to learning present themselves pertaining to the following problematic aspects of understanding.

a) The essence of chemical equilibrium concept (Akkus et al., 2003, Voska and Heikkinen, (2000); Chiu et al., 2002; Berquist and

Heikkinen, 1990; Camacho and Good, 1989; Cros et al.,1984; Hackling and Garnet, 1985; Wheeler and Kass, 1978).

b) Interpretation of the reversed arrow convection (Cros et al., 1984; Johnstone et al., 1977).

c) Left and right sidedness (Akkus et al., 2003; Huddle and Pillay, 1996; Gorodetsky and Gussarsky, 1986).

d) The effect of changing equilibrium conditions: Le Chatelier's Principle (Huddle and Pillay, 1996; Voska and Heikkinen, 2000; Banerjee, 1991; Berquist and Heikkinen, 1990; Camacho and Good, 1989; Cros et al., 1984; Hackling and Garnet, 1985; Wheeler and Kass, 1978).

e) Confusion between rate and extent of reaction (Banerjee, 1991; Driscoll, 1960; Gorodetsky and Gussarsky, 1986)

f) The effect of adding a catalyst (Gorodetsky and Gussarsky, 1986; Huddle and Pillay, 1996; Hackling and Garnet, 1985).

g) Heterogeneous systems: difficulties in mass-concentration (Wheeler and Kass, 1978) and in the appication of Le Chatelier's Principle to find the response to changes in the amounts of solids (Pardo and Portoles, 1995; Gorodetsky and Gussarsky, 1986).

In most cases, such conceptual errors should not be viewed as spontaneous ideas but rather as ensuing from being taught (Johnstone et at., 1977; Hackling and Garnett, 1985; Akkus et al., 2003). Among other things they are a product of the teaching context because of the analogies used by teachers, textbooks, other teaching and learning reference materials to teach the chemical equilibrium concept (Maskill and Cachapuz, 1989). At times those conceptual errors are even coupled with language problems (Berquist and Heikkinen, 1990), as students make their own associations and analogies based on concepts used in physics and daily living (Gorodetsky and Gussarsky, 1986).

It is a fact that many students worldwide have difficulties with many concepts in chemical equilibrium as by literature stated above. It also is a fact that almost many students entering the UNIFY programme complain about the difficulty of the topic of chemical equilibrium as studied at Grade 12 level. This is confirmed by the unpublished data (Mathabatha, 2002a) collected from entering foundation year (UNIFY) students at the University of Limpopo on the attitudes towards chemistry topics done at Grade 12 level. Although most students have been taught the topic of chemical equilibrium and were also exposed to some practical work during the teaching and learning of this topic, they dislike it because of its complexity. The practical work done at Grade 12 is just not enough to enable them to grasp the concepts involved with ease. I discovered that a wide variety of misconceptions held by the UNIFY students and entering University mainstream (Year 1 Chemistry) students are also held by most of the high school science educators. This information was captured by a misconception identification test (same as the one used in this study), whereby the same questionnaire given to teachers was also given to students (Unpublished work of Mathabatha, 2002b).

Some of the objectives of the module of chemical equilibrium offered in UNIFY Chemistry are, namely, (1) to enable students to distinguish between static and dynamic equilibrium, (2) to enable students to distinguish between molecular and symbolic representations of species existing at equilibrium, (3) to enable students to observe, interpret and understand the effect of various variables on homogeneous gaseous and liquid chemical reactions in equilibrium, and (4) to enable students to understand the effect of variables on the equilibrium constant of some reactions at equilibrium. Although there are other objectives for this topic, these four objectives were the most relevant to my study.

1.3 Aim of the Study

The primary aim of the study was to investigate the effectiveness of laboratory based teaching (LBT) and traditional based teaching (TBT) in enhancing the conceptual understanding of chemical equilibrium concepts in UNIFY chemistry. LBT in this case refers to the teaching process (activities) that was undertaken by students in the laboratory setting. The integrated learning material, including theoretical and practical based tasks, was developed and implemented with one group of students in the foundation year chemistry course. In this case, all learning activities were done in a laboratory setting. By contrast, the TBT is defined as a teaching approach whereby a lecturer gives a lecture, tutorials and practicals separately. Teaching and learning of the content is separated into distinct lectures, tutorial and practical sessions. The interaction between the teacher and the students is limited by the focused questions from the teacher.

The above aim of the study was achieved by comparison of the nature of student misconceptions about chemical equilibrium before and after instruction according to each of these models. A misconception refers to an individual's ideas that conflict with the accepted scientific ideas as a result of some parts of such ideas that contain either incorrect, or correct and incorrect aspects. The students' mental models and the validated Misconception Identification Test (MIT) were used to identify misconceptions in some aspects of chemical equilibrium. A model is a representation of an object, event or idea.

This representation creates a vehicle through which the object, event or idea can be conceptualized and understood. A mental model is the model that each of us visualizes in our mind. The students developed these mental models using some common chemical equilibrium reactions, such as the reaction between $Fe^{3+}(aq)$ and $SCN^{-}(aq)$, to produce $FeSCN^{2+}(aq)$ and all the information accumulated in high school as well.

1.4 Research Questions

The research aim stated above is very broad. It was therefore necessary to state the research questions as follows:

1. What misconceptions exist in the area of chemical equilibrium reactions among entering foundation year students?
2. What effect will the Laboratory Based Teaching and Traditional Based Teaching have on entering foundation year students' understanding of chemical equilibrium concepts?

In relation to the first research question, I intend to establish the misconceptions that students possess with regard to some concepts of chemical equilibrium. For example, students usually attach different meanings to the reverse arrow used to indicate reactions in equilibrium. They use it like the equality sign in mathematics. By using the misconception identification test and analyzing the students' mental models, I could detect some conceptual difficulties held by the students.

In relation to the second research question, my intention was to determine whether or not the LBT and TBT methods I used have some effect on the improvement of students' conceptual understanding. I looked into the misconceptions (identified by the misconception identification test and mental models) before and after instruction.

1.5 Significance of the Study

The study will add value to the current literature on identification and remediation of misconceptions. As in most review studies, the identification of misconceptions is done solely by the use of a pencil and paper multiple choice test. However, in this study, the use of data interpretation from interviews was helpful in consolidating the identified misconceptions. The detailed description of LBT and TBT used to remedy the misconceptions will also be helpful to other science educators and researchers.

The study enabled me to understand the conceptual difficulties held by students in the area of chemical equilibrium. Through my interaction with students in this study, I could see the way I was growing professionally and academically. The knowledge I gained through this study has added value to my personal view of conceptual development in this study area. I could use some of the methods employed in this study on other topics within UNIFY chemistry.

The findings of this study could help the UNIFY chemistry section to prepare learning materials that match the students' level of conceptual understanding of this chemical concept. This information, if disseminated properly, can also enlighten the mainstream chemistry teachers about the conceptual difficulties held by first entering students.

The findings of this study would also provide high school teachers with resource support materials based on science education research for the teaching and learning of various aspects of equilibrium. They would also familiarize teachers with the reported literature on conceptual difficulties and misconceptions in various areas of chemical equilibrium. The findings of the study will add value to the educational research literature on conceptual difficulties encountered by foundation year chemistry students. They may also provide an alternative method for the teaching and learning of some chemistry concepts that can be adopted by most science educators having the necessary support structures and facilities.

1.6 Overview of the Dissertation

The contents of this dissertation contain the following: Literature review in Chapter 2; Research methodology in Chapter 3; Results and discussion in Chapter 4; Conclusion and Implications in Chapter 5; and References and Appendices respectively follow Chapter 5.

CHAPTER 2

LITERATURE REVIEW

In this chapter, I will outline some important aspects from the literature review relevant to this study. The review consists of an introduction, misconceptions in chemical equilibrium, mental models, laboratory teaching and the theoretical framework of the study.

2.1 Introduction

Science education is becoming increasingly popular and important as it is seen as a means of improving the method of scientific thinking, providing students with more experience of explaining and interpreting their environment and capable of finding a solution to a problem (Akkus et al., 2003). In recent years research has focused on identifying and characterising students' understanding and difficulties about many science topics in science education. It has been widely accepted that learning is the result of an interaction between what the student is taught and his/her current concepts (Revised National Curriculum Statement, 2002). The cognitive structure of the learner prior to a new instruction determines the fate of the learning process. Concepts, schemes, rules, etc. are referred to as the cognitive structure of the learner (Ausubel, 1968). According to the cognitive model, students build an understanding of the events and phenomena in their world from their own point of view (Osborne and Wittrock, 1983). Before instruction, students have views and explanations of natural phenomena that differ from the views held by scientists (Osborne, 1982). These different concepts have been called preconceptions (Driver and Easley, 1978). Research has consistently shown that students do not come to the classroom with blank slates, rather they come with a well-established understanding about how and why everyday things behave as they do (Posner et al., 1982). During instruction, learners generate their own meaning based on their backgrounds, attitudes, abilities and experience.

Student mastery of new material is believed to depend upon students' ability to integrate the new information with existing knowledge. Bodner's (1986) summary of the constructivists' view stresses that a learner strives to organize information in terms of previous experiences. He also views learning as a process of "equilibration" as students attempt to relate new information to their existing knowledge through the processes of assimilation and accommodation. Johnstone et al., (1977), define learning as an active process, occurring as a result of mental construction by a learner. These authors' stress that knowledge and meanings are actively constructed in the mind of a learner. A common perception in the Constructivist approach is that, prior beliefs can interfere with new learning by causing rejection or, at least, a restructuring of the new material to fit current ideas. Moreover, intuitive conceptions resist change, since many of them are often in direct conflict with the new material (Gilbert and Watts, 1983). Learners appear to accept selectively those events that support their conceptions while ignoring, even rejecting, and those observations that conflict. Therefore, it becomes very important that chemical educators attempt to identify the nature and depth of their students' "common sense" ideas rather that assuming that working examples and defining new vocabulary will lead students to the same degree of understanding that they have gradually come to possess. Education should be thought of as producing change in a student's conceptions rather than simply accumulating new information within the student memory.

By the time children enter school and are experienced in formal instruction, their preconceptions about natural phenomena are often well developed. In some instances, these preconceptions are precursors of concepts, principles and theories. Sometimes in science lessons, however, the preconceptions may be at odds with the accepted scientific concepts on which formal instruction is based. In these cases, the preconceptions may prove a serious obstacle to the acquisition of scientific concepts. The focus of much of the science education research has been on children's conceptions which are not in agreement with the experts. These different conceptions generated by students have been called misconceptions (Fisher, 1985; Lin and Chang, 2000).

The common aim of all science education researchers is to help students learn science subjects in the most appropriate way. There has been many investigations in science teaching strategies and curriculum development in order to improve the effectiveness of science teaching. In the last two decades, educators have emphasized the constructivist approach in teaching science. According to the constructivist model learning, all of our knowledge is the result of our having constructed it (Tobin, 1990; Trumper, 1997). The constructivist view is very a powerful and influential perspective to many science education research studies. In this view, the most important ingredient in the process of learning is the interaction between new knowledge and existing knowledge.

Learning science is an attempt to explain and account for the real nature of the physical universe; it is not simply a matter of making sense of the world. In this sense, people give much emphasis to constructivist teaching, because this teaching has many advantages. Hodson (1992), summarized the main four steps of the constructivist approach: (1) identify students' ideas and views, (2) create opportunities for students to explore their ideas, (3) provide stimuli for the students to develop, modify and where necessary, change their ideas and views, and (4) support their attempts to rethink and construct their ideas and views. The teacher's role is merely to provide support in helping students to find sources of information or perhaps in breaking down problems. According to Saunders (1992), in the constructive perspective, meaningful learning or understanding is constructed in the internal world of the learner as a result of his/her sensory experiences with the world. Therefore, the more effective learning activities should be developed to help students acquire meaningful learning in place of role learning. To assure meaningful learning, students should be able to construct and organize their knowledge in away that can direct them to use required information accurately.

The constructivists approach can be reinforced with conceptual change instruction which lets students activate and modify their existing knowledge or misconceptions. Currently, many innovative curricula and teaching strategies are constructed such that they are directed towards the building of conceptual change from alternative to scientific conceptions (Strike and Posner, 1992; Chambers and Andre, 1997). In this study, the laboratory instruction as a model of conceptual change based on constructivist principles and cognitive apprenticeship model was designed. Students were asked explicitly to predict what would happen in a situation before being presented with the information that demonstrated the inconsistency between common misconceptions and the scientific conceptions. Some researchers have reported that teaching informed by the conceptual change based on the constructivist principles caused a significantly better acquisition of scientific concepts and elimination of misconceptions (Guzetti et al., 1993; Hynd et al., 1994).

2.2 Misconceptions on chemical equilibrium

Chemical equilibrium is a core chemical concept, an understanding of which is essential for most qualitative and quantitative work in chemistry and thus its study forms the central part of advanced chemistry courses (Wheeler and Kass, 1978). Studying equilibrium, therefore, involves both difficult and/or repetitive calculations. It is a conceptual area where previous work (Banerjee, 1991) has shown that students have well-structured 'alternative conceptions' that are highly resistant to change. Research (e.g. Hackling and Garnett, 1985; Gussarky and Gorodetsky, 1988; and Cachapuz and Maskill, 1989) has reinforced the feeling, long held by teachers, that many pupils find the concept of chemical equilibrium difficult. In particular, it has highlighted the way that students base their understandings of chemical equilibria on ideas and meanings associated with other, more everyday, concepts of equilibrium. They have a different qualitative understanding of 'the way things are' to a scientist.

It is also a conceptual area where previous work (Banerjee, 1991) has shown that students have well-structured 'alternative conceptions' which are highly resistant to change. Research (e.g. Hackling and Garnett, 1985; Gussarky and Gorodetsky, 1988; Cachapuz and Maskill, 1989) has reinforced the feeling, long held by teachers, that many pupils find the concept of chemical equilibrium difficult. In particular it has highlighted the way that students base their understandings of chemical equilibria on ideas and meanings associated with other, more everyday, concepts of equilibrium. They have a different qualitative understanding of 'the way things are' to the scientist. The misconceptions are so resistant to change that they present a major challenge to science educators (Hameed et al., 1993; Palmer and Flagen, 1997). Also, these misconceptions are very resistant to instructional change and some students persist in giving answers consistent with their misconceptions even after large amounts of instruction (Driver and Easley, 1978; Osborne, 1983; Champagne et al., 1985; Wandersee et al., 1994). What a student learns, therefore, results from the interaction between what is brought to the learning situation and what is experienced while in it (Stofflet, 1994).

The study of the behavior of the chemical equilibrium has been a fundamental part of high school chemistry courses for many years (Johnstone et al., 1977). This topic includes the concepts, which seem to give high school students trouble because they involve abstract concepts and some words from everyday language are used with different meanings. It has also been suggested that understanding the chemical equilibrium is fundamental to students' understanding other chemical topics such as acid and base behavior, oxidation/reduction reactions and solubility. Mastery of the concepts associated with equilibrium facilitates the mastery of these other chemical concepts. The concept of chemical equilibrium includes a label that is known to students attending chemistry classes and for which they have a preconception. This preconception stems from the label 'equilibrium' being used in Physics as well as in some everyday life balancing situations such as circus acrobatics, bicycle riding or weighing scales. The label 'equilibrium' acquires attributes that are characteristic of these situations. Attributes of equality in general, equality of two sides, stability, and a static nature become associated with the concept of chemical equilibrium (Schafer, 1984). However, these attributes of equilibrium are the very ones that actually differentiate between physical and chemical equilibria. Phenomena that reach chemical equilibrium appear naturally macroscopically as stable and static systems. On the their hand, on the microscopic level, the system is dynamic not only because of molecular movement but also because of the process of breaking and creating bonds goes on with the net result of zero. Attributing macroscopic qualities to the microscopic level leads to misconceptions in the understanding of the concept chemical equilibrium (Gussarsky and Gorodetsky, 1990).

Examinations can help determine which concepts and skills students already possess. Two qualities expected of any accepted assessment method are that (1) students' responses are valid – that is, they accurately reflect the student' current level of understanding, and (2) changes in test performance reflect changes that have taken place in students' minds. Unfortunately, correlations between understanding of concepts and written test performance are not as high as most educators might wish. Since high marks on an examination are generally interpreted by students as an indication that they understand the material, it is likely that such students will assimilate any misunderstandings of chemical equilibrium into their reasoning patterns and thus propagate additional misunderstandings about other chemical concepts. High-test scores may also mask basic student misunderstanding of major concepts. Many standardized chemistry examinations focus on computational skills and recall of definitions. Questions that require students to synthesize information and apply concepts are not very common in such examinations. To demonstrate the mastery of chemical equilibrium concepts, for example, students are typically asked to solve computational problems; correct results are accepted as an indication that students "understand" equilibrium correctly. Such a belief is risky since many equilibrium computations are readily solved by the application of an algorithm memorized through repeated drill. Thus, correct responses do not necessarily reveal whether a student understands chemical equilibrium or not, but only indicate that the student can compute equilibrium constants or calculate equilibrium concentrations (Hackling and Garnett, 1985). The conceptual understanding of chemistry by students is an important issue. Many students tend to memorise numerical equations or algorithm rather than actually learn the concepts. Therefore, they can solve numerical problems, but fail to answer conceptual questions (Hackling and Garnett, 1985; Kousathana and Tsaparlis, 2002; Huddle and Pillay, 1996).

Chemical equilibrium problems are among the most important, and at the same time most complex and difficult general chemistry problems (Kousathana and Traparlis, 2002). It is not the surprising that many researchers have dealt with them from a number of perspectives. Camacho and Good (1989) studied the problem solving behaviors of experts and novices engaged in solving chemical equilibrium problems, and reported that unsuccessful subjects had many knowledge gaps and misconceptions about chemical equilibrium. Wilson (1994) examined the network representation of knowledge about chemical equilibrium, and found that the degree hierarchical organization of conceptual knowledge (as demonstrated in concept maps constructed by the students) varied, and that the differences reflect achievement and relative experience in chemical equilibrium. Similar findings have previously been reported by Gussarsky and Gorodetsky (1988). On the other hand, a conclusion, which applies to the students in general, is that of Gabel et al. (1984), whose subjects used algorithmic methods without understanding the concepts upon which the problems were based. Niaz (1995) has compared student performance on conceptual and computational problems of chemical equilibrium and reported that students who perform better on problems requiring conceptual understanding also perform significantly better on problems requiring manipulation of data, that is, computational problems; he further suggested that solving computational problems before conceptual problems would be more conducive to learning.

Furio et al. (2000) used four qualitative tasks on chemical equilibrium, all involving Le Chatelier’s principle, and concluded that the procedural knowledge used by twelve-grade as well as first- and third year chemistry students (in Spain) in answering these tasks were very poor. Students apply mechanically reasoning based exclusively on Le Chatelier ‘s principle, even when a solid is added to a heterogeneous system at equilibrium or an inert gas is added to a homogeneous system at equilibrium. These authors maintained that students demonstrate a memoristic ‘fixedness’ of reasoning, which is the standard method that has been used (‘fixed’) previously in similar problems, and which hinders the students’ reflection of new situations.

Voska and Heikkinen (2000) developed a 10-item pencil and paper, two-tier diagnostic instrument, the Test to Identify Student Conceptualizations (TISC), and used it to identify and quantify chemistry conceptions students’ use when solving chemical equilibrium problems requiring application of Le Chatelier’s principle. They administered the test to students attending a second-semester university general chemistry course, after the students received regular course instruction, concerning equilibrium in homogeneous aqueous, heterogeneous aqueous, and homogeneous gaseous systems. Eleven prevalent incorrect student conceptions about chemical equilibrium were identified.

Banerjee (1991) for example, found that students often selected the correct multiple-choice answer on an examination dealing with chemical equilibrium without a corresponding level of understanding of the underlying concepts. Many students assumed that concentrations fluctuate as equilibrium is established and that addition of more reactant changes only the product concentrations. An additional misunderstanding that emerged was the belief that the volume of a gas could be different from the volume of the flask containing it.

Hackling and Garnett (1985) probed students' confusion regarding rates of the forward reactions as physical conditions changed. The most common misunderstanding was that the rate increased as a function of time – or as the reaction proceeds. Students also believed that the forward and reverse reactions alternate and exist as distinctly separate events when equilibrium is attained. In addition, Garnett and Hackling found that many students interpreted Le Chatelier's principle as implying the possibility for a change in conditions to increase the rate of the favoured reaction and at the same time decrease the rate of the opposing reaction.

Tyson et al. (1999) used a two-tier test, coupled with interviews from a case study, to explore students' understanding of what happens when reaction mixtures at equilibrium are disturbed. Three levels of explanation can be used at the secondary level: (i) (the qualitative statement of) Le Chatelier' principle; (ii) the (quantitative) equilibrium law; (iii) the (qualitative) consideration of changes that occur to the rates of the forward and the backward reactions (collision theory). According to the findings, it did not appear that one explanation is better than the other, while language (that is, the use of terms such as 'equilibrium position' or equilibrium balance) turned out to be a key factor, causing misinterpretations by students. Care should taken to identify not only the similarities but also the differences between physical and chemical equilibrium`

Wheeler and Kass (1978) found that students failed to distinguish between how fast a reaction proceeds (rate) and how far the reaction goes (extent). Many students believe that even though equilibrium reactions are reversible they still go to completion, whereas other students think that the forward reaction goes to completion before the reverse reaction commences. In addition to the above stated conceptual difficulties students have about chemical equilibrium and those stated in Chapter 1 of this thesis (pages 11 -12), the following areas were found to pose great challenges to students: (i) mole and concentration calculations (Berquist and Heikkinen, 1990; Hackling and Garnett, 1985) (ii) The meaning of K_c/ K_p (Camacho and Good, 1989; Wheeler and Kass, 1985) (iii) Competing equilibria (Driscol, 1960; Gorodetsky and Gussarsky, 1986; Akkus et al., 2003; Voska and Heikkinen, 2000).

In probing the quantitative aspects of equilibrium systems, Johnstone et al. (1977), found that students knew they had to compensate for changes in the concentration of one reactant but could not correctly adjust all species involved in the reaction. Students often acted on the belief that the concentrations of reactants must equal the concentrations of products at equilibrium. In addition, these studies identified a general inability of students to distinguish between mass and concentration. In investigating the misconceptions of students and teachers in chemical equilibrium, Banerjee (1991) found that both groups had high misconceptions despite professional experience in the case of the teachers. Akkus et al. (2003), successfully used instruction based on a constructivist approach to address students' misconception. They also found the new misconception that "when one of the reactants is added to the equilibrium system, the concentration of the substance that was added will decrease below its value at the initial equilibrium".

In this study, the UNIFY students' misconceptions on some aspects of chemical equilibrium will be identified prior to the instruction and an attempt to address them will be made through the teaching of the topic using Traditional Based Teaching and Laboratory Based Teaching.

2.3 Mental Models

Chemistry as a course is dominated by the use of models and modeling. Chemists, like other scientists, use models to explain data, to predict events and to help understand chemical reactivity (Gilbert and Rutherford, 1998). These models, often highly abstract in nature, are referred to as mental models. An understanding of the students' mental models is important because teachers employ increasingly complex models throughout the degree program (Johnston – Laird, 1983; Vosniadou, 1994). However, there are many reports in the literature indicating that students' understanding and the use of mental models is limited in comparison with experts and desired teaching outcomes (Fensham and Kass, 1988; Harrison and Treagust, 1996; and Raghavan and Glaser, 1985). A deep understanding of chemistry involves being able to link what one sees substances doing in the laboratory (*the laboratory level*), to what one imagines is happening within these substances at an invisible *molecular level*. Only then can these ideas be communicated meaningfully using abstract chemical symbolism, terminology and mathematics (the *symbolic level*). The 'three thinking levels' approach, first described by Gabel (1987), encourages students to learn new chemistry concepts by thinking about them at the laboratory, molecular and symbolic levels. However, due to the shortage of high quality resources that portray the molecular level, most chemistry teaching only occurs at the laboratory and symbolic levels, in the hope that the students' mental models of the molecular world will develop naturally. Students are left to construct these models from the static, often oversimplified two dimensional diagrams in textbooks, or static, often confusing ball and stick models, or their imagination (Coll and Tailor, 2002).

Mayer (1989) defined a good model as one that fulfils the following criteria:

(i) structurally complete in the relationship of its elements – i.e., has all the essential elements of the target idea;

(ii) coherent and appropriate in its level of detail;

(iii) considerate in its form – appropriate vocabulary and form of presentation;

(iv) concrete in its representation – the relationship of all parts of the model are obvious;

(v) Provides clear conceptual explanation – the associated theory can be explained through the model; and

(vi) Highlights the correct comparatives between the model and the target idea – the scope and limitations of the model are pointed.

Chiu et al. (2002) investigated the use of mental models for chemical equilibrium at symbolic and molecular levels by 10th grade students. They subjected one group of students to teaching and learning using cognitive apprenticeship (CA) strategy and another group of students using non-cognitive apprenticeship (non CA) strategy, which was more traditional. They found that students in the CA group were able to construct better mental models and hence have better conceptual understanding of chemical equilibrium than students in the non CA group. They found that the CA instruction was superior to the non-CA instruction in enhancing conceptual understanding.

In this present study, students' mental models at the symbolic level of reactions at equilibrium were investigated before and after instruction to identify the students' misconception, namely, that at equilibrium not all substances exist. This was done to have a clear understanding of students' characterization of reactions at equilibrium (i.e. at chemical equilibrium, all species exist and are in equilibrium). Although this could be incorporated under the Misconception Identification Test, I saw the need to investigate it separately.

2.4 Cognitive Apprenticeship

Cognitive Apprenticeship is a method of teaching aimed primarily at teaching the processes that expects use to handle complex tasks. The focus of this learning-through-guided-experience is on cognitive and metacognitive skills, rather than on the physical skills and processes of traditional apprenticeship. It can be used in a classroom as an instructional design or learning technique, in which students learn through the help and guidance of the teacher or expert. This guided participation helps the student achieve a task that independently would be too hard or complicated. Applying apprenticeship methods to largely cognitive skills requires externalization of processes that are usually carried out internally. Observing the processes by which an expert listener or reader thinks and practices these skills can teach students to learn on their own more skillfully (Collins et al., 1989). This method includes:

(i) Modeling – the teacher designs a context to allow a student to construct a conceptual model of the processes that are required to accomplish a similar task;

(ii) Scaffolding – the teacher provides suggestions or help to assist the student to carry out a task;

(iii) Articulation – the teacher systematically encourages students to articulate their thoughts, via prompting questions, as students carry out their problem-solving task;

(iv) Reflection – the teacher encourages students to reflect on their learning using various techniques for eliciting their understanding;

(v) Exploration – the teacher encourages students to apply some basic exploration skills and knowledge from other activities to solve a novel problem; and

(vi) Coaching – the teacher offers hints, feedback, reminders, suggestions, and new tasks to direct students' attention to the more specific aspects of the task.

Cognitive apprenticeships are situated within the social constructivist paradigm. They suggest students work in teams on projects or problems with close scaffolding of the instructor. Cognitive apprenticeships are representatives of Vykotskian "zones of proximal development" in which student tasks are slightly more difficult than students can manage independently, requiring the aid of their peers and instructor to succeed. Cognitive apprenticeship reflects situated cognition theory (Collins et al., 1989).

Below is a brief review of some instructional systems developed by cognitive psychologists. Some of these systems were cited by Collins et al. (1989) exemplifying cognitive apprenticeship features. Others were cited by Glaser and Bassok (1989) as incorporating the best new knowledge coming out of cognitive psychology.

Qualitative Mental Models

Chiu et al. (2002) investigated the use of mental models for chemical equilibrium at symbolic and molecular levels by 10th grade students. They subjected one group of students to teaching and learning using cognitive apprenticeship (CA) strategy and another group of students using non-cognitive apprenticeship (non CA) strategy, which was more traditional. The students in the CA group were presented with experiments and asked more probing questions whereas the teachers gave the students in the non-CA explanations. The teachers also played the role of scaffolding either by stimulating the learners to make inferences or by offering opportunities for self-reflection or self-correction. The teacher in the non-CA did not construct a learning framework for the students to facilitate their learning. They found that students in the CA group were able to construct better mental models and hence have better conceptual understanding of chemical equilibrium than students in the non CA group. They found that the CA instruction was superior to the non-CA instruction in enhancing conceptual understanding.

White and Frederiksen's (1986) program to teach troubleshooting in electrical circuits emphasizes the relationship between qualitative models and causal explanations. White and Frederiksen believe that mastery of qualitative reasoning should precede quantitative reasoning. Their program builds on students' intuitive understandings of the domain, carefully sequencing "real-world" problems that require the student to construct increasingly complex qualitative models of the domain. Although the program encourages students to engage in diverse learning strategies (exploring, requesting explanations, viewing tutorial demonstrations or problem solving), it tries to minimize errors. It does not directly address buggy algorithms and misconceptions.

Reciprocal Teaching

Brown and Palincsar (1989) have developed a cooperative learning system for the teaching of reading, termed *reciprocal teaching*. The teacher and learners assemble in groups of 2 to 7 and read a paragraph together silently. A person assumes the "teacher" role and formulates a question on the paragraph. This question is addressed by the group, whose members are playing roles of *producer* and *critic* simultaneously. The "teacher" advances a summary, and makes a prediction or clarification, if any is needed. The role of teacher then rotates, and the group proceeds to the next paragraph in the text. Brown and colleagues have also developed a method of assessment, called *dynamic assessment*, based on successively increasing prompts on a realistic reading task. The reciprocal teaching method uses a combination of modeling, coaching, scaffolding, and fading to achieve impressive results, with learners showing dramatic gains in comprehension, retention, and far transfer over sustained periods.

Schoenfeld's Math Teaching

Schoenfeld (1985) studied methods for teaching math to college students. He developed a set of heuristics that were helpful in solving math problems. His method introduces those heuristics, as well as a set of control strategies and a productive personal belief system about math, to students. Like the writing and reading systems, Schoenfeld's system includes explicit modeling of problem-solving strategies, and a series of structured exercises affording learner practice in large and small groups, as well as individually. He employs a tactic he calls "postmortem analysis," retracing the solution of recent problems, abstracting out the generalizable strategies and components. Unlike the writing and reading systems, Schoenfeld carefully selects and sequences practice cases to move learners into higher levels of skill. Another interesting technique is the equivalent to "stump the teacher," with time at the beginning of each class period devoted to learner-generated problems that the teacher is challenged to solve. Learners witnessing occasional false starts and dead ends of the teacher's solution can acquire a more appropriate belief structure about the nature of expert math problem solving. Schoenfeld's positive research findings support a growing body of math research suggesting the importance of acquiring a conceptual or schema-based representation of math problem solving.

2.4 Laboratory teaching

Laboratory teaching is expensive requiring equipment, facilities and teacher time, yet most science teachers and lecturers would consider laboratory sessions as a necessary and essential part of teaching in the sciences (Gallagher, 1987). Science teachers and lecturers expect that, through the laboratory experience, students' understanding of scientific concepts will improve as will the level of their manipulative skills. It is believed that students' understanding of the way scientific knowledge is generated and validated will be enhanced. Most science teachers and lecturers organise laboratory sessions with one or more of the following goals in mind (Shulman & Tamir, 1973):

1) to arouse and maintain interest, positive attitude, satisfaction, open-mindedness and curiosity in science;
2) to develop creative thinking and problem solving ability;
3) to promote aspects of scientific thinking and the scientific method (e.g. formulating hypothesese and making assumptions);
4) to develop conceptual understanding and intellectual ability; and
5) to develop practical abilities (e.g. designing and executing investigations)

Giddings and van den Berg (1992) added the following goal:

6) to develop skills in using experimental techniques and common instruments (e.g. using a microscope).

However, some reviews of the research on the effectiveness of laboratory lessons as compared to other ways of teaching science, have thrown some doubt on this general feeling. For example, Fuller and Heineman (1989) argue that science laboratories do not boost student achievement and that the high status given to laboratory activities is not justified.

In addition, many studies that have focused on purposes, uses and learning from laboratories have significant things to say, and draw conclusions of relevance to this study. Johnstone and Wham (1982) noted that laboratory activities often cognitively overload students with too many things to recall, whereas Hodson (1990) described laboratory work as often being dull and teacher directed, and highlighted the fact that students often failed to relate the laboratory work to other aspects of their learning.

According to three extensive reviews on the outcomes of laboratory teaching (Bates, 1978; Hofstein & Lunetta, 1982; and Lunetta, 1998), laboratory teaching is better than any other methods (e.g., demonstrations, lectures) in teaching experimental skills and techniques (goal 6). In other words, when we compare students who have participated in laboratory lessons with students who have not participated, the "laboratory students" perform better in experimental techniques and using instruments. Several studies (quoted in Hofstein and Lunetta, 1982, p.210) have also shown that laboratory experiences can result in more positive attitudes towards science (part of goal 1). However, laboratory students do not perform better than non-laboratory students with respect to goals 2), 3), 4), and 5). According to these reviews the laboratory teaching is not better than any other methods in teaching science concepts, scientific thinking and inquiry skills. For example, Reif and St. John (1979, p.950) wrote the following about undergraduate physics laboratory lessons at a major university, Berkerley:

> We found that most students cannot meaningfully summarise
> the important aspects of an experiment they have just completed.
> Usually they recall some of their manipulations in the laboratory,
> but are unable to articulate the central goal of the experiment,
> its underlying theory, or its basic methods. Thus, despite several
> hours spent working with laboratory apparatus, many students
> seem to learn from this experience little of lasting value.

Performing laboratory practicals, as well as reporting their outcomes, has been a difficult task for many first entering students at institutions of higher learning in South Africa and other countries. Teaching and learning in the laboratory has been a persistent and recurring problem in the practice of science education. Laboratory lessons are not prepared for meaningful and useful learning in most high schools within the country. This is because science programs are not inquiry orientated and do not have laboratory emphasis. Students are learning science from textbooks and lessons, which emphasize the recall of facts and procedures (Tobin, 1989). Even in England, where practical work has always been given great emphasis, it was found that many secondary schools students have failed to develop basic practical skills such as observations, estimating quantities, designing experiments and making inference (Assessment of Performance Unit, 1984). Careful planning of laboratory lessons is essential if students' learning potential is to be recognized. Often students enter into a laboratory or field setting wondering what they are supposed to do or see, and their confusion is so great that they may not get as far as asking what regularities in events or objects they are to observe, or what relationships between concepts are significant. As a result, they proceed blindly to make records or manipulate apparatus with little purpose and little subsequent enrichment of their understanding of the relationships they are observing and manipulating (Novak and Govin, 1984; Fraser et al., 1999).

In his review research on laboratory teaching, Bates (1978) concluded that:

> Research studies on the role of the laboratory consistently report that laboratory experiences neither help nor hinder science content learning, as measured by conventional paper and pencil tests. It would appear, at least at the present time, that good quality verbal instruction is sufficient for content mastery by students; however, this conclusion should be considered tentative pending results of

research on the effects of matching various teaching methods with student background and abilities.

Other reviews on misconceptions and results of science teaching have shown that verbal instruction is not necessarily all that effective. For example, Gunstone and Champagne (1990) argue that laboratory work could successfully be used to promote conceptual change if small qualitative tasks are used. Such tasks aid in students' reconstructing their understanding as less time is spend on interacting with apparatus, instructions and recipes, and more time gets spend on discussions and reflections.

Hegarty-Hazel (1990, p.27) suggests there is a real need for greater understanding of the interactions between learning in the laboratory and elsewhere. It is therefore important to review the convictions of most science teachers and lecturers and rethink of the ways laboratory teaching and learning can be used. Giddings and van den Berg (1992) identified five main weaknesses of traditional laboratory lessons as follows:

(1) Lack of distinction between priorities and objectives (e.g. among concept, process and skill labs).

This is very important because concept laboratory teaching requires carefully designed interaction between students and experiments, resulting in correction and refinement of students' concepts and misconceptions). Process laboratory teaching requires open laboratory experiments with ample opportunity for students to make their own decisions regarding various steps in the experimentation process. Skill laboratory teaching is often highly structured and requires techniques designed to help students model and reinforce specific psychomotor skills;

(2) Choice of experiments commonly used

Many experiments have been canonized in laboratory manuals with little serious evaluation of their educational value and method of presentation. Often the nature of the equipment used can limit the educational value of experiments by forcing students in a kind of hardware straightjacket which leaves no options for experimental design. Much of the commercially available laboratory equipment hides in a "black box" rather than reveals its science. In other instances, the equipment does not allow for alternative ways of executing an experiment thus encouraging a recipe approach. The use of simple equipment often helps to link laboratory science to everyday life phenomena, while sophisticated equipment may obscure that link. Too few science teachers and lecturers have tried to make use of what is known about concept learning in choosing their lab (concept) experiments. Cognitive psychology and related science education research can provide some guidelines concerning the type of experiments that are most likely to affect student learning positively. Both the research in the Piagetian tradition and the more recent research on students' misconceptions in science provide suggestions with regard to the kinds of experiences that may help in correcting misconceptions (Gilbert and Watts, 1983)

(3) Mismatch between lab goals and written lab instructions

Giddings and van den Berg (1992) reported that student misconceptions tend not to be used in the design of concept labs. Consequently, instructions for concept labs usually ignore knowledge about common misconceptions of students. The student is assumed to be learning a new concept from a zero base and little conscious effort is made to adjust the teaching to what is already in the student's mind (preconceptions).

Experiments in many widely used texts have answers which are known by students before they start the lab or which can easily be found by students looking in the text. So students work through a cookbook recipe to obtain the expected results sometimes adjusting their data to get the "right" answer. In some cases students also have access to the laboratory reports of past course graduates.

(4) Mismatch between lab goals and teaching strategies;

Another weakness in laboratory teaching concerns the role of the instructor. In an interesting series of studies, Kyle et al. (1980) observed teacher and student behaviour in university undergraduate laboratories. They found that the instructors inhibited rather than stimulated the kinds of learning related to many of the previously identified lab goals; No wonder the students only seemed to learn manipulative skills for handling equipment and did not show any improvement in their understanding of scientific thinking, process skills, and science concepts. These laboratory instructors tended to act as technical assistants providing equipment service and related advice.

(5) Mismatch between laboratory goals and assessment practices.

Concept labs can be partially assessed in written form and some aspects of process lab performance maybe. However, many aspects of process labs and skill labs definitely cannot be assessed with paper-and-pencil or lab reports only. Alternative methods are needed such as those used in national high school biology examines in Israel (Tamir, 1974) and those described in Bryce and Robertson (1985), Hofstein and Giddings (1980) and Woolnough (1991).

I believe that these weaknesses, if remedied, can help students understand the concepts being taught in the laboratory. These must, however, be coupled with the creation of a suitable laboratory learning environment that will encourage student cohesiveness, integration of theory and practical work, and open-endedness of the laboratory tasks.

Renner et al. (1985) examined ways of making the laboratory an active learning environment for students and found that a discussion activity was pivotal. The importance of this finding is enhanced by the observation that a large number of science teachers struggle with discussion as a pivotal activity in laboratory work. In fact, they also found that many students preferred laboratory work that offered them opportunities to better direct their enquiries clearly, and discussions were found to be important in helping students to clarify their thinking, and this is specially so in self-directed enquiry. Conclusions such as this resonate well with the individual impressions of many teachers about the role and place of science laboratory work; teachers often identify with this outcome through personal experience. A consequence of this, for some science teachers, is a continual search for ways of addressing their concerns about science laboratory work, of seeking alternative approaches to the use of the laboratory that might lead to consequences more in line with the claims often made for the laboratory.

Given the significance attached to laboratory work in science curriculum statements, such as the *Revised National Curriculum Statements* for Natural Sciences (2002), South African National science textbooks, and teacher education programmes, this research attention is not surprising. Laboratory work is almost ubiquitously seen as being of great importance to science education, and by some as almost the defining characteristic of this component of the school curriculum. However, research on aspects of laboratory work and its consequences does not provide strong support for this view. Some studies have even concluded that the fundamental concern of many students while in the laboratory is the completion of the task, and that this concern can overwhelm any serious learning possibilities (Edmondson and Novak, 1993).

The following arguments and recommendations from previous studies advocating the use of LBT to teach concepts are adopted:

1. Giddings and van den Berg (1992) stated that, in theory lessons, students meet idealized concepts. In order for the students not to get a rather distorted view of reality, they should experience the often messy and disorganized, and then link the theoretical concepts to what is observable and measurable. For example, when trying to confirm the dependency of solubility of a substance on temperature, using a thermometer, water bath and potassium nitrate mixed with water, students will find out that real data only roughly conforms to the dependency of solubility on temperature (although this is limited to some salts);

2. The study of misconceptions or alternative frameworks (Gilbert and Watts, 1983; and Tamir, 1991) and the theory of conceptual development support the use of laboratory to teach concepts (Giddings and van den Berg, pp. 14, 1992). Suggestions include a greater emphasis on the quantitative aspects of equilibrium, a greater differentiation in the range of examples presented to students when discussing Le Chatelier’s Principle, and, most importantly, a greater emphasis on the laboratory approach; and

3. Locaylocay et al. (1993) also recommended the use of experiments and demonstrations utilizing discrepant events to study the progressions in the conception evolution of the students with reference to chemical equilibrium.

Through this study, I hope to find out whether or not the Laboratory Based Teaching can be superior to Traditional Based Teaching in enhancing students' conceptual understanding of chemical equilibrium. I hope to create a laboratory learning environment that will be conducive for students to learn scientific concepts. Many studies on laboratory teaching and misconceptions have been done among grade 12 students, college students and first entering university students. This study focuses specifically on the Historically Disadvantaged Students at a foundation year chemistry course in South Africa.

2.5 Theoretical framework of the study

For the past years, a considerable number of studies have been done in conceptual change in science education. The most well known conceptual theory was proposed by Posner et al. (1982). They claimed that four conditions of accommodation needed to be present for conceptual change to occur. First, there must be dissatisfaction with existing conceptions. Second, a new conception must be intelligible. Third, a new conception must appear initially plausible. Finally, a new concept should suggest the possibility of a fruitful program. Treagust and Harrison (1993) adopted Posner' s theoretical framework to empirical studies and found that implementing Posner' conditions into instructional materials could promote student's conceptual change in learning science.

In many science lessons concepts are presented to the students as labels with lists of characteristics to be absorbed verbatim by the student. The laboratory session is then expected to support the verbal memory with visual and psychomotor reinforcement and it is hoped that this will result in student understanding of the concept. However, both conventional alternative frameworks (Gilbert and Watts, 1983) have indicated that new concepts and experiences are not just recorded on a blank spot of the student's memory, but that complex assimilation and accommodation processes take place to link new information and structures with old ones. This is a process of construction.

Preconceptions can interfere with the common scientific meaning of concepts and theories being taught and results in misconceptions (also called alternative framework). More often that intuitive conceptions or "student theories" are retained, while the new lab and classroom experiences are being memorised for "special occasions" (meaning routine problems exercised in class). In unfamiliar new problems and in everyday-life the original “student theories” take precedence over the “scientist theories” taught. For example, the student’s idea that s new force is needed to keep anything moving usually takes priority over the memorised notion that objects which experience a zero net force, may be a rest or move at a constant velocity (Newton’s First Law). In everyday-life and not considering friction as a force, this student intuition serves him/her quite well; however, not in the physics classroom.

Concepts are labels for things and ideas: a table, a chair, force, energy. Concepts are usually leaned by abstracting the basis idea (table) form many examples (seeing many tables and contracting a mental prototype) rather that through a formal definition (Tennyson and Cocchiarella, 1986). Science concepts do not stand alone, but receive meaning through their links with other concepts. For example “force” is linked with “energy”, “momentum”, “acceleration”, “mass”, “weight”, etc. Through propositional statements such as Newton’s law (F=ma). One can map out such relationships in concept map. One cannot really teach a concept in isolation without considering other concepts, yet this is often done. In such cases one ends up with a disconnected (isolated) concept: a concept which cannot be used.

A network of concepts and prepositional links between them in some ways resembles a religious or political belief system as studies of paradigm changes in science illustrate (Kuhn, 1970; Holton, 1973). Consequently misconceptions (and their propagation through a concept map) are very resilient to changes (Hashweh, 1986). The process of changing them is not unlike religious or political conversion, even in children. Studies of remediation of misconceptions (for example, Newton’s Laws) have demonstrated this very clearly. How then can one approach the task of moving (converting) the student from misconceptions towards scientific conceptions?

In concept development one can distinguish several levels of concept attainment (Licht, 1987). On the *intuitive* levels students relate concepts to each other in an intuitive way, based on preconceptions, direct structuring of observations, common everyday language, etc. Typical examples are those provided earlier of students who may have memorised proper definitions of concepts and principles, but who cannot apply them in contexts which deviate just a little form typical school problem exercises.

On the *descriptive* level students relate concepts to each other based on observations and measurements. On this level concepts are defined in descriptive operational ways without theories. For example, after an electrical circuit lab activity a student concludes that the current that enters the lamp is the same as the current that leaves the lamp (at the intuitive level the student would tend to think that the current entering the lamp is larger (Osborne and Freyberg, 1985).

On the *theoretical* level students relate concepts to each other using a deductive, logical-hypothetical way of thinking. On this level most of the concepts are defined in a prescriptive way. The concepts introduced on the theoretical level provide an explanation for the relations found in the descriptive level. Linking the theoretical concepts with the concept and relations on the descriptive level is the only way to demonstrate the fruitfulness of these concepts in the field of observations and measurements

To bridge the gap between the intuitive level and the descriptive level, the designer of laboratory Software (written student instructions and teacher notes) and hardware needs to construct lab experiences in which student pre- and misconceptions will surface and be contrasted and challenged by the scientific concept in crucial discriminating experiments. Such labs should also be fully integrated with other teaching-learning activities. How can this be done?

Alternative frameworks researchers have not yet come up with "the best method" to teach concepts or "the best method" to teach labs. However, a number of suggestions have resulted from their research. We will discuss those suggestions and add some of our own. In their outstanding book "learning in science: the implications of children's science", Osborne and Freyberg (1985) review several models for teaching concepts which arose from the misconception or alternative frameworks research (e.g. Nussbaum and Novick, 1981, 1982).

The *preliminary* phase in most of these models is an assessment of student preconceptions from the literature (abundant in Physics, but less in other subjects) or through a surveyor interview. This preliminary phase takes place some time before the actual teaching and intends to guide the teacher in her/his preparation. No labs are included in this phase as it is a non-teaching phase, unless the teacher wants to use an activity to 'diagnose misconceptions. It is important that these preconceptions are not only assessed in school-type problems, but also in everyday-life situations as that is where preconceptions developed.

The *first* phase in teaching concepts (according to most models) repeats this assessment in an open discussion of' the phenomena studied. If possible one can start this phase with a real life situation which proved fruitful during the preliminary phase. To make it easier and safer for observation one has to transfer this real world situation to a school type problem situation. When the same intuitive ideas pop up in this (school problem) situation, one can be sure that the students consider the transfer from real life to school situation meaningful. The main purpose of this phase is to motivate students by starting with a relevant daily life situation and to elucidate student views and increase awareness of students of the phenomena studied and of their own views. Osborne and Freyberg call this the *focus* phase. Often the teacher will demonstrate the daily life situation. The school-type problem situation could either involve more demonstration-discussion or discussion among students guided by lab experiments. The purpose of the demonstrations or lab activities is to focus student attention on the phenomena and variables being studied.

In the *second* phase students' views are challenged by creating cognitive conflict (Nussbaum & Novick, 1981, 1982). Osborne and Freyberg call the phase the *challenge* phase as students' beliefs are challenged. Students are presented with alternative views of other students and evidence which contradicts their (mis) conceptions or student theories (and supports the scientist's view). The evidence can come from laboratory teaching and demonstration experiments. Laboratory teaching and learning is an important tool at this stage, however, demonstrations are useful too as they allow for a more controlled "whole class" experience where students' attention can be focused on salient characteristics (a fine example of using demonstrations for conceptual change is contained in Minstrell, 1983).

Certainly students cannot just switch on to the scientific view in the face of convincing evidence. As with religious or political conversation, the process of accommodation to new points of view is slow and remnants of the old faith or the old concept are often utilized. Once again it is important to remember that:

concepts and their inter-relationships constitute a network rather than a

single entity,

b) the pre- or misconceptions students have, are the result of many years in which these preconceptions have served students reasonably well (Hashweh,1986).

Ample evidence is available to show that college-level science graduates tend not to have completed the conversion to the generally accepted scientific point of view in many key areas. Actually, it seems likely that in the second phase most students can only move from the intuitive to the descriptive level of concept attainment and not yet to the theoretical level. It also appears that one cannot bridge the gap between the intuitive level and the theoretical level just by demonstrations or hands-on activities. Through activities and demonstrations (constituting an empirical-inductive learning cycle) students can formulate (new) relationships between concepts based, on the measurement of values of variables representing the concepts. In addition students will already meet some aspects of a more hypothetical deductive learning cycle, which will be used later on to bridge the gap between the descriptive and theoretical level. The students will have to consider their own views as hypotheses and deduce implications from them which can then be tested in demonstrations and experiments.

The *third* phase in most models involves a consolidation process through application of "new" concept. Osborne and Freyberg (1985) call this phase the *application* phase. One could say that in this phase a large number of crosslinks should be created between the new concept and other experiences and concepts in the student's mind in order to ensure that the new concept is not just a side track of the brain for use in a specific type of science textbook problems, while the "old" concept remains at hand for all other situations. Again labs could be useful to present such new school type situations. To ensure adequate motivation, such problem situations should be directly related to already known or new everyday-life situations.

In the *fourth* phase (not present in most models) students become aware of the process that is going on. They are invited to reflect on the process of conceptual conflict and conceptual change by comparing their present thinking with their intuitive ideas at the beginning of the process. The important role of their own ideas, concepts, and ways of reasoning will be made explicit. In this phase it is possible to compare the meaning and values of ideas and ways of reasoning in daily life to concepts in the scientific domain. As Solomon (1983, p. 57) stated:

"the fluency and discrimination with which we learn to move between the two contrasting domains of knowledge - life world domain and school world domain - determines the degree and depth of our understanding. "

This more or less metacognitive review phase concludes the bridging process between the intuitive and the descriptive level. Again it should be pointed out that the conversion from students' misconceptions to scientists' concepts will be slow and incomplete, therefore teachers should revisit the concept from time to time after having shifted to new units or topics.

In summary, the role of the laboratory in the first phase is to focus student attention on the phenomena to be studied. In the second phase labs are used to create cognitive conflict between the student concept and the scientist's concept. In the third phase similar cognitive conflict labs are used to exercise the new concept and see to what extent students have accommodated the new ideas. In the fourth phase no labs are used.

Furthermore, laboratory teaching and learning and other experimental exercises should focus on applying the new concept to explain everyday-life phenomena and experiences - the concept network should be linked to reality. A series of carefully constructed teaching-learning activities is needed to teach a concept and its inter-relationships with other concepts.

To facilitate the student moving back and forth between the theoretical level and the descriptive level, students need experiences in deducing hypotheses and" predictions from theoretical concepts and testing them in experiments. The teacher guides discussions in which students and teacher try to link abstract and often not directly measurable concepts and observable phenomena. Then experiments can be designed to test the predictions, which can be done either in a straightforward recipe-like verification laboratory teaching and learning.

CHAPTER 3

RESEARCH METHODOGY

This chapter describes research methodology components used in the study. It begins with the description of the research design and quality control measures used in the study. These are followed by the description of the sampling procedures for the study, procedures adopted, instrumentation used, data collection methods, data analysis methods, ethical issues and the quality control measures.

3.1 Research design

This study is both quantitative and qualitative in nature. Amongst many types of quantitative methods such as descriptive; causal comparative; correlational; and experimental, causal comparative research method is adopted because of the nature of the study. The purpose of causal comparative research is to identify a possible cause-and-effect relationship between an independent variable and a dependent variable. However, this relationship is more suggestive than proven, as the researcher does not have complete control over the independent variable.

The basic design of this study involved the selection of two groups, namely, Laboratory Based Teaching (LBT) group and Traditional Based Teaching (TBT) group. The two groups were then compared on the dependent variable, which is conceptual understanding. The results of this study will only be generalized to the UNIFY students.

One of the problems with causal-comparative research is that since the participants are not randomly placed in the groups, the groups may differ on other variables that may have an effect on the dependent variable. Some controls of the extraneous variables, which might have weakened this study, are discussed in section 3.8 below. In this design, research participants are not randomly assigned to the treatment groups. I used intact groups for this study.

The interpretive qualitative method is also adopted. The purpose of the interpretation was to get qualitative information from the students in cases where interviews and open responses were needed.

3.2. Sampling procedure

Sampling is the process of selecting units (e.g. people, organizations, etc.) from a population of interest, so that by studying the sample we may generalize our results on the population from which they were chosen (Hinkle, 1998). Amongst various sampling techniques, convenience sampling (Gall et al., 1996) was adopted.

The participants in this study were UNIFY students in mathematics and science at the University of Limpopo, South Africa. All students entering the UNIFY programme are in possession of a grade 12 certificate with or without exemption (with exemption means the student is allowed admission to Universities although some institutions might have other special admission criteria), and about 80 % of them come from the Limpopo Province. Most of the participants are from rural areas and their schools are educationally disadvantaged. The participants' science educational background is such that they have been exposed to inadequate teaching, lack of laboratory facilities, and little attention on skills development. All these unfortunate circumstances resulted in rote learning by students, lack of interest, negative attitude and very little or no understanding. The UNIFY intervention in science subjects brings the integration of theory to practicals; well-designed practicals based on daily life experiences, identification of students' misconceptions and the development of skills. Most of the participants have never been in a laboratory or have little experience in laboratory learning environment (Lubben et al., 2000). Fifty three (53) potential students participated in the study because I was their chemistry class teacher. The 53 students were divided into two groups of twenty-six and twenty-seven students, respectively. The grouping of students was done by the UNIFY administrator prior to the study being conducted based on the performance in the UNIFY science selection test. The group of 26 students was labeled the Laboratory Based Teaching (LBT) group and the other group of 27 students was labeled the Traditional Based Teaching (TBT) group. The LBT group was given access to the use of a chemistry laboratory throughout their learning whereas the TBT group was given access to the same chemistry content information in the traditional teaching situation. All the students studied Physical science in their Grade 12. The students' ages ranged from 17 to 20 years.

3.3 Research Procedure

The procedure incorporates the preparation of the participants for the treatments. The preparation in this study included invitation to all students participating in it to the initial meeting where the intention of the study, the role of the students in the study, and the students' rights during the research study period were fully outlined. An orientation to the classroom and laboratory sites was done. The teaching and learning materials for the research study were made available to the learners and its contents were explained.

Firstly, the introductory chapter on chemical equilibrium was taught to all the students to accommodate those who did not study the topic at high school level due to various reasons such as Higher Grade (HG) and Standard Grade (SG) categorization at Grade 12. Secondly, the pre misconception identification test (Pre MIT) measuring the dependent variable (conceptual understanding) was administered to both the experimental and the control groups. The activity on the representation of reactions in equilibrium using mental models was undertaken with students in both groups. This activity was used as a data collection activity and not a teaching activity at this point. Thirdly, the treatments consisting of TBT and LBT were implemented to two groups of students. The post misconception identification test (Post MIT) which was the same as the Pre MIT was administered to both groups after the treatments. The same set of activities on students' mental models of reactions in equilibrium was done by both groups of students before and after the instruction. Both LBT and TBT approaches were undertaken to illuminate some basic chemical concepts for chemical equilibrium reactions. The treatment lasted for four weeks. Each group had six periods per week arranged as follows:

In LBT, the three plus three (3 + 3) system of periods per week of teaching and learning was adopted. This means three successive periods (three periods continuously following each other) twice a week (or two triple periods per week). In TBT, the one plus two plus three (1 + 2 + 3) system of periods per week of teaching and learning was adopted (1 - represents a single lecture period, 2 - represents double periods (two periods continuously following each other) for tutorials, 3 – represents a triple period (three periods continuously following each other) for practicals.

Laboratory Based Teaching is one level of the independent variable of the study. The laboratory lessons were designed within the context of the purpose they intend to achieve. This means that more of integrated concept laboratory-based materials and a suitable laboratory-learning environment were created for the students. The learning materials incorporated and integrated the practical activities with theory. The teaching and learning was done in a laboratory class setting.

Since learning and teaching are more activity based, more useful interactions are held practical sessions. The cognitive apprenticeship features mentioned in chapter 2 are hopefully used to promote effective interaction between students and teachers, and also to create a friendlier learning environment for the students. Steps followed in teaching of science concepts (Giddings and van den Berg, 1992) using laboratory-based instruction are:

(1) Definition of the concept and listing of its attributes, specify the concept's relationships with other concepts. Concept maps and other content analysis tools (Tennyson & Cocchiarella, 1986) might be quite helpful here.

(2) Making a list of common misconceptions regarding the concepts to be taught. The misconceptions come from results of the pre-MIT and other literature cited in Chapter 2 (e.g. Banerjee, 1995; Wheeler and Kass, 1978). Other misconceptions may be identified during the laboratory activity which can then be addressed immediately or in the subsequent activity

(3) Prepare a teaching-learning sequence using the steps listed above and selected experiments for focusing student attention (phase 1 – from theoretical framework, chapter 2), for creating cognitive conflict (phase 2 – from theoretical framework, chapter 2) and for exercise (phase 3 – from theoretical framework, chapter 2). The concept laboratory should be well integrated with other components of the concept teaching-learning sequence. For example, demonstrations may sometimes be preferable as they offer realistic alternatives in many cases.

(4) Experimental procedures and equipment should be simple as to not distract from the concept attainment. Yet experimental results should be sufficiently clear and Accurate so that there is no need for making students believes that the results should have been different from what they obtained. If more sophisticated equipment has to be used, students should be provided with pre-lab exercises in its use so that concept studies later on will not be confused by experimental procedures.

(5) Challenging the student by making sure that they experience the contrast between his/her own concept or prediction and what actually happens. This can be done by having them make (and write down) predictions or expectations before they do the experiments. If this is not done, they may simply accept whatever outcomes they get and not realize that the outcomes are different from what one might have expected. It is important to note that students may not experience conflicts where one expect they might. Through experience one will hopefully come to a more realistic assessment of the most appropriate experiments.

(6) During the laboratory sessions, stimulation of extensive interaction between the students and between students and the teacher. Without such interactions many misconceptions will remain undetected and students will not be aware of their

own concepts. Extensive small group and whole class discussion may take place in between the laboratory session. The teacher will have to walk a fine line between facilitating discussion, explaining and bringing up the scientific view.

(7) Evaluation and revision of the teaching-learning sequence until things work. Interviews on concepts with some students after the laboratory activities may be useful.

It is hoped that the implementation of the above steps with some principles of cognitive apprenticeship (e.g. scaffolding, articulation and reflection) will eliminate some chemical equilibrium misconceptions from students.

Traditional Based Teaching was the other level of the independent variable of the study. The teaching and learning for the students took place in a traditional classroom setting. The students in this group used similar learning materials of chemistry content which is the same as the one in LBT. The layout of the material had separate tutorial activities, lecture and practical activities. The features of cognitive apprenticeship that mostly guided the interactions between the students and the teacher are coaching, exploration, modeling. These features are applicable only when situations allow. The interaction between the teacher and students during practical activities is different to that of LBT in that the teacher gives more focused information to students. The following steps were followed in the teaching of concepts using traditional approach.

1. Introduction: the teacher gives (or the students read) a brief overview of what material will be covered that day.

2. Direct Instruction: the teacher explains a concept and presents an example to illustrate the idea. Giving demonstrations where necessary. At this state the misconceptions captured by the MIT are addressed and emerging ones identified.
3. Guided Practice: the teacher and class work together on some examples. Identification of other misconceptions not covered by the pre MIT is done at this stage.
4. Independent Practice: the students work on some problems, individually or in small groups, and the teacher only helps when necessary.
5. Evaluation and revision of the teaching-learning sequence until things work. Interviews on concepts with some students after the teaching activity may be useful.

The main differences between these methods are that:

1. Students in LBT did more experiments for the same concept. For example, in the study of the effect of temperature of the equilibrium mixture, the following sequence of experiments were performed:
   - Fe^{3+} (aq) + SCN^{-} (aq) $\rightleftharpoons$ $FeSCN^{2+}$ (aq) equilibrium mixture;
   - $2NO_{2\,(g)}$ (brown) $\rightleftharpoons$ $N_2O_{4(g)}$ (colourless) equilibrium mixture and lastly
   - $Co(H_2O)_6{}^{2+}{}_{(aq)} + 4Cl^{-}{}_{(aq)} \rightleftharpoons CoCl_4{}^{2-}{}_{(aq)} + 6H_2O_{(l)}$ equilibrium mixture.

In the case of the TBT, only the first experiment on Fe^{3+} (aq) + SCN^{-} (aq) $\rightleftharpoons$ $FeSCN^{2+}$ (aq) equilibrium mixture was performed and the others were done theoretically.

2. Even when the same experiment was performed, the interactions between the teacher and the students were different. In LBT, the teacher used mostly the scaffolding, articulation, and reflection as some principles of cognitive apprenticeship whereas in TBT the educator gave more explanation to the students as such exploration, modeling, coaching as principles of cognitive apprenticeship were encouraged. In all the methods, emphasis was on the elimination of the misconceptions identified by the pre MIT held by the students.

The dependent variable that was measured is conceptual understanding. Conceptual understanding is the degree to which a student's understanding of a concept at the molecular level corresponds to the scientifically accepted explanation of the concept. The Misconception Identification Test (appendix 1) was used to investigate six categories of students' misconceptions. Another category of misconceptions (i.e. at equilibrium, not all substances exist") was investigated using the students' mental models on equilibrium. The results of the MIT and mental models gave an indication of the conceptual understanding of the students.

3.4 Instrument Development

The data collected were on misconceptions and mental models. The investigation of the first six categories of misconceptions was done by the MIT questionnaire. The data on mental models focusing on the seventh category of the misconceptions was captured by interviews and self-reports. These were guided by the activities to be undertaken and information needed.

3.4.1 Misconception Identification Test

The MIT developed for this study is a 30 item multiple choice and reasoning test that requires a student, for instance in some items, to predict the effect of changing certain variables, e.g., temperature, pressure, concentration, on the equilibrium conditions of selected chemical systems involving homogeneous gas reactions. In this case, the questions were answered by choosing the most appropriate of the following responses, namely, *(a) greater than at the first equilibrium; (b) Less than at the first equilibrium; (c) the same as at the first equilibrium; and (d) Data insufficient for conclusion*, to decide among the above alternatives. For all the test items, space was provided for students to give a reason or reasons for their choice.

The MIT was developed following the normal procedures. The steps, as outlined by Treagust (1988), are, namely,

(a) Examining related literature – this was done to identify students' common misconceptions, methods of addressing the identified misconceptions, students' mental models of reactions at equilibrium, etc;

(b) Identifying propositional knowledge statements – this was done so as to identify concepts and terms that characterize chemical equilibrium;

(c) Validating the content – this was done to establish that the MIT related concepts are congruent with prepositional knowledge statements that describe the selected chemistry content domain. Content validity of the prepositional knowledge statements was established by subjecting all statements to a review by five chemistry educators knowledgeable in chemical equilibrium;

(d) Developing MIT items – this was done to ensure that the prepositional knowledge statements are used to guide the writing of the MIT items;

(e) Designing the specification grid – this was done to ensure that the diagnostic test covers the prepositional knowledge statements underlying the topic fairly (Treagust, 1988, p. 163); and

(f) The reliability of the test was determined using the results of the pilot studies of University of Fort Hare Foundation Year students and the UNIFY students. The reliability coefficient of 0.79 was found, thus confirming the internal consistency of the test items.

The test is based on the content of a unit of chemical equilibrium in the chemistry foundation year course in the University of Limpopo. The content validation of the test was undertaken by a group of school and university chemistry educators and academics. The construct validity was established by comparing answers and reasons identified by the MIT for a particular student with comparable responses subsequently identified in that student's blind interview.

The six major misconceptions under investigations were the following:

A. Left – and right – sidedness: Students perceive each side of a chemical equation as a separate physical quantity;

B. Interpretation of the reversed arrow convention: Students perceive the rate of the forward reaction being different to the rate of the reverse reaction because of equilibrium arrows of unequal lengths;

C. The constancy of the equilibrium constant: This includes the ability to judge when and how the chemical equilibrium constant changes. This possible misconception refers to the changes in concentration, pressure and temperature, as well as the addition of a catalyst. For example, students fail to grasp the influence of a catalyst on a chemical system, viz., that it has an effect on the reaction rates but not on the equilibrium as such. They perceive the catalysts as leading to a higher yield of the product;

D. Rate versus extent: Inability to distinguish how fast the reaction proceeds (rate) and how far (extent) the reaction goes;

E. Definition of equilibrium constant expression: Inability to relate the equilibrium concentrations of reactants and products using the equilibrium law; and

F. Misuse of Le Chatelier's principle: The application of Le Chatelier's type reasoning in inappropriate situations.

The MIT consists of four questions as briefly described below: **Question 1** consists of 1 item. **Question 2** consists of 2 items, **Question 3** consists of 24 items and **Question 4** consists of 3 items. The total number of items for this test is 30.

Question 1: The purpose of this question was to identify whether or not students can visualize the equilibrium system as consisting of two independent and separate compartments or as one whole.

Question 2: This question attempted to assess the students' interpretation of the reversed arrow symbol in instances whereby the forward and reversed arrows are of unequal lengths.

Question 3: This question dealt with the effect of variables on an equilibrium mixture of chlorine, carbon monoxide and phosgene. Questions were posed that tested students' ability to decide what happens to the composition of an equilibrium mixture when it is subjected to stress, and were expected to motivate their answer. The problem selected was not familiar to the students. The question was then divided into subsections as follows:

3.1 Effect of temperature;

3.2 Effect of pressure;

3.3 Effect of removal of some amount of reactant/product on other equilibrium variables;

3.4 Effect of catalyst;

3.5 Equilibrium constant expression for the given equilibrium mixture; and

3.6 The meaning of equilibrium constant – this includes the magnitude of equilibrium constant value.

Question 4: Students were presented with the heterogeneous equilibrium mixture consisting of solid and gaseous substances. The purpose of this question was to identify whether or not students can predict the effect of the addition of a solid substance to an equilibrium mixture already containing it.

The MIT was expected to yield two scores. The performance score refers to the score a student obtains on a test when it is keyed accurately in a chemical sense. An analysis of the distracters was performed to identify the individual's misconceptions. This resulted with the misconception score which refers to proportions of students having a particular misconception. For example, if 10 out of 27 participants in TBT get item1 correct, then 63% of the participants have the misconception targeted by this item. In cases where 2 or more items are capturing the same misconception, a total number (using sums) of participants responded incorrectly to that item will be determined and divided by the sum of the total number of participants in the group(s).

The interpretation of the multiple–choice type diagnostic items presents certain problems. A student can arrive at the correct answer either by guessing or by otherwise arguing incorrectly. He/she may also arrive at a particular incorrect answer by a variety of incorrect pathways. If a student answers a given question incorrectly, this may not reveal much unless backed up by written reasoning and/or even a follow up interview. Students’ reasoning for each item served as an aid to interpretations. Follow up interviews were made in some cases for students to give free response accounts of their reasoning or their predictions.

3.4.2 The Self-report Sheets

Self-report sheets were used to capture data on students’ mental models for a specific misconception that was not targeted by the MIT. The misconception captured is that “at equilibrium, not all substances exist.” Follow-up interviews were done to consolidate students’ symbolic mental models. Three forms of symbolic models were used, namely, tabular, graphical and mathematical representations.

3.4.3 Pilot Study Sample

Two pilot studies were carried out. The first pilot study was for the validation of the instruments, and the other pilot study was meant for research as a whole. The MIT instrument was piloted with the 2001 UNIFY students, 2001 first entering mainstream students, and 2002 University of Fort Hare (UFH) Science Foundation Year Students. Also, some Test and Item Analysis of MIT was done from the responses of the pilot study. From these preliminary findings, some of the MIT items were adapted and reworded to ensure that the items were relevant. The same procedure was followed with some interview schedules. The final version of the MIT was administered to 128 UNIFY students from which 53 students were randomly selected for the study. The study as a whole was piloted with two chemistry groups of UNIFY 2001.

3.5 Data Collection

Data collection involves the capturing of information needed in the research study. Data can be collected by various means, such as class tests, self-reports, questionnaires, interviews, observation and content analysis. In this study, data were collected through the MIT questionnaire, interviews, and self-reports. These methods of data collection were most suitable to capture both quantitative and qualitative information required in this study.

Quantitative as well as some qualitative data were collected using the pre- and post-MIT questionnaires. Qualitative data on mental models were collected from participants through both instant interviews (recorded on audio-tape) and self-reports during the lessons. No rigid schedule of questions was used in the case of interviews. The investigator first attempted to get the students involved in some aspect of the task, and after having established some avenue of inquiry or interest, open-ended questions were posed, using English as medium of communication. Students were requested to speak all their thoughts aloud in the presence of the researcher and explain their arguments. The verbal reports were first recorded on audiotape and later transcribed into written protocols for analysis. Through observation, though not compulsory in each teaching and learning setting created, some data were collected to compensate for other methods. The researcher read through the transcripts to identify common themes.

3.6 Data Analysis

Quantitative data were analysed using descriptive and inferential statistics. The mean and standard deviation of all the pre-and post-test scores were determined. Furthermore, the dependent t-test was performed to test for the significant difference between the pre-test and post-test scores of the treatment groups. Qualitative data obtained through interviewing and observation sheets were analyzed by interpretation. In this case, conversations during practical activities that yielded common thoughts were put together to find common thinking amongst the students.

Data obtained from students' self-reports about mental models were quantified and converted into percentages. Most of the students' thoughts on mental modes from the interviews were categorized through interpretation, and a representative sample of an interaction between a student and a teacher is presented as it occurred (see chapter 4, for example, section 4.2.

3.7 Ethical Issues

The study was conducted at an institution where the researcher works as a chemistry educator. A formal letter was written to the University authority to request permission to do the study. Other chemistry lecturers within UNIFY and mainstream chemistry were informed informally through verbal conversation and formally through an officially written letter. All the lecturers involved were promised feedback once the study was completed.

Since the MIT was to be administered directly to the UNIFY students, an accompanying letter was attached to it. The letter included all the information about the purpose of the study and its benefits. The students were assured that their names would not be revealed to any person, their responses would be kept in a very safe and locked place where only the researcher had the key for the lockers.

Amongst the UNIFY group of students who participated in the study, there were no students with physical or mental disabilities. It was therefore easy to work with all the students in the classroom and laboratory settings. Agreement was reached between the researcher and the students that in all the conversations, English, as medium of instruction and communication, be used.

3.8 Quality control

An excellent quality control measure in educational research involves the checking of the internal validity and external validity of the treatments used in the study.

3.8.1 Internal validity

The internal validity of an experiment is defined as the extent to which extraneous variables have been controlled by the researcher, so that any observed effect can be attributed solely to the treatment variable (Gall et al. 1996). An extraneous variable is any variable other than the treatment variable that, if not controlled, can affect the experimental outcome. Campbell and Stanley (1963) identified eight types of extraneous variables that can affect the results of the study, and Cook and Campbell (1979) expanded these variables to 12. The variables are, namely, history, testing, maturation, instrumentation, statistical regression, differential selection, experimental mortality, selection-maturation interaction, experimental treatment diffusion, compensatory rivalry by the control group, compensatory equalization of treatments, and resentful demoralization of the control group. All these variables are clearly defined and explained in Gall et al. (1996).

All the variables of internal validity are taken care of by the fact that this study involves the treatment in both groups. I have also taken into consideration the following factors in this study: random assignment done by the UNIFY administrator and pre- and post-testing. These factors were important in creating a set of conditions suitable for the study. In brief, the internal validity of this experimental design study was accomplished. Although this study was not experimental, these variables could have weakened the findings of this study if not controlled.

3.8.2 External validity

External validity means the extent to which the findings of an experiment can be applied to individuals and settings beyond those that were studied. It is a fact that the findings of an educational experiment may be externally valid for one setting, less externally valid for a different setting, and not externally valid at all for some other setting. Hence there is a need to establish whether or not the experiment is externally valid and for which kind of setting. Bracht and Glass (1968) identified twelve factors that affect the external validity of an experiment. These factors and their role in this study are discussed below:

3.8.2.1 Population validity

Population validity concerns the extent to which the results of an experiment can be generalized from the sample that was studied to a specified, larger group. Two types of population validity are, namely,

3.8.2.1.1 *The extent to which one can generalize from the experimental sample to the defined population*. The results of this study can be generalized only to the experimentally accessible population; in this case UNIFY chemistry students. This is so because the sample under study comes from this population. I cannot generalize the results of this study to the target population, viz, all foundation year chemistry students in South Africa because not all foundation programmes in South Africa are the same. The study can yield different results with different populations elsewhere depending on various factors such as learning environments and social interaction.

3.8.2.1.2 *The extent to which personal variables interact with treatment effects*. I only did this study with a particular group of UNIFY students. The results of my study cannot be generalized to another population of different grade (e.g. first entering chemistry students in the main stream). Many other factors affecting the external validity of my experimental research are discussed in the section of ecological validity below.

3.8.2.2 Ecological validity

Ecological validity concerns the extent to which the results of an experiment can be generalized from the set of environmental conditions created by the researcher to different environmental conditions. These threads, discussed in Gall et al. (1996), have been controlled in this study.

(i) Explicit description of the experimental treatment. This involves the description of the methods used in the study so that other researchers can use them with their students. In this study all the details on how the study was carried out are given. I tried to elaborate and specified procedures such that any other researcher can follow them. I can say with confidence that my experimental procedures are generalizable to other settings.

(ii) Multiple – Treatment interference. This involves a researcher using an experimental design in which each participant is exposed to more than one experimental treatment. In my study I used only one experimental treatment to each group. The members of the two groups never swapped in any way with each other and they never attended any other chemistry classes within the university. So I managed to control this factor.

(iii) Hawthorne effect. This refers to any situation in which the experimental conditions are such that the mere fact that individuals are aware of participating in an experiment, are aware of the hypothesis, or are receiving special attention improves their performance. In this study I made sure that I give both groups treatments. The individuals were all made aware of the intentions of the study and each group was treated as special. I did not encourage other educators or learners to prefer one treatment to the other. All teachers and learners were motivated to participate, as this was also part of their daily teaching and learning process.

(iv) Experimenter effect. An experimental treatment might be effective or ineffective because of the particular experimenter, teacher or individual who administer the treatment. I could not separate myself from the actual processes involved in the study, as I was their chemistry class teacher. I interacted with learners fully in both groups.

(v) Pretest sensitization. In some experiments the pretest may interact with the experimental treatment and thus affect the research result. In this study I controlled this variable by giving a pretest and posttest to both groups. The posttest was the same as the pretest.

(vi) Interaction of History and treatment effects. It is a fact that a treatment can be effective at one particular point and later be ineffective due to various reasons such as motivation. In this case I believe the methods and procedures outlined can be undertaken at any stage of the year as long as the students don't get additional or prior knowledge from other related courses or through visits to science centers, science expos, etc.

(vii) Measurement of the dependent variable. The generalizability of an experiment might be limited by the particular pretest and posttest design to measure the achievement gains or another outcomes variable. With particular reference to this study, the dependent variable was investigated mainly by the use of the MIT which consists of multiple choice questions and reasoning. The results of this study might be different if another type of the measurement of the dependent variable is used.

(viii) Interaction of time of measurement and treatment effects. Administration of a posttest at two or more points in time may result in different findings about treatment effects as recommended by many science educators. I administered the posttest immediately after the treatment. In this study, the chemistry achievement test was also given at the end of the chapter to check the students' performance. This also helped in checking that students understood the concepts under study. It is however advisable to administer the posttest more than once after the treatment to check whether similar results could be obtained.

(ix) Posttest sensitization. The result of an experiment may be dependent upon the administration of a posttest. This usually happens if a posttest is a learning experience. My posttest served only as a measure of the dependable variable. This threat to external validity is effectively controlled in this study.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, I will outline the results of the study. The results of this study are presented under the following subheadings: Students' performance on the pre and post MIT; Misconceptions from pre and post MIT items, Misconceptions from students' mental models; and The influence of TBT and LBT on students' misconceptions in this study.

4.1 Students' performance on the Pre- and Post- MIT.

The results of students' performance on the pre-and post-MIT was analysed using descriptive statistics. The results of the mean and standard deviation are presented on table 1 below.

Table 1: Means and Standard deviations (SD) of the pre- and post MIT

		Pre-MIT		Post-MIT	
Group	N	Mean	SD	Mean	SD
Traditional Based Teaching	27	39	10	44	12
Laboratory Based Teaching	26	41	9	54	15

N – number of students in a group

The average performance of these two groups in the MIT's pre test is similar with TBT group having an average of 39 % and standard deviation of 10 and LBT group having an average of 41 % and standard deviation of 9. This result is not surprising as the two groups were sampled based on their UNIFY selection test results, and consisted of students from the same educational background.

Table 2: Results of the t - tests

Groups	MIT	t_{crit}	t_{stat}	CI_{95}	df
TBT – LBT	Pre – Pre	-2.02	-0.48	-5.24;3.24	51
TBT – LBT	Post – Post	-2.02	-2.79*	-15.98;-4.02	51

*significant value at 0.05

The t – test statistic was used to test the significant difference between the two independent sample means at $\alpha = 0.05$ and 51 degrees of freedom. The critical value is –2.02 (Hinkle et al. 1998). Using the procedures outlined in Hinkle et al. (1998) the calculated statistic value is – 0.48. This calculated value is less than the critical value, hence the null hypothesis that "the difference in the two samples means is zero" is therefore accepted. As such, there is no significant difference between the two sample means at $\alpha = 0.05$. The constructed confidence interval for these data is found to be CI_{95} = (–5.24; 3.24). Since this interval contains zero, therefore there is no significant difference between the two means. This comparison of the performance of the students on the pre MIT was done to check the initial equivalence of the two groups.

Table 1 above also shows that the average performance of these two groups is different after the treatments with the TBT having an average of 44 % and the LBT having an average of 54 %. This result is not surprising as the two groups were subjected to different teaching approaches. The t–test statistic (Table 2 above) was used to test the significant difference between the two independent sample means at $\alpha = 0.05$ and 51 degrees of freedom. The critical value is –2.02 (Hinkle et al. 1998). Using the procedures outlined by Hinkle, the calculated statistic value is –2.79. This calculated value is greater than the critical value, hence the null hypothesis that "the difference in the two samples means is zero" is rejected in favour of the directional alternative hypothesis. As such there is significant difference between the two sample means at $\alpha = 0.05$. This implies that the traditional teaching method employed in TBT was less effective for teaching foundation year chemistry than the laboratory teaching method employed in LBT. The constructed confidence interval for these data is found to be $CI_{95} = (-15.98; -4.02)$. This also confirms the rejection of the null hypothesis in that it does not contain the calculated statistic value of zero.

In general, the results showed that students in both groups held some misconceptions, even after formal instruction, but the students taught through TBT appeared to have more of them when compared to students taught through LBT approach.

4.2 Identification of misconceptions

Misconceptions of students were identified before and after the treatment using both the MIT and students' symbolic mental models captured through self-reports coupled with interviews. Six categories of misconceptions, namely, left and right sidedness; interpretation of the reversed equilibrium arrows; constancy of the equilibrium constant; rate of reaction versus extent of reaction; definition of the equilibrium constant; and application of Le Chatelier's principle, were identified solely by the MIT. The seventh identified category of the misconceptions, namely, characterization of chemical equilibrium (i.e. at equilibrium, not all species exist) was investigated using students' symbolic mental models and was captured by using self-reports coupled with interviews.

4.2.1 Misconceptions from MIT

The performance of the students on each item (or groups of items), probing a particular misconception from the MIT, yielded the percentage of students possessing a particular misconception within a given category. The distracters of the multiple-choice items solely reflected the misconceptions (Appendix 2). These were the common misconceptions in certain conceptual areas of chemical equilibrium as reported in Wheeler and Kass (1978), Johnstone et al. (1977), Banerjee (1991), and Akkus et al. (2003). A full classification of common student misconceptions probed by the MIT is given in Table 3 below. It must be noted that the total number of students who responded to items in each category of the misconception depended much on the number of items addressing that particular misconception. For example, on the misconception that " *it is possible to increase the pressure of the chemical equilibrium system on one side only because reactants and products are separated*", under the category of the left and right sidedness, the total number of students' responses is 27 for TBT because there was only one item capturing that particular misconception. With the first misconception, namely, that "*the magnitude of* K_c *does not depend on the temperature irrespective of whether energy is released or absorbed*", under the category of the *constancy of equilibrium constant*, the total number of students' response is 54 in TBT because two test items were used to capture this particular misconception. The reasons for the choices in the MIT were mainly used to detect the cause of the misconception. The distracters analysis results on Appendix 2 were used to construct Table 3 given below.

Table 3: A classification of common student misconceptions (related test items in brackets) probed by MIT grouped by catergory.

Category	Misconceptions	TBT		LBT	
		Pre MIT	Post MIT	Pre MIT	Post MIT
Left and right sidedness.	- It is possible to increase the pressure of the chemical equilibrium system on one side only because the reactants and products are separated. (1)	89%	81%	90%	58%
Interpretation of the reversed equilibrium arrows	- Equilibrium arrows of unequal lengths mean that the reaction is not reversible and dynamic. (2.1)	37%	52%	77%	73%
	- Equilibrium arrows of unequal lengths mean that the percentages (proportions) of reactants and products are the same. (2.2)	41%	37%	33%	33%
Constancy of the equilibrium constant	- The magnitude of K_c does not depend on temperature irrespective of whether energy is released or absorbed. (3.1.3 and 3.6.3)	31%	24%	35%	42%
	- The magnitude of K_c depends on the addition or removal of reactants and products at equilibrium (3.3.2 and 4.2.2)	61%	35%	67%	37%
	- The magnitude of K_c depends on the volume/pressure of the system (3.2.6)	44%	40%	64%	50%

Category	Misconceptions	TBT Pre MIT	 Post MIT	LBT Pre MIT	 Post MIT
	- The catalyst affects the magnitude of K_c. (3.4.5)	37%	15%	23%	23%
Rate vs extent	- The rate of reaction depends on the magnitude of K_c. That is, if K_c is large, the reaction rate is fast and if K_c is low, the reaction rate is slow. (3.6.2)	26%	15%	39%	12%
Definition of the equilibrium constant	- At equilibrium, K_c is not defined as the ratio of the product of the concentrations of the products each raised to its stoichiometric coefficient to the product of the concentrations of the reactants each raised to its stoichiometric coefficient, taking into account the phases of the reactants and products involved. (3.5 and 4.1)	50%	43%	44%	25%
Application of the Le Chatelier 's principle	- Temperature does not affect the equilibrium mixture. (3.1.1, 3.1.2 and 3.1.4)	37%	57%	50%	32%
	- Addition or removal of reactants or products at equilibrium does not affect the equilibrium system. (3.3.1, 3.3.3, 3.3.4, 4.2.1, and 4.2.3)	35%	46%	44%	37%
	- Changes in the volume of the	49%	48%	41%	45%

Category	Misconceptions	TBT Pre MIT	 Post MIT	LBT Pre MIT	 Post MIT
	container never affect the equilibrium system. (3.2.1, 3.2.2, 3.2.3, 3.2.4 and 3.2.5)				
	• Addition of a catalyst speed up the rate of the forward reaction only and increases the quantities of products at equilibrium. (3.4.1, 3.4.2, 3.4.3, and 3.4.4	34%	30%	28%	17%
	• Increasing the amount of a solid substance that is already in equilibrium with other solid products and gaseous products (i.e., the decomposition of calcium carbonate equilibrium system) will affect the equilibrium system. (4.2.1 and 4.2.3)	76%	61%	64%	62%

4.2.1.1 Category 1: Left and right sidedness

With reference to the category of *the left and right sidedness* in Table 3 above, it can be seen that before the instruction, both the TBT group and the LBT group had very large number of students (89% for TBT and 90% for LBT) having the misconception that “it is possible to increase the pressure of the equilibrium system on one side only because reactants and products are separated". This result is consistent with the findings of previous studies by Akkus et al. (2003); Wheeler and Kass, (1978); and Hackling and Garneth (1989). In their investigations of students' misconception in chemical equilibrium, these authors found a large percentage of students having this misconception before instruction. Akkis et al. (2003) found that instruction based on Constructivist Approach improved students' understanding of concepts better than the traditional instruction. For this misconception, they found that 25% of the students (N=32) in the experimental group had this misconception after treatments, whereas 67% of the students (N= 39) in the control group had this misconception after treatment. However, the number of students having this misconception decreased only slightly after instruction in TBT (89% to 81%), and to some great extent after the instruction in the LBT (90% to 58%). It is very clear that the misconception may be deeply rooted in the students' minds because even after instruction, there were still high proportions of students in both groups with the misconception. The use of LBT in this case has reduced the students' misconceptions significantly as compared to the use of TBT. This significant reduction in the number of students with this misconception can be attributed to sufficient discussions held during practical sessions as students had more time to write their thoughts down and also share with others during the activity. This view is shared by the study of Renner et al. (1985), when they recommended focal discussions within the laboratory with small tasks being done by students. For this misconception, a follow-up interview was conducted immediately after the administration of both the Pre- and Post-MIT. This was done to establish some qualitative data to support the student's choice of options. An example of common students' pre and post cognitive with regard to item 1 (refer to appendix 1), consisting of the following equilibrium mixture, is given below:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

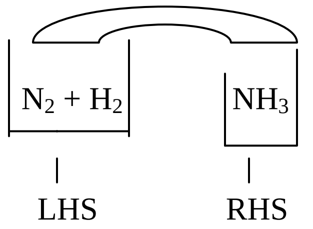
During an interaction with students E01 in LBT and C01 in TBT, the following questions were posed before instruction commenced and even after instruction. The protocols are given below:

Teacher – Would you say there is left side and right side of the given reaction? Explain!

E01 – Yes, substances on the left hand side of any chemical reaction are always reactants. It is just like when children are playing on a seesaw, whereby one will be at the LHS and another one on the RHS.

Teacher – Draw a sketch to show the given equilibrium mixture in a closed container and indicate how you would increase the pressure of the system on the right hand side only.

E01 - Here is my drawing, the containers are closed by the connecting tube.



I can press NH_3 to increase its pressure and N_2 and H_2 will be produced in the RHS and then be transported to the LHS via the connecting tube. These substances must be in separate containers.

Teacher - Thank you

Similar conversation was held with student C01 in the TBT group.

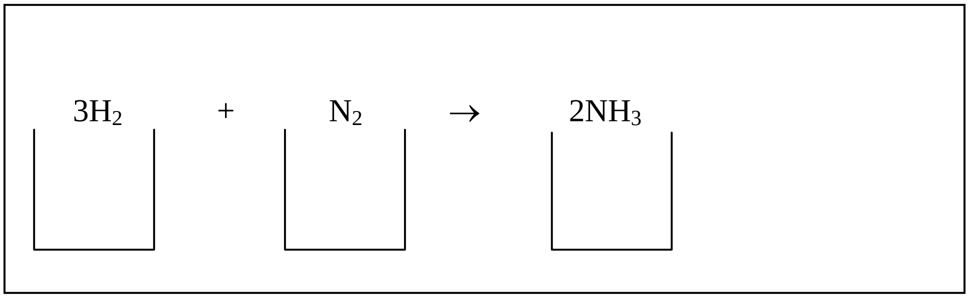
Before Instruction

Teacher – Would you say there is left side and right side of the given reaction? Explain!

C01 – Yes, the left side contains hydrogen and nitrogen whereas the right side contains ammonia.

Teacher – Draw a sketch to show the given equilibrium mixture in a closed container and indicate how you would increase the pressure of the system on the right hand side only.

C01 – Here is my drawing! All containers are open.



C01 - [continues talking] the reaction is not in equilibrium because the left hand side must balance the right hand side. In other words, the given reaction must first have equal moles on the LHS and on the RHS. But I can shake the container having ammonia only to increase its pressure because it has less number of moles.

Teacher - Thank you

However, after both instructions, both students had an improved understanding of the concept, with student E01 having a better understanding of the concept than student C01.

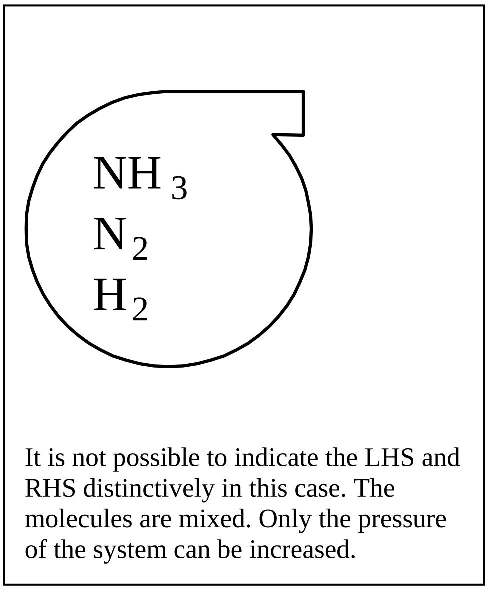
With student E01 after instruction

Teacher – Would you say there is left side and right side of the given reaction? Explain!

E01 – No, since the reactants and products are in gaseous form and are mixed. One cannot actually refer to the two reactions as distinct sides. As we observed when doing an experiment with brown nitrogen dioxide in equilibrium with dinitrogen pentoxide, the two gases are in the same container and mixed.

Teacher – Draw a sketch to show the given equilibrium mixture in a closed container and indicate how you would increase the pressure of the system on the right hand side only.

E01 – Here is my drawing, the container is closed.



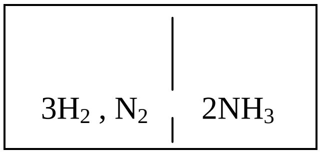
It is not possible to indicate the LHS and RHS distinctively in this case. The molecules are mixed. Only the pressure of the system can be increased.

With student C01 after instruction

Teacher – Would you say there is left side and right side of the given reaction? Explain!
C01 – Yes, as we were told during the class that the equilibrium mixture is in one container and the reaction is reversible, the left side can produce the right side and vice versa.

This student at least grasped the concept of the reversibility of the reaction to some extent, but he lacked the understanding that might have been facilitated by doing the activity practically.

Teacher – Draw a sketch to show the given equilibrium mixture in a closed container and indicate how you would increase the pressure of the system on the right hand side only.
C01 – Here is my drawing! The container is closed.



The conversations presented above were the common ideas that emerged from the interviews with students. Checking on the open responses of the students on item 1, the following emerged as possible causes of the misconception captured by this item:

- Most students have already established and held firmly the concept of a static, two-sided equilibrium derived from physical and mechanical experiences. Unless care is taken deliberately to point out the differences between the chemical concept and the more intuitive physical concept, pupils may tacitly and justifiably interpret what the teacher says on chemical equilibrium in terms of what they already know about physical equilibrium, and thus a static two-sided picture would arise;

- The use of a chemical equation with its centrally placed reversed arrow symbol, will possibly also contribute to the two-sided view. Again, students are liable to make the tacit assumption of two-sidedness. Chiu et al. (2002) reported this in their recent study;

- Various physical analogies are employed in conveying the concept of chemical equilibrium. Some of these (for example, water being transferred between two containers by different beakers, and fan operated enthalpy box with adjustable reactant and product levels) actually consist of two sides;

- Some of the actual equilibrium systems themselves have two sides. The partitioning of iodine between two solvents, the equilibrium between iodine monochloride and iodine trichloride, where the latter is apparently removed in the upper portion of the tube from the former in the lower portion of the tube, possibly consolidates this compartmental view of an equilibrium system; and

- Enthalpy changes are often depicted diagrammatically where the diagram shows a left side and a right side at different levels with a hump between them.

The results of this misconception are consistent with those from literature (Huddle and Pillay, 1996; Furio and Ortiz, 1983 and Gussarsky and Gorodetsky, 1986). Gussarsky and Gorodetsky (1986) found that even after instruction, grade 12 learners (aged 17 – 18) were failing to conceive the mixture oat chemical equilibrium as a single entity and consequently manipulating each side of the chemical equation independently (the balance analogy). Huddle and Pillay (1996) found that University entrance chemistry students failed to conceive the dynamic nature of the system at equilibrium.

4.2.1.2 Category 2: Interpretation of the reversed equilibrium arrows

With reference to the category of the "*interpretation of the reversed equilibrium arrows*", there were two misconceptions targeted. The first misconception was based on the fact that "*equilibrium arrows of unequal lengths mean that the reaction is not reversible and dynamic*". It is surprising that there is huge difference in the students having this misconception from the pre-MIT in the TBT (37%) and LBT (77%) groups. Although the groups were not randomly sampled, I expected the students' performance on this misconception not to differ too much because (a) most of the students in these groups are from similar educational background, and (b) their Grade 12 results and UNIFY selection test results do not differ much. This finding is consistent with that of Voska and Heikkinen (2000), Cros et al. (1984) and Johnstone et al (19977). Johnstone et al. (1977) found that students cannot interpret the reversed equilibrium symbol of unequal length. The students were confident that its' only when the symbol has equal arrows that chemical equilibrium is attained. This difference could have been traced by follow-up interviews immediately after the Pre-MIT. It would be interesting to investigate the nature and extent of each misconception through this MIT, followed by interviews for all the items. However, the number of students in TBT having this misconception increased from 37% to 52% after the instruction. This implies that the instruction had negative impact on the students' conceptions belonging to this group. It was very difficult for students to understand the use of equilibrium arrows of unequal lengths. In fact, most of the students acknowledged that they rarely saw and used the symbol before. However, few students acknowledged that the appearance of the arrows might be related to the equilibrium constant. This also highlights the fact that the choice of subjects in higher grade and standard grade, as used at high schools, deny most students opportunities to learn more concepts. With students in LBT, there was a slight decrease in the number of students (77% to 73 %) possessing this particular misconception. Most of the students in this group also acknowledged that they rarely saw the reversed arrow symbol. It was then very difficult for the majority of the students to get acquainted to the use and meaning of the symbol. Although few teachers do use this equilibrium sign of arrows of different lengths, they rarely emphasise the meaning of it and when to use it. This non-significant difference might have caused by the effect of guessing on multiple choice test.

The second misconception in this category is that "*Equilibrium arrows of equal length mean that the percentage (proportions) of reactants and products is the same*".

The use of LBT clearly had no effect on the students' understanding of this concept. Although there were no practical activities dealing with the concept, I expected the students' to have improved understanding because a few examples of equilibria involving the use of arrows of unequal length were discussed during our theoretical sessions. The use of TBT had little effect on the number of students having this misconception. The numbers decreased from 41% to 37%. This decrease is not statistically significant and hence the TBT approach had no effect on students' understanding of this concept. The use of these arrows is not significant in indicating the difference between the extents of reactions. The magnitude of the equilibrium constant should be used instead of these arrows. Generally, the understanding of the students with regard to this category of misconception is not satisfactory and neither of the teaching methods significantly improved the students' misconceptions. This result agrees with the findings of Hofstein and Lunetta (1982), and Bates (1978) that the academic achievement of students in LBT and TBT does not differ. It is, however, recommended that the teacher using the equilibrium symbol of unequal lengths in the teaching of chemical equilibrium must consistently emphasise its meaning and usage because most of the current chemistry textbooks do not use the symbol.

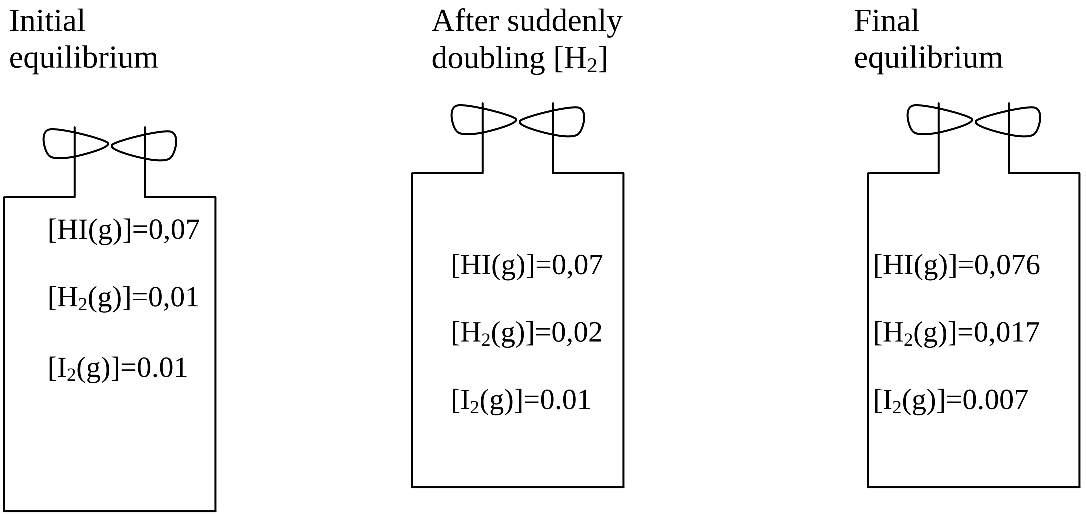
4.2.1.3 Category 3: Constancy of the equilibrium constant

With reference to the category of the constancy of the equilibrium constant, there were four misconceptions targeted. The first misconception was that "*the magnitude of* K_c *does not depend on the temperature irrespective of whether energy is released or absorbed*". Students' ability to know whether the equilibrium constant is affected by changes in the temperature of the system was tested. Generally, few students (31% in TBT and 35% in LBT) had this misconception initially. After the TBT treatment, only 24% of the students had this misconception. This reduction in students having the misconception clearly indicates that the TBT treatment had impact on students' learning of the concept. The difference can be attributed to more tutorial discussions, and lecture discussions held during classes, wherein numerical data of the equilibrium constant and temperature were used. The scope and depth of the discussions were primarily limited to the activities covered in the teaching material. However, it must be noted that limited discussions were held during the practical sessions of TBT. After the LBT treatment, 42% of the students had this misconception. I did not expect this increase (from 35% to 42%) in the student's misconceptions since I expected students to relate the equilibrium constant with the observed colour change of products and reactants as temperature changes. This colour change could then be related to concentrations of reactants and products at equilibrium. Most of the teaching of this concept in LBT was done through practical activities and this limited the students' understanding. I should have first spent quality time with students in the LBT treatment on a theoretical discussion of the equilibrium constant using mathematical relationships before embarking on a series of practical activities. Renner et al. (1985) concluded in their studies that discussions during laboratory activities play a pivotal role in enhancing students' understanding of concepts. Based on my result for this misconception, I agree with them because the concept investigated here required a good understanding of the mathematical relationship between the equilibrium constant and the equilibrium concentrations of reactants and products which was not fully accomplished. It is, therefore, clear that even though the practical work can be done and supported by fruitful discussions, as emphasised, a systematic integration or reference to theory must still play an important role.

The second misconception under this category was that "*The magnitude of* K_c *depends on the addition or removal of reactants and products*". Initially, both groups had very high proportions of students having this misconception (i.e. 61% for TBT and 67% for LBT). These results are consistent with the results of Barnejee (1991); Hackling and Garnett (1985); Johnstone et al. (1977), and Akkis et al. (2003). However, there was a significant reduction in students (61% to 35% in TBT and 67% to 37% in LBT) having this misconception. This implies that most students in both TBT and LBT were able to understand that additional concentration of the reactants or products does not affect the equilibrium constant. Two experiments were done with both groups during the treatment to investigate the effect of concentration on the equilibrium mixture. Not much was discussed about the mathematical relationship between the equilibrium constant, and equilibrium concentrations of reactants and products during these experiments. The emphasis during these experiments was on the shift in equilibrium as observed by a colour change. Theoretical exercises relating the equilibrium constant with equilibrium concentrations of reactants and products were done with both TBT and LBT groups, and have greatly influenced the students' understanding. A suitable example is the introductory teaching activity based on the mixture of $H_2(g)$, $I_2(g)$ and HI(g). One important teaching and learning sequence I used is stated below:

"Although the concentration of individual substances in equilibrium may vary, the equilibrium constant is always the same at a particular temperature. This, of course, is the crucial point of the equilibrium law. We can emphasise this further by considering the effect of suddenly increasing the concentration of hydrogen in an equilibrium mixture of H_2(g), I_2(g) and HI(g).

Fig 1: The effect of concentration on equilibrium constant



$$\frac{[HI(g)]^2}{[H_2(g)][I_2(g)]} = \frac{(0{,}07)^2}{0{,}01 * 0{,}01}$$
=49
=K_c

$$\frac{[HI(g)]^2}{[H_2(g)][I_2(g)]} = \frac{(0{,}07)^2}{0{,}02 * 0{,}01}$$
=24,5
<K_c

$$\frac{[HI(g)]^2}{[H_2(g)][I_2(g)]} = \frac{(0{,}076)^2}{0{,}017 * 0{,}007}$$
=49
=K_c

In the initial equilibrium mixture above (fig. 1), [HI(g)]=0,07 M, [H_2(g)]=0,01 M, [I_2(g)]=0,01 M

$$K_c = \frac{[HI(g)]^2}{[H_2(g)][I_2(g)]} = \frac{(0{,}07)^2}{0{,}01 * 0{,}01} = 49$$

When the [H_2] concentration is suddenly doubled:

$$\frac{[HI(g)]^2}{[H_2(g)][I_2(g)]} = \frac{(0{,}07)^2}{0{,}02 * 0{,}01} = 24{,}5 < K_c$$

The system is no longer in equilibrium. In order to restore the equilibrium, the concentration of HI(g) must rise, whilst that of H_2(g) and I_2(g) must drop. This is achieved by a conversion of some of the hydrogen and iodine into hydrogen iodide.

When equilibrium is restored once more, we find that [HI(g)]=0,076 M, [H_2(g)]=0,017 M and [I_2(g)]=0.007 M.

$$\frac{[HI(g)]^2}{[H_2(g)][I_2(g)]} = \frac{(0{,}076)^2}{0{,}017 * 0{,}007} = 49 = K_c$$

Notice that only a part of the added hydrogen is used up in restoring equilibrium. The concentration of H_2 (g) was suddenly doubled from 0,01 M in the initial equilibrium, to 0,02 M. When equilibrium is achieved once more the final concentration of hydrogen is not 0,02 M but 0,017 M. Obviously, [HI(g)] in the final equilibrium is greater than that in the initial equilibrium whilst [I_2(g)] in the final equilibrium is less than that initially". This way of introducing this concept has added value to the conceptual understanding of students as observed by the decrease in the population of students having this misconception in both groups. This is in line with the modeling and coaching as principles of cognitive apprenticeship used in TBT. The conceptual understanding of students is reflected by their responses to the following task related to this misconception

The students were given the following task and were requested to solve in groups of four. The answers were written on their self-report sheets. Most popular response means that out of six groups of students, four or more groups gave that particular response.

Task A – Effect of concentration: Ethanol, CH_3CH_2OH, react with ethanoic acid, CH_3COOH, to form ethylethanoate, $CH_3COOCH_2CH_3$ and water, H_2O. In a 1L solution, 2 moles ethanol were added to 2 moles ethanoic acid at 15 °C. After establishing the equilibrium, 0.5 mole ethylethanoate was formed.

(a) Give the reaction equation for this reaction.

Most popular response: $CH_3CH_2OH + CH_3COOH \rightleftharpoons CH_3COOCH_2CH_3 + H_2O$,

(b) If more ethanoic acid is added to the equilibrium mixture, what will happen to the amount of ethylethanoate? Explain!

Most popular response: the amount of ethyl ethanoate will increase because of the Le Chatelier 's principle. By adding more ethanoic acid we have disturbed the initial equilibrium and as such more of the ethanoic acid will react with ethanol to produce more of the products, in this case, ethyl ethanoate and water. Equilibrium will favour the reaction to the right.

(c) Will the value of equilibrium constant be the same as before the additional ethanoic acid was introduced into the equilibrium mixture? (do not calculate, just predict with justification).

Most popular response: Yes, the magnitude of the equilibrium constant won't change. We learned this when doing the calculations with the other equilibrium involving hydrogen gas, iodine gas and hydrogen iodide gas. In fact, when the amount of ethanoic acid is increased, the amount of ethanol decreases proportionally and the amount of the products also increases according to the balanced equation. This will result in the ratio of numerator and denominator in the equilibrium law of the new equilibrium system being the same as the one for the initial equilibrium.

(d) Will the new equilibrium be the same (i.e. contain the same amounts of reactants and products) as the initial equilibrium?

Most popular response: Yes, why not. Since the equilibrium constant before and after the new equilibrium is the same, therefore the equilibrium is the same.

(e) Elaborate on your answer to (f)?

Most popular response: After the establishment of the new equilibrium constant, the reactants and products are the same in nature and have equal amounts.

Lets consider the same task given above under initial conditions:

(f) If more ethyl ethanoate is added to the equilibrium mixture, what will happen to the amount of water? Explain!

Most popular response: the amount of water will decrease because of Le Chatelier 's principle. By adding more ethyl ethanoate to the equilibrium mixture we have disturbed the initial equilibrium and as such more of the water which was remaining after initial equilibrium will react with some ethyl ethanoate to produce the products. Thus why the amount of water will decrease. Equilibrium will favour the reaction to the left.

(g) Will the value of equilibrium constant be the same as before the additional ethanoic acid was introduced into the initial equilibrium mixture? (do not calculate, just predict with justification).

Most popular response: Yes, the magnitude of the equilibrium constant won't change. We learned this when doing the calculations with the other equilibrium involving hydrogen gas, iodine gas and hydrogen iodide gas. In fact, when the amount of ethyl ethanoate is increased, the amount of water decreases proportionally and the amount of the products also increases according to the balanced equation. This will result in the ratio of numerator and denominator in the equilibrium law of the new equilibrium system being the same as the one for the initial equilibrium.

(h) Will the new equilibrium be the same (i.e. contain the same amounts of reactants and products) as the initial equilibrium?

Most popular response: Yes, why not. Since the equilibrium constant before and after the new equilibrium is the same, therefore the equilibrium is the same, meaning we have equal amounts of reactants and products as in the first equilibrium.

(i) Elaborate on your answer to (h)?

Most popular response: After the establishment of the new equilibrium constant, the reactants and products are the same in nature and have equal amounts.

From these answers of the students' self reports sheets, I can conclude that students understood the effect of concentration of equilibrium constant. But they have a misconception that the initial equilibrium and final equilibrium are the same. This might have been caused by the contradiction in them of not being able to distinguish between equilibrium constant and equilibrium mixture, which involves the proportions of reactants and products at equilibrium. Generally, both instructions had a satisfactory effect on the students' understanding of this concept, and for this misconception, no method is considered superior to the other.

The third misconception under this category was that "*the magnitude of K_c depends on the volume or pressure of the system*". Students in both groups understood the concept very well. Their pre-knowledge might have contributed a lot to this factor. There is a significant difference between the proportions of students in TBT and LBT having this misconception from the pre MIT scores. This difference might have caused by the effect of guessing on the multiple choice test. After TBT approach, there was an insignificant decrease (44% to 40% in TBT) in the proportions of students having this misconception. This is an indication that the TBT approach did not have considerable effect on the students' understanding of this scientific concept. After LBT approach, there was significant decrease (64% to 50%) in the proportions of students having this misconception. This is an indication than the LBT approach improved the students' understanding of this scientific concept. Many studies (Huddle and Pillay, 1996; Johnstone et al., 1977; Akkus et al., 2003; Cachapuz and Maskill, 1989; Hackling and Garnet, 1985; Voska and Heikkinen, 2000) have reported this conceptual difficulty. The study of chemical equilibrium involving pressures and volumes is however difficult for students to grasp because in most cases they confuse pressure and volume. This is because (i) not many practical examples involve the gases with colour - even if some do, they need conditions not appropriate for high school or entering University laboratory setting. Some students don't even realize that the application is limited to gaseous substances (i.e. students don't look at the given equation to see whether the equilibrium mixture is homogeneous - containing only gaseous substances or heterogeneous with some gaseous substances). An example of the teacher – student conversation after the pre-test administration is as follows:

Teacher: How does pressure affect equilibrium constant in this chemical reaction equation?

$$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$$

Student 2: Not sure, but I think for every reaction at equilibrium there should be an effect on equilibrium constant when the pressure is increase or decreased.

Student 7: Pressure and volume work alike, so if the pressure is increased, the volume is increased and as such the amount of products will be more and equilibrium constant will increase.

Teacher: What does it mean in case of the reaction given above?

Student 2: Increase in pressure will produce more products to make equilibrium constant more? I guess reactions are always going forward no matter what happens?

Student 7: More of CaO(s) and CO_2(g) will be formed and as these are products, it means equilibrium constant will be large.

Both students did not realise that the given equilibrium mixture is heterogeneous with only one gaseous substance, carbondioxide (CO_2) as the product of the forward reaction and also that pressure and volume are inversely proportional. They were only interested in getting bigger equilibrium constant value without looking at the nature of the substances involved at equilibrium. According to these students when the pressure of the given system is increased and new equilibrium established the equilibrium constant is greater than under the initial conditions. This finding was also established by Hackling and Garnet (1985) in their study of chemical equilibrium misconceptions held by Year 12 students from two independent church schools and five state schools in the Perth metropolitan area in Australia.

The fourth misconception under this category was that "*the catalyst affects the magnitude of the equilibrium constant*". Initially, high proportions of students had this misconception in the TBT approach compared to that in LBT approach (i.e. 37% in TBT and 23% in LBT). Previous studies (Gorodetsky and Gussarsky, 1986; Hackling and Garnet, 1985; Huddle and Pillay, 1996 and Akkus et al., 2003) have revealed this misconception. Huddle and Pillay (1996) investigated the misconceptions of first entering University of Witwatersrand students in chemical equilibrium. They found that students cannot distinguish the effect of a catalyst on the equilibrium constant and also on the equilibrium mixture. Students' always think of a catalyst as something added to the mixture to increase the production. They think it takes part in a chemical reaction and as such lead to the increase in the product which will affect the magnitude of equilibrium constant. After the TBT approach, there was significant decrease (37% to 15%) in the proportions of students having this misconception. Since there were no practical activities involving the use of a catalyst, the concept was learned through theoretical discussions which characterize the TBT approach. In this case, articulation as a principle of cognitive apprenticeship was emphesised. Students were systematically encouraged to articulate their thoughts, as they carried out their problem solving tasks.

4.2.1.4 Category 4: Rate versus extent of chemical reaction

With reference to the category of the "rate vs extent of chemical reaction", there was only one misconception targeted. The misconception was that "*the rate of reaction depends on the magnitude of the equilibrium constant*". It was very pleasing to see that, even before the instructions, there were few students in both groups (26% in TBT and 39% in LBT) having this particular misconception. Even in the previous studies (Barnejee, 1991; Driscoll, 1960, Voska and Heikkinen, 2000) this misconception was found to exist to lower population of students. The findings of this misconception suggest that many students can distinguish between how far the reaction goes and how fast the reaction occurs. After the treatment, there was satisfactory reduction (26% to 15% in TBT and 39% to 12% in LBT) in the number of students having the misconception. Since there were no practical activities related directly to this concept, much of the students' understanding of the concept was stimulated during the theoretical interactions.

4.2.1.5 Category 5: Definition of equilibrium constant

With reference to the category of the “the definition of the equilibrium constant”, there was one misconception targeted. The majority of the students in both groups (50% in TBT and 44% in LBT) had difficulty of defining the equilibrium constant as targeted by the test items. After TBT approach, more students (44%) still failed to define the equilibrium constant correctly using the equilibrium concentrations of reactants and products and their stoichiometric coefficients. However, after LBT approach, a lower proportion of students (25%) as compared to that of in the TBT group had not successfully understood the definition of the equilibrium constant. This implied that the LBT approach had positive impact on the students’ understanding of the concept investigated. Interviewing some students after the treatment could have validated this claim, hence it reflect some weakness of this study. This can only be attributed to the variety and nature of exercises done during the teacher’s interaction with the students, and also the fact that students’ prior knowledge on this concept was good. It is important to emphasize to students that it is rarely the case that at equilibrium, the concentrations of reactants and products are equal; and also that equilibrium concentrations of the reactants and products having the same coefficients are not equal. The equilibrium concentrations depend also on the initial amounts of reactants and products. The studies by Akkus et al. (2003) and Voska and Heikennen (2000) revealed a significant number of students who just assumed a simple arithmetic relationship between equilibrium concentrations of reactants and products. This was attributed to students’ insufficient prior knowledge gained from previous studies.

4.2.1.6 Category 6: Application of Le Chatelier's Principle

With reference to the category of the "*application of the Le Chatelier's principle*", there were five misconceptions targeted. The first misconception was that "temperature does not affect the system at equilibrium". This meant that temperature does not affect the proportions of reactants and products of species at equilibrium and rates of reactions at equilibrium. There is a considerable increase in the number of students (37% to 57%) having this misconception in the TBT group. This is contrary to the expectation that after some treatment, the conceptual understanding must improve. Most students still expected the equilibrium concentrations of reactants to be unaffected by temperature despite having observed in a practical activity or being told otherwise during the class interaction with the teacher. On the contrary, there is a significant drop in students (50% to 32%) having this misconception in the LBT treatment. This decrease may be attributed to sufficient in-depth discussions during the practical activities and much exposure to practical activities that were not offered in the TBT treatment (see section 4.3 of this chapter).

The same arguments presented earlier hold for the second misconception, namely, that "addition or removal of reactants or products at equilibrium does not affect the proportions of reactants and products at equilibrium and the rate of reaction at equilibrium". There is a considerable increase in the number of students (35% to 46%) having this misconception in the TBT group whilst there is a decrease in the number of students (44% to 37%) in the LBT group possessing this misconception. Many authors reported this misconception over the years (Gorodetsky and Gussarsky, 1986; Hackling and Garnet, 1985; Johnstone et al., 1977; Huddle and Pillay, 1996; Voska and Heikkinen, 2000; Akkus et al, 2003). Examples of the teacher student interactions during the practical activities are given under section 4.3 of this chapter below.

The third misconception under this category was that "*changes in the volume of the container never affect the equilibrium system*". Initially, equal proportions (49% in TBT and 48% in LBT) of students in both groups had this misconception. After the treatments, 41% of the students in the TBT approach and 45% of the students in the LBT approach had this misconception. This is a non-significant decrease which indicates that both approaches had little impact on the students' understanding of this scientific concept. This result is not surprising as they are consistent with the findings of other authors of misconceptions in chemical equilibrium elsewhere (Akkus et al., 2003; Johnstone et al., 1977; Banerjee, 1991; Wheeler and Kass, 1978; Hackling and Garnet, 1985; Voska and Heikkinen, 2000; Camacho and Good, 1989). The major teaching implication of this misconception is that students cannot distinguish between pressure and volume, they cannot realise the inverse relationship that exist between these two variables. This is amazing because these two quantities are dealt with in many sections of the Physical science syllabus of grades 10 - 12 in most schools worldwide.

The fourth misconception under this category was that "the addition of a catalyst speeds up the rate of the forward reaction only and increases the quantities of products at equilibrium". The questions relating to the addition of a catalyst were generally answered reasonably well. Initially there were 34% of the students in the TBT approach and 28% of the students in the LBT having this misconception. These proportions of students are relatively low. As stated above, the common misconception was the notion that the rates of the forward and reverse reactions could be affected differently by the addition of the catalyst. This probably reflects incomplete understanding by students of the existence of a common reaction pathway and transition state for the forward and reverse reactions. An example of the students' ideas on this concept is indicated below. Students wrote their answers on their individual self-report sheets. Most popular response means that out of five students, three or more gave that particular response. This was done only with students who had the misconception stated above.

Task A -Addition of a catalyst: Given the following equilibrium mixture at certain constant pressure and temperature: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$,

(a) What will the effect of the addition of vanadium pentoxide as a catalyst have on the rate of the forward and reverse reactions?

Most common response: Addition of a catalyst will increase the rate of the forward reaction and decrease the rate of the reverse reaction

(b) Explain your answer in (a) above.

Most common explanation: When a catalyst is added, its purpose is to increase the forward reaction so that more products can be formed in the chemical reaction. Its effect does not depend on whether the reaction goes to completion or not.

(c) What will the effect of the addition of vanadium pentoxide as a catalyst have on the concentrations of $SO_2(g)$ and SO_3 at equilibrium?

Most common response: The concentration of the product which is $SO_3(g)$ will increase whereas that of the reactant which is $SO_2(g)$ will decrease.

(d) Explain your answer in (c) above.

Most common explanation: A catalyst is always added to increase the production of something or product. In this case, the production of $SO_3(g)$ is favoured. This happens because a catalyst will make more reactants to react faster and produce more products faster. Its effect does not depend on whether the reaction goes to completion or not.

From these answers of the students' response to the questions, I can deduce that students did not understand the role of a catalyst as stated before.

This observation was also captured in other literature on misconceptions in chemical equilibrium (Wheeler and Kass, 1978; Hackling and Garnet, 1985; Quilez-Pardo and Solaz-Portolez, 1995; Niaz, 1995; Akkus et al., 2003). After the TBT approach there were 30% of the students having this misconception. This decrease is non significant and therefore implies that the TBT approach had little influence on the students' understanding of this concept. However, after the LBT approach, there were 17% of the students having this misconception. This decrease is significant and therefore implies that this method had some impact on the students' understanding of the concept.

The last misconception under this category was that "increasing the amount of a solid substance that is already in equilibrium with other solid and gaseous products (i.e. the decomposition of calcium carbonate equilibrium system) will affect the equilibrium system". Initially, 76% of the students in the TBT and 64% of the students in the LBT had this misconception. After the TBT approach, a large number of students (61%) had the misconception. This decrease is significant and therefore implies that the TBT approach had an impact of the students' understanding of the concept. However, the majority of the students in this group still had the misconception. Again after the LBT treatment, a large number of students (62%) had the misconception. This is an indication that the LBT approach had an insignificant impact of the students' understanding of this scientific concept. An interesting point is that students confuse the mass and concentration of species added at equilibrium. As Johnstone et al. (1977) reported, most students will assume that the mass of a substance is the same as its concentration and hence they fail to make correct predictions on systems at equilibria. Chemistry instructors should try to build deeper student understanding of heterogeneous equilibria. In particular, it must be clarified that adding more of a solid substance participating in an equilibrium system changes the amount of that solid substance but not the concentration of its dissolved species.

4.2.2 Misconceptions from students' Mental Models of chemical equilibrium

The last category of the misconceptions investigated in this study was that "at equilibrium, not all species exist". This misconception was limited to the equilibrium systems undertaken during this study. This was investigated through students' symbolic mental models captured through self-reports and interviews.

I intend to identify the misconception that "at chemical equilibrium, not all species exist" which students possess as they observe a certain chemical reaction in equilibrium. The use of symbolic mental models was encouraged. These mental models helped the students to construct and rearrange their understanding of the concepts. Self-reports were used to capture students' mental models. They also help in building up self-reflection of concepts under study, as such can provide useful indications of conceptual understanding

Before embarking on the activities pertaining to symbolic mental models with students, I introduced to students the role of mental models in the teaching of science. I, thereafter, requested them to write down possible ways in which they thought their construction of mental models would benefit them in their learning. The most frequently recurring points were as follows:

(i) I will use a mental model as a visualization of a structure or process;

(ii) I will use a mental model to remember a concept or idea;

(iii) I will use a mental model to simplify a difficult concept;

(iv) I will use a mental model to link familiar ideas with unfamiliar ideas; and

(v) I will use a mental model to represent the way I think about and understand a concept.

Students' symbolic mental models were captured using the self-report sheets during a demonstration with the practical activities. The data on self-report sheets were consolidated by follow-up interviews. Students were requested to present their observations through symbolic representations. In most cases, there were clear connections between the students' symbolic models and the interview responses. The chemical formulae of the substances used (e.g. SCN^-, Fe^{3+}, and $FeSCN^{2+}$) were given to students but they wrote the reactions themselves. The emerging ideas were gathered together and categorized. The students' symbolic models are illustrated in Table 4 given below.

Table 4: Students' pre and post mental models of the reaction $Fe^{3+} + SCN^- \rightarrow FeSCN^{2+}$, for the concept of chemical equilibrium.

Concept	Description	Types of student's mental model	No. of Students in LBT		No. of Students in TBT	
			Pre	Post	Pre	Post
At chemical Equilibrium, all the species are at equilibrium	Type 1- At equilibrium, All the species are used up	$4Fe^{3+} + 4SCN^- \rightarrow 4FeSCN^{2+}$	7	1	6	3
	Type 2 – At equilibrium, one species must be used up	$4Fe^{3+} + 7SCN^- \rightarrow 4FeSCN^{2+} + 3SCN^-$	17	2	21	9
	Type 3 – At equilibrium, not all species are used	$6Fe^{3+} + 8SCN^- \rightarrow 4FeSCN^{2+} + 2Fe^{3+} + 4SCN^-$	2	23	0	15
			N = 26		N = 27	

Table 4 above illustrates that the students have three types of symbolic mental models of chemical equilibrium in response to the reaction $Fe^{3+} + SCN^{-} \rightarrow FeSCN^{2+}$. Before both instructions, 7 students (26.9%) in LBT and 6 students (22%) in TBT held the Type 1 model, i.e., the conception that at equilibrium all the reactant species must be used up. This clearly indicates that the students assumed that the reaction in equilibrium must go to completion and only products are available at equilibrium. However, after both instructions, there was 1 student (4%) in LBT and 3 students (11%) in TBT still having the original conception. This clearly indicates that both instructions had some effect on the students' understanding of this concept. These students' Type 1 mental model was further supported by their explanation during the interaction with the teacher. The protocols with student C01 from TBT are indicated below:

Practical activity 4a**:** Here are the solutions of $FeCl_3$ (yellow), KSCN (colourless) and $FeSCN^{2+}$ (brick red) in beakers 1, 2 and 3, respectively. Let us divide the solution in beaker 3 into three test tubes labeled A, B and C respectively (the teacher poured the solution equally into three test tubes).

Teacher – What will you observe if 2 drops of $FeCl_3$ solution are added to test tube A?

C01 – Nothing will happen.

Teacher – Why?

C01 – Because all of KSCN and $FeCl_3$ present have initially reacted completely. So there is no KSCN available to react with the added $FeCl_3$.

Teacher – Are you saying at equilibrium all initial reactant species are consumed?

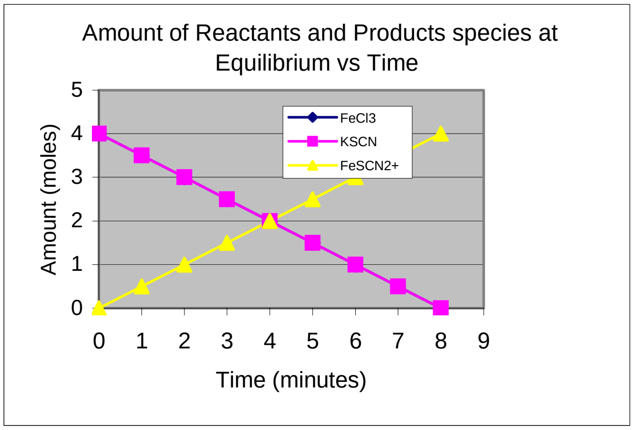
C01 – Yes. When equilibrium is reached, all amounts of reactants present must have reacted equally to produce equal amounts of products. For example, if we have 4 moles of KSCN, we must also have 4 moles of $FeCl_3$ and all of this must produce 4 moles of $FeSCN^{2+}$ at equilibrium.

Teacher – Can you represent your model graphically, showing how the amount of reactants and products changes with time until equilibrium is attained?

C01 – Yes. Here is my tabular and graphical representation.

Amount of Substances in moles

Time	$FeCl_3$	KSCN	$FeSCN^{2+}$
0	4	4	0
1	3.5	3.5	0.5
2	3	3	1
3	2.5	2.5	1.5
4	2	2	2
5	1.5	1.5	2.5
6	1	1	3
7	0.5	0.5	3.5
8	0	0	4



C01 – [continues] Mnr., at the beginning there are 4 moles of both reactants and nothing of the product. After the first minute, we have 3.5 moles of each reactant and 0.5 moles of the product. This amount of the product is coming from the amount of reactants consumed. Since they react in a 1: 1 molar ratio, then any amount of reactant consumed equals the amount of product formed. After 8 minutes it is where the reaction has reached equilibrium and at this stage all amounts of reactants are finished and we have products only.

Teacher - Thank you.

However, after instruction, this student responded differently to the similar activity involving $FeCl_3$ – yellow, $Na_2(HPO_4)_3$ – colourless, $Fe_2(HPO_4)_3$ – white solutions. The protocols with student C01 after instruction are shown below.

Practical activity 4b: Here are the solutions of $FeCl_3$ – yellow, $Na_2(HPO_4)_3$ – colourless and $Fe_2(HPO_4)_3$ – white in beakers 1, 2 and 3, respectively. Let us divide the solution in beaker 3 into three test tubes labeled A, B and C respectively (the teacher poured the $Fe_2(HPO_4)_3$ solution equally into three test tubes).

Teacher – What will you observe if 2 drops of $FeCl_3$ solution are added to test tube A?

C01 – The colour will turn whiter because of some chemical reaction that will occur between the added $FeCl_3$ and $Na_2(HPO_4)_3$ that is available at equilibrium.

Teacher – Are you saying at equilibrium all initial reactant species are still present?

C01 – Yes. When equilibrium is reached, all species still exist with different amounts. For example, if we have 4 moles of $Na_2(HPO_4)_3$, we can have 8 moles of $FeCl_3$ and at equilibrium have 2 moles of $Na_2(HPO_4)_3$, 6 moles of $FeCl_3$ and 2 moles of $Fe_2(HPO_4)_3$.

Teacher – Can you represent your model in a tabular form showing how the amount of reactants and products changes with time until equilibrium is attained?

C01 – Yes. Here is my tabular representation.

Amount of Substances in moles

Time/min	$FeCl_3$	$Na_2(HPO_4)_3$	$Fe_2(HPO_4)_3$.
0	8	4	0
1	7	3	1
2	6.5	2.5	1.5
3	6	2	2
4	6	2	2
5	6	2	2
6	6	2	2

C01 – [continues talking] in this case, equilibrium is attained only after two minutes of the reaction and from here onwards the amounts of any species remains constant unless there is some disturbance.

Teacher - Thank you.

These observations are only applicable to the reactions under investigation. They cannot be generalized to any other equilibrium system of a different nature (e.g. equilibrium in precipitation reactions).

Again, from Table 4 above, before both instructions 17 students (65 %) in LBT and 21 students (78%) in TBT held the Type 2 model, i.e. the conception that “at equilibrium one reactant species must be used up”. This clearly indicates that the majority of the students had the conception that the reaction at equilibrium must go to completion and only products and excess reactants are available at equilibrium. However, after both instructions, there were 2 students (8%) in LBT and 9 students (33 %) in TBT still having the original conception. This clearly indicates that both instructions had some significant effect on the students’ understanding of this concept. These students’ Type 2 mental model was further supported by their explanation during the interaction with the teacher. The protocols with student E02 are indicated below:

Practical activity 4a: Here are the solutions of $FeCl_3$ (yellow), KSCN (colourless) and $FeSCN^{2+}$ (brick red) in beakers 1, 2 and 3, respectively. Let us divide the solution in beaker 3 into three test tubes labeled A, B and C respectively (the teacher poured the solution equally into three test tubes).

Teacher – What will you observe if 2 drops of $FeCl_3$ solution are added to test tube A?

E02 – Nothing will happen.

Teacher - Why?

E02 – Because KSCN must have been used up. So if we add $FeCl_3$ solution it won't react with anything.

Teacher – What if we add few drops of KSCN into test tube B.

E02 – The colour will be more brick red.

Teacher – Why?

E02 – Because we still had some excess $FeCl_3$ remaining in the solution. What I am saying is that whenever there is a reaction, one of the reactant must be used up. In this case, that reactant is KSCN.

Teacher – Are you also referring to reactions at equilibrium?

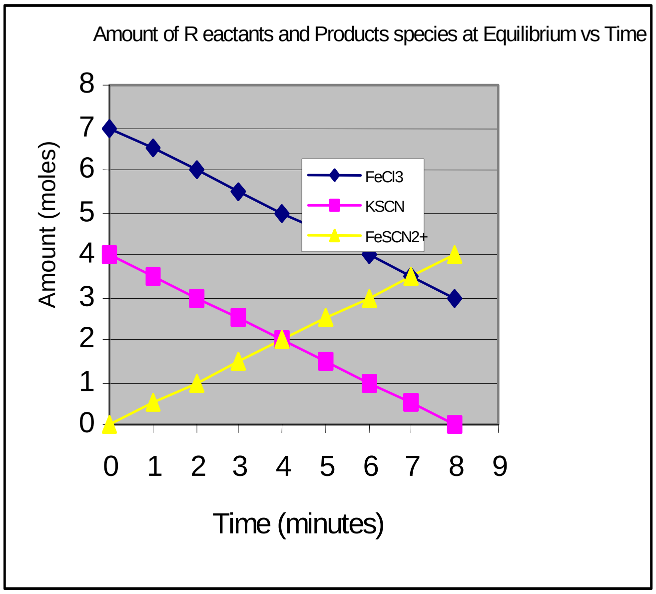
E02 – Yes. In any reaction, we have limiting reactant. When the reaction reaches equilibrium it means one of the reactant is consumed. For example, if we have 4 moles of KSCN and 7 moles of $FeCl_3$ reacting, at equilibrium they must produce 4 moles of $FeSCN^{2+}$ and 3 moles of $FeCl_3$ remaining in solution.

Teacher – Can you represent your model both in a tabular form and graphically, showing how the amount of reactants and products changes with time until equilibrium is attained?

E02 – Yes. Here is my tabular and graphical representation.

Amount of Substances in moles

Time/min	$FeCl_3$	KSCN	$FeSCN^{2+}$
0	7	4	0
1	6.5	3.5	0.5
2	6	3	1
3	5.5	2.5	1.5
4	5	2	2
5	4.5	1.5	2.5
6	4	1	3
7	3.5	0.5	3.5
8	3	0	4



E02 – [continues] you see Mnr., at the beginning there are 4 moles of KSCN and 7 moles of $FeCl_3$ and nothing of the product. After the first minute, we have 6.5 moles of $FeCl_3$, 3.5 moles of KSCN and 0.5 moles of $FeSCN^{2+}$. This amount of the product is coming from the amount of reactants consumed. Since they react in a 1: 1 molar ratio, then any amount of reactant consumed equals the amount of product formed. After 8 minutes it is where the reaction has reached equilibrium and at this stage only KSCN is consumed, 3 moles of $FeCl_3$ are still available and 4 moles of $FeSCN^{2+}$ are formed at equilibrium. There is no reaction occurring at equilibrium.

Teacher - Thank you

However, this student had a similar understanding and mental model with that of student C01 after instruction. Both instructions had impacted on student' mental models and their conceptual understanding of reactions at equilibrium with respect to the given conception.

Also, from Table 4 above, before both instructions, 2 students (8%) in LBT and none of the students (0%) in TBT held the Type 3 model, i.e., the conception that "at equilibrium not all species must be used up" – all the reactant and product species are available. This clearly indicates that only very few students had the conception that the reaction at equilibrium must not go to completion. However, after both instructions, there were 23 students (88%) in LBT and 15 students (55%) in TBT having this conception. This clearly indicates that both instructions had huge effect on the students' understanding of this concept. Type 3 model represents the correct mental model. The impact has been more in LBT (from 8% to 88%) as compared to TBT (from 0% to 55%). It is very clear that, initially, there was no significant difference in the students' conceptions on how they perceive species at equilibrium. However, after both treatments, more students had Type 3 model than any other model in both LBT and TBT. The difference is more in LBT than in TBT. These students' Type 3 mental model was further supported by their explanation during the interaction with the teacher. The protocols with student E10 are indicated below:

Practical activity 4a: Here are the solutions of $FeCl_3$ (yellow), KSCN (colourless) and $FeSCN^{2+}$ (brick red) in beakers 1, 2 and 3, respectively. Let us divide the solution in beaker 3 into three test tubes labeled A, B and C, respectively (the teacher poured the solution equally into three test tubes).

Teacher – What will you observe if 2 drops of $FeCl_3$ solution are added to test tube A?

E10 – The colour will turn brick red.

Teacher - Why?

E10 – Because KSCN will react with the added $FeCl_3$ to produce more $FeSCN^{2+}$ solution that is brick red in colour.

Teacher – What if we add few drops of KSCN into test tube B.

E10 – The colour will also be more brick red.

Teacher – Why?

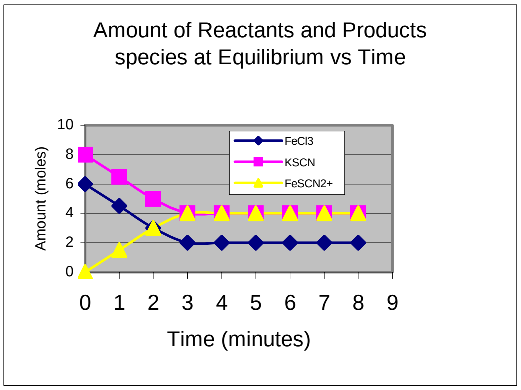
E10 – Because we still have some excess of both $FeCl_3$ and KSCN remaining in the solution at equilibrium. What I am saying is that for a state of equilibrium to be attained, not all reactant species must be consumed. In fact, at equilibrium, all substances exist and the reversible reactions are occurring at the same rate. For example, if we have 6 moles of KSCN and 8 moles of $FeCl_3$ reacting, at equilibrium they may produce 4 moles of $FeSCN^{2+}$ and still have 2 moles of KSCN and 4 moles of $FeCl_3$ remaining in solution.

Teacher – Can you represent your model both in a tabular form and graphically, showing how the amount of reactants and products changes with time until equilibrium is attained?

E10 – Yes. Here is my tabular and graphical representation

Amount of Substances in moles

Time/min	$FeCl_3$	KSCN	$FeSCN^{2+}$
0	6	8	0
1	4.5	6.5	1.5
2	3	5	3
3	2	4	4
4	2	4	4
5	2	4	4
6	2	4	4
7	2	4	4
8	2	4	4



E10 - [continues] At the beginning there are 8 moles of KSCN and 6 moles of $FeCl_3$ and nothing of the product. After the first minute, we have 4.5 moles of $FeCl_3$, 6.5 moles of KSCN t and 1.5 moles of $FeSCN^{2+}$. This amount of the product is coming from the amount of reactants consumed. Since they react in a 1: 1 molar ratio, then any amount of reactant consumed equals the amount of product formed. After 3 minutes it is where the reaction has reached equilibrium and the concentrations of all species remain unchanged. That is for every mole of product produced, at the same time the mole of that product is decomposed. The rate of the reverse process equals the rate of the forward process. As we can see we still have 2 moles of $FeCl_3$, 4 moles of KSCN and 4 moles of $FeSCN^{2+}$ available at equilibrium. Both the forward reaction and the reverse reaction are occurring at equilibrium.

Teacher – Why does your graph become horizontal at one particular point?

E10 – Because the graphs are related to one another and it is the point where equilibrium is reached. The horizontal lines indicate to us that there is constant formation of the reactants and products.

Teacher – Thank you.

Both the students' symbolic mental models and the interactions amongst the teacher and the students, as indicated above, gave a clear indication of the way students visualise reactions at equilibrium. These visualizations (whether correct or incorrect) held by the students, have contributed to their understanding of the concepts in their own way. Chiu et al. (2002) examined students' symbolic and molecular models of chemical equilibrium reactions. They found that students who received special attention, such as probing during observations and coaching during teaching and learning constructed better mental models than those who were independent. It is, therefore, important to actively engage students mentally during the practical activities.

4.3 The influence of TBT and LBT

Both the LBT and TBT approaches had positive and negative contributions towards the students' conceptual understanding. One of the positive contributions of LBT is that it allowed students to engage mentally with laboratory tasks. This offered students an opportunity to reflect on what they see (observe), what they do and what they explore. The interactions between the teacher and the students were recorded, which reflected students' understanding of the concepts. The following protocols were recorded during the interaction between the teacher and student E04 in LBT, during an activity involving the equilibrium state between bromine liquid and bromine vapour.

Teacher – In this activity we have liquid bromine, a stoppered flask, a gas syringe and hood cupboard. What do you think will happen to the liquid bromine when transferred into the stoppered flask?

E04 – It might try to evaporate, I am not quite sure.

Teacher – Why would you think it would try to evaporate?

E04 – Because in its original bottle I can see some bromine vapour, that means it has evaporated from the liquid bromine. Since the flask is stoppered, the vapour will not escape to anywhere.

Teacher – [transferring bromine into a stoppered flask] What do you observe?

E04 – A cloud of bromine vapour trying to escape. The colour intensity is very light.

Teacher – How can you intensify the colour?

E04 – By shaking the bottle, more bromine vapour can be formed.

Teacher – Look carefully as I am shaking this flask. What is happening?

E04 – More bromine vapour is formed as expected. But as you keep on shaking the colour intensity is no longer increasing?

Teacher – Why do you think the intensity is no longer increasing?

E04 – Because there is more bromine vapour, as such some of it is condensing. I can see by small droplets. Yes, both the vapour and droplets are continuously formed at the same rate. This is called state of dynamic equilibrium where by the rate of the forward process equals the rate of reverse process.

Teacher – Now lets' remove some of the bromine vapour using this gas syringe without affecting the system in any other way. Will the rate of condensation of gas molecules still equal the rate of evaporation of liquid molecules? Explain!

E04 – It seems more molecules are evaporating to form vapour, Yea! The rate of condensation is slower than that of evaporation. In fact, there is no balance between the two processes.

Teacher – What is happening to the concentration of molecules in the gas phase as time goes on?

E04 – The concentration of the molecules in the gas phase is increasing slowly. If we shake the bottle the rate of evaporation will be high. This will increase until equilibrium is reached again. At equilibrium, the concentrations of both liquid bromine and bromine vapour remains unchanged if the system is not disturbed.

Teacher – Where else did you learn about this type of equilibrium?

E04 – When boiling water at home in a closed pot.

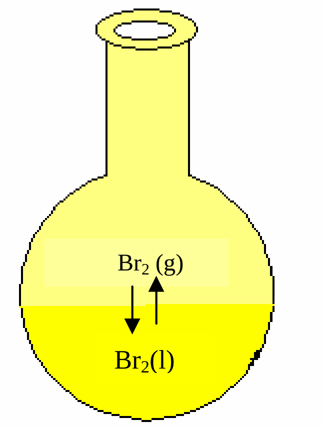
In this case, observing the movement of the molecules rising inside the stoppered flask has contributed to the student's way of reasoning. This finding is consistent with that of Chiu et al. (2002) and Locaylocay et al. (1993). These authors argued that giving students the opportunity to observe scientific concepts could arouse interest and help acquiring new scientific view of the concept. This new scientific view of the concept might take longer than what the teacher expected depending on the understanding of the students and the level of the misconception held by that particular student.

In contrast, the interaction between the teacher and the learners in TBT was different. The protocols of the interactions between the teacher and the student C02 from TBT are shown below:

Teacher –	When liquid bromine is shaken in a stoppered flask, some liquid evaporates forming an orange gas. Eventually, the intensity of the gas does not change anymore. What do you think has happened?
C02 –	I think the bromine vapour has reached the maximum value inside the container. So there is no need to form any more vapour.
Teacher –	Are you saying the process of vapour formation has stopped at particular time?
C02 –	Yes, there is no more formation of bromine in vapour form. The process has stopped.
Teacher –	You said the bromine vapour has reached its maximum value, what do you mean by this?
C02 –	I mean that it has reached the state of equilibrium where by the bromine vapour has balanced the liquid bromine.
Teacher –	Will you say the type of equilibrium attained is static or dynamic?
C02 –	It is static because the bromine vapour will be on the upper part inside the container whereas the liquid bromine will be on the lower part of the container and they won't interact.

At this point the teacher distributes a plain sheet to the student and gives them the following task: Make a drawing that will indicate the equilibrium between liquid bromine and gaseous bromine and explain your drawing.

C02: Here is my drawing;



C02 –	[continues] the liquid bromine is denser than the gaseous bromine. I think the rate at which evaporation occurs will be equal to the rate at which condensation occurs. Just like when someone boils water in a closed container.

* The conversation continues after some pause.

Teacher –	Are you saying there is a process that is taking place at equilibrium?
C02 –	Yes, Meneer. Both evaporation and condensation occur at the same rate.
Teacher –	Now suppose that some of the vapour is suddenly removed without affecting the system in any other way. Will the rate of condensation of gas molecules still equal the rate of

evaporation of liquid molecules? Explain!

C02 – No, less condensation will occur, as there won't be much vapour to condense.

Teacher – What do you think will happen to the concentration of molecules in the gas phase as time goes on?

C02 – I think it will increase until equilibrium is reached again. That is, at equilibrium there will be no change in the amount of liquid bromine and bromine vapour.

Teacher – Will you still say the equilibrium is static?

C02 – No, It has to be dynamic since the process has not stopped.

Teacher – Yes. The equilibrium is a dynamic one. The rate of forward reaction equals the rate of reverse reaction. This happens only in a closed system. [The teacher continues to explain some important features of dynamic equilibrium]. Do you have any question regarding this activity and the establishment of equilibrium?

C02 – No.

Initially, this student did not show an understanding of equilibrium, but after being asked to draw a model, he realized that as the vapour is going up, it would condense back as shown by his arrows on the diagram. There should be continuous movement between molecules in gaseous form and molecules in liquid form as a result of condensation and evaporation taking place. This was a more theoretical but fruitful approach to the students' learning process.

The other significant contribution of LBT was that it offered students more time to discuss with the educator and as such provided more scope also. Examples of the interaction between the teacher and students in both instructions are given below:

(a) The effect of temperature on the chemical equilibrium mixture

The effect of temperature on chemical equilibrium in the LBT group was investigated using three activities consisting of the following experiments: the effect of temperature on $Fe^{3+}\ (aq) + SCN^{-}\ (aq) \rightleftharpoons FeSCN^{2+}\ (aq)$ equilibrium mixture; on $2NO_{2\ (g)}$ (brown) $\rightleftharpoons N_2O_{4(g)}$ (colourless) equilibrium mixture and lastly on $Co(H_2O)_6{}^{2+}{}_{(aq)} + 4Cl^{-}{}_{(aq)} \rightleftharpoons CoCl_4{}^{2-}{}_{(aq)} + 6H_2O_{(l)}$ equilibrium mixture. The students in the LBT group were able to have more clearer conceptual understanding after doing the three experiments involving changes in temperature and asked probing questions. The teacher however gave more explanations to students in the TBT group and as such this might have limited their conceptual understanding. The learning environment created in the TBT group was not as active as that created in the LBT group. Students E07 and C05 's protocols were chosen to compare the interaction between the teacher and the class during the experiments. The protocols are listed below starting with E07 from the LBT group.

Teacher – Here are the solutions of $FeCl_3$, KSCN, and $FeSCN^{2+}$ in test tubes 1, 2 and 3 respectively. What is the colour of Fe^{3+}, SCN^- and $FeSCN^{2+}$

E07 – the colour of Fe^{3+} is yellow, that of SCN^- is colourless and that of $FeSCN^{2+}$ is brick red.

Teacher – In test tube 3, the following chemical equilibrium exist:
Fe^{3+} (aq) + SCN^- (aq) $\rightleftharpoons$ $FeSCN^{2+}$ (aq) , Predict what will happen if we add some heat to the solution in test tube 3.

E07 – Nothing will happen

Teacher – Why?

E07 – Because I think heat does not affect or change anything, it will only make the solution to boil after some time.

Teacher – I am now putting this test tube 3 in hot water, what do you observe?

E07 – The colour is becoming more lighter.
Teacher – Why?

E07 – Because of increased temperature. The equilibrium is now affected.

Teacher – What exactly do you think has happened?

E07 – The concentration of the product is less, this means some product decomposed or reacted to form original reactants.

Teacher – Would you say the forward reaction is exothermic or endothermic?

E07 – It must be exothermic since it is not favoured by increase in temperature.

Teacher – Suppose we put test tube 3 into ice water, what do you think will happen?

E07 – Ao, sir! That's easy. It will be the opposite of what we did above.

Teacher – Can you elaborate?

E07 – In cold conditions the mixture will become darker. What I mean is that more of the product will be formed. The forward reaction will be favoured by decrease in temperature.

Teacher – What will happen if the test tubes from cold water and hot water are left at room temperature for some time?

E07 – The solutions will look alike because the temperature is the same.

Teacher – Can you briefly describe what you have learned about chemical equilibrium from this activity?

E07 – Temperature can affect equilibrium depending on whether the forward reaction is exothermic or endothermic. This means it also affects the proportions of reactants and products at equilibrium as such equilibrium constant is affected.

Teacher – How is equilibrium constant affected by temperature?

E07 – from our experimental results, we can say that when the temperature is increased, the endothermic reaction is favoured, in this experiment the reverse reaction is favoured and as such more of the product will decompose and less equilibrium constant will be attained.

The concept was similarly was reflected by student E12 in the LBT group when using the following chemical equilibrium: $2NO_{2(g)}$ red -brown $\rightleftharpoons$ $N_2O_{4\ (g)}$ colourless in the gas syringe.

Teacher – Predict what will happen if we add some heat to the contents of this syringe?
E12 – It will definitely change.
Teacher – Why?
E12 – Because we saw in the previous experiment that heat affect equilibrium depending on the energy of the reaction.
Teacher – [Putting this syringe in hot water] What do you observe?
E12 – The colour is becoming more brownish.
Teacher – Why?
E12 – Because of increased temperature. The equilibrium is now affected. The concentration of the nitrogen dioxide is more, this means some product decomposed or reacted to form original reactants.
Teacher – Would you say the reverse reaction is exothermic or endothermic?
E12 – It must be endothermic since it is favoured by increase in temperature.

The effect on temperature on chemical equilibrium mixture was investigated using the same chemical reaction to those of the LBT group but only one experiment was done. The other tasks were done theoretically not using laboratory equipment. The first experiment outlined above (Fe^{3+} (aq) + SCN^{-} (aq) $\rightleftharpoons$ $FeSCN^{2+}$ (aq)) was performed by students in the TBT group with the guidance of the teacher. Contrary to the conversations in the LBT group, the teacher and the students in the TBT group interacted differently in the same activity whilst keeping in mind that the intention is to eliminate the misconceptions held by students. The protocols are shown below.

Teacher – When $FeCl_3$ reacts with KSCN, a state of dynamic equilibrium exists amongst the Fe^{3+}, SCN^{-} and $FeSCN^{2+}$. Here is $FeSCN^{2+}$ in three test tubes labelled 1, 2 and 3 respectively. We have ice water, hot water and water at room temperature in beakers A, B and C respectively. We are going to put the first test tube into the ice water and compare what changes compared with the originals. [put the first test tube into cold water]
C25 – The colour of the solution becomes darker. That is if we compare it with the original solutions in test tubes 2 and 3.
Teacher – What do you think will happen if we put test tube 3 in beaker B containing hot water?
C25 – The colour of the solution will become lighter!
Teacher – [Puts test tube 3 into beaker A containing hot water]. Can you see any colour change?
C25 – Yes, sir. It is turning lighter.
Teacher – In these two experiments we can express the equilibrium this way: Fe^{3+} (aq) + SCN^{-} (aq) $\Leftrightarrow$ $FeSCN^{2+}$ (aq) , The reaction to the right is exothermic, and hence the when we increase temperature, more products will be formed. Since in the first part of these two experiments we decreased temperature by putting it in the cold

water…then the decrease in temperature favours the exothermic reaction. But when the temperature was increased, the endothermic reaction was favoured. What is the main cause of the change in equilibrium in this experiment?

C25 – Temperature.

Teacher – Of course, an increase in temperature favours endothermic reaction and a decrease in temperature favours an exothermic reaction. Have you heard about Le chatelier's principle?

C45 – Yes, when doing grade 10. It is about the stress that is caused to systems at equilibrium and how the system responds to the stress.

Teacher – Yes, what other things can affect reactions at equilibrium?

C25 – Pressure and concentration.

(b) Effect of Pressure

The effect of pressure and volume was investigated using the equilibrium of red brown nitrogen dioxide (NO_2) gas with colourless dinitrogen pentoxide (N_2O_4) in a gas syringe represented as follows: $2NO_{2\,(g)}$ (red-brown) $\rightleftharpoons$ $N_2O_{4(g)}$ (colourless). The students in the LBT group were able to have more clearer conceptual understanding after doing the experiment involving changes in pressure and asked probing questions. The teacher however gave more explanations to students in the TBT group and as such this might have limited their conceptual understanding. The learning environment created in the TBT group was not as engaging by means of observations as that created in the LBT. Students E16 and C10 's protocols were chosen to compare the interaction between the teacher and the class during the experiment. Both students were academically poor especially with physical science. The protocols are listed below starting with student E16 from the LBT group.

Teacher – Here is a syringe with an equilibrium mixture of nitrogen dioxide and dinitrogen pentoxide ($2NO_{2\,(g)}$ (brown) $\rightleftharpoons$ $N_2O_{4(g)}$ (colourless)). Do you understand this chemical equilibrium [pointing at $2NO_{2\,(g)}$ (brown) $\rightleftharpoons$ $N_2O_{4(g)}$ (colourless) mixture in the syringe]

E16 – Yes

Teacher – What do you think will happen if the syringe is pressed forward (compressed).

E16 – I am not sure, maybe nothing will happen

Teacher – [Pushes the syringe inward] let's see.

E16 – It is turning colourless, I am sure of that.

Teacher – Why? What does it mean!

E16 – Because the pressure was increased, and it means more of dinitrogen pentoxide is formed.

Teacher – [Pulls the syringe outward] what do you observe?

E16 – The gas in the syringe turn darker, in this case we reduced the pressure by increasing the volume. More nitrogen dioxide is produced.

Teacher – What have you learned from this activity.

E16 – An increase in pressure favours the side with lesser number of moles of gas substances whereas a decrease in pressure favours the side with more moles of gaseous substances.

Teacher – Note that this experiment is suitable for gaseous substances [continues to explain why it is not suitable for solids and liquid substances].

As in other activities, the teacher and the students in the TBT interacted differently in the same activity. The protocols are shown below with student C10.

Teacher – Here is a syringe containing a mixture of $NO_{2(g)}$ and $N_2O_{4(g)}$ in equilibrium as follows: $2NO_{2\,(g)}$ (brown) $\rightleftharpoons$ $N_2O_{4(g)}$ (colourless). What do you observe [pushes the syringe inwards]

C10 – I see, the colour is becoming very light.

Teacher – Why?

C10 – Because we have increased the concentration of $N_2O_{4(g)}$. Actually we increased the pressure of the system.

Teacher – That's right, an increase in pressure has got effect on equilibrium of gaseous substances like in this case. You must check your balanced equation to have good prediction as to which side will the equilibrium shift. In this case when the pressure was increased, the equilibrium shifted to the side of the smaller number of moles. [pulls the syringe outwards] what do you observe?

C10 – The colour is turning brown. This means we have produced more of nitrogen dioxide by increasing the volume and decreasing the pressure.

Teacher – Yes, it is the opposite the initial part of this experiment. A decrease in pressure favours a reaction with more number of moles and vice versa. Do you have any question regarding this activity?

C10 – Yes, can this experiment about pressure be done with solid and liquid substances also?

Teacher – No. [the teacher explains why it is suitable for gaseous substances]

(c) Effect of Concentration

The effect of concentration on equilibrium was investigated using two experiments with the LBT group, for the following equilibrium mixtures: $Co(H_2O)_6{}^{2+}{}_{(aq)} + 4Cl^-{}_{(aq)} \rightleftharpoons CoCl_4{}^{2-}{}_{(aq)} + 6H_2O_{(l)}$ and $Fe^{3+}\,(aq) + SCN^-\,(aq) \rightleftharpoons FeSCN^{2+}\,(aq)$. In both cases, the student's responses were similar in that they understood that not all reactants are consumed when equilibrium is established. Most students were in a position to realize that the limiting reactant concept is not applicable to reactions at equilibrium (those selected for the study). The protocols of the student and teacher interaction are given below starting with student E01 in the experimental group using the cobalt chloride equilibrium.

Teacher – Do you understand this chemical equation: $Co(H_2O)_6^{2+}{}_{(aq)} + 4Cl^-{}_{(aq)} \rightleftharpoons CoCl_4^{2-}{}_{(aq)} + 6H_2O_{(l)}$. The purple solution of $Co(H_2O)_6^{2+}{}_{(aq)}$ is prepared in ethanol.

E02 – Yes, it mean we have two substances of cobalt existing together at equilibrium. These two substances possess different colours.

Teacher – What do you think will happen if few drops of HCl is added to the solution?

E02 – I think it will consume some purple compound to form more of the blue compound?

Teacher – Why will that happen?

E02 – Mnr, remember at equilibrium we still have all substances existing, so adding HCl will cause it to react with $Co(H_2O)_6^{2+}{}_{(aq)}$ to produce $CoCl_4^{2-}{}_{(aq)}$ which is blue in colour.

Teacher – Lets' see [putting drops of HCl in the solution]. What do you notice?

E02 – Yea! It's turning blue as I predicted. So it's really true that when a disturbance is caused, the system will try to counteract the effect.

This very same student responded similarly to the same questions when studying the equilibrium involving $FeCl_3$, KSCN, and $FeSCN^{2+}$. The protocols are listed below:

Teacher – Do you understand this chemical reaction: $Fe^{3+}\,(aq) + SCN^-\,(aq) \rightleftharpoons FeSCN^{2+}\,(aq)$.

E02 – Yes Mnr., it shows that there is equilibrium amongst the species on both sides of the equilibrium sign and all the species are there.

Teacher – What do you think will happen if few drops of $FeCl_3$ solution are added to the mixture of $FeCl_3$ and KSCN?

E02 – I think the mixture will turn more brick red because addition of $FeCl_3$ will cause more KSCN to react and produce more $FeSCN^{2+}$ (aq).

Teacher – [Pointing at three test tubes] here are three test tubes containing the mixture of $FeCl_3$, KSCN and $FeSCN^{2+}$ (aq). [Putting few drops of $FeCl_3$ solution in the first test tube], what do you observe?

E02 – The colour is turning more brick red, that means more of $FeSCN^{2+}$ (aq) ion species is formed. This shows that we still had some KSCN in the solution that reacted with $FeCl_3$ added.

Teacher – [Putting few drops of KSCN in the second test tube] well observe this?

E02 – The same colour change (more brick red) as before Mnr. That means we still had some $FeCl_3$ solution in the mixture at equilibrium. This available $FeCl_3$ reacts with some added KSCN to produce $FeSCN^{2+}$ (aq).

Teacher – Can you summarise what you have learned?

E02 – Yes, the increase in concentration of a reactant to a system at equilibrium causes the system to shift to the side of the product and vice versa.

Teacher – Do you have any question regarding this activity?

E02 – No, thanks.

Teacher – [Then continues to explain how the effect of concentration affects equilibria in reactions involving gases and solid species].

On the contrary, the teacher and the student in the TBT group interacted differently whilst doing the same activity. The protocols are listed below:

Teacher – Here is the solution of cobalt chloride in ethanol. The equilibrium that exist in solution is $Co(H_2O)_6^{2+}{}_{(aq)} + 4Cl^-{}_{(aq)} \rightleftharpoons CoCl_4^{2-}{}_{(aq)} + 6H_2O_{(l)}$. $Co(H_2O)_6^{2+}{}_{(aq)}$ is purple in colour and $CoCl_4^{2-}{}_{(aq)}$ is blue in colour. What do you think will happen if some drops of HCl solution are added to the mixture?

C02 – I think there won't be any colour change?

Teacher – Lets see [putting some concentrated HCl into the solution of $Co(H_2O)_6^{2+}{}_{(aq)}$]

C02 – Whao! It's changing colour into blue one.

Teacher – Why is that so?

C02 – It means we are forming more of $CoCl_4^{2-}{}_{(aq)}$ by adding some HCl. In other words we still had some $Co(H_2O)_6^{2+}{}_{(aq)}$ existing at equilibrium that reacted with the added HCl. By why Mnr?

Teacher – Before I respond to your answer, lets' do another one? [Pointing at three test tubes] here are three test tubes containing the mixture of $FeCl_3$, KSCN and $FeSCN^{2+}$ (aq). These species are in equilibrium represented as follows: Fe^{3+} (aq) + SCN^{-} (aq) $\rightleftharpoons$ $FeSCN^{2+}$ (aq). Fe^{3+} (aq) is yellow, SCN^{-} (aq) is colourless and $FeSCN^{2+}$ (aq) is brick red. [Putting few drops of $FeCl_3$ solution in the first test tube], what do you observe?

C02 – The colour is becoming more brick red.

Teacher – Why?

C02 – I think the reaction of $FeCl_3$ and KSCN is favoured and as such more of the product $FeSCN^{2+}$ (aq) is formed. Thus' why I observe deep brick red colour? But then it means that at equilibrium all of $FeCl_3$ was finished. So as we added some drops, it can became available and reacted.

Teacher – Are you sure of your last statement?

C02 – Yes, quite sure.

Teacher – [Putting some drops of KSCN into the second test tube] now observe this.

C02 – The colour is becoming more brick red again?

Teacher – Why? What has happened?

C02 – It means more of $FeSCN^{2+}$ (aq) is formed by the addition of KSCN. Ao! In the previous one we added $FeCl_3$ and the colour became more brick red, and even this time the result is the same. Maybe all the species are present in the solution at equilibrium.

Teacher – You see student, now is the right time to answer your initial question. The reaction in equilibrium has not gone to completion, we still have all species existing and by increasing the concentration of either reactant, we are causing a disturbance and the system will try to counteract the disturbance by shifting towards the side of the products. This is called Le Chatelier 's principle. [Then continues to explain how the effect of concentration affects equilibria in reactions involving gases and solid species].

These interactions reflected the extent and level of the students' understanding of the concepts. The social interaction between the teacher and the students were more focused and in-depth in LBT. Studies by Bodner (1986), Johnstone (1977), and Renner et al. (1985), concluded that discussions in laboratory sessions play a vital role in helping students grasp concepts. However, these discussions must be clearly guided. The major advantage of LBT is that scaffolding was dominantly used as opposed to explaining done by the teacher in TBT. The major disadvantage of LBT was that it was expensive in equipment, chemicals, human resources and teacher time.

The strength of TBT was that it helped the students in grasping some of the concepts, especially those related to the quantitative aspects of chemical equilibrium. It offered students an opportunity to relate theoretical concepts mathematically with ease, more than students in LBT. However, it could not provide an opportunity to observe more qualitative phenomena through experimentation.

CHAPTER 5

CONCLUSIONS AND IMPLICATIONS

In this chapter, I will discuss the conclusions drawn from the results of the study, its implications to science teaching, and limitations of the study.

5.1 Conclusions from the results

The broad aim of the study was to determine the effectiveness of LBT and TBT on the students' conceptual understanding of chemical equilibrium. The results show that LBT caused a significantly better acquisition of scientific concepts than TBT. The main difference between the two modes of instruction was that LBT explicitly dealt with students' misconceptions through series of practical activities coupled with scaffolding as a principle of cognitive apprenticeship. In this case I presented students with experiments and asked them probing questions as reflected under section 4.3 of chapter 4. The interactions between myself and the students in the LBT group shows that the teacher was probing for reflection and thinking whereas I lectured the students with the key concepts of the experiment to make sure the students understood what the main purpose of the activity was. Instruction based on laboratory teaching offered a set of guidelines to help students to gain experience in grasping concepts. These guidelines provided special learning environments, such as activating students' misconceptions by presenting simple qualitative practical examples, identifying common misconceptions during the practical activity, presenting descriptive evidence in the laboratory that the typical misconceptions are incorrect, providing a scientifically correct explanation of the situation, and giving students the opportunity to practice the correct explanations by using numerous practical activities. On the contrary, I provided some explanations to the students in the TBT group and these explanations might have taken over the students' constructing opportunity for learning the concepts. Therefore, even though all the students were exposed to the same teaching and learning activities through experimentation, tutoring, lecturing and demonstration, they were scaffolded differently while developing their concepts. Chiu et al. (2002) also found that when the teacher played a role of scaffolding for conceptual change either by stimulating the students to make inferences or by offering opportunities for self reflection and self correction, students had better understanding of the chemical equilibrium concepts through the construction of mental models.

Also, it would appear that a reason for the poor progress of the students in the TBT to acquire scientific concepts lies with the continued presence of the alternative concepts in their conceptual framework (Wheeler and Kass, 1978; Banerjee, 1991). The more established alternative concepts are likely to be more useful to an individual and therefore more difficult to eliminate. The instructional strategy has to be designed in such a way that the individual is convinced that the presented scientific concept is more useful than the already existing alternative concept. LBT represents an alternative approach designed to encourage students to alter preconceived concepts. It means that the alternative concepts can be reduced even if not completely eliminated in the course of the instruction. The nature of LBT can enable students to progress at their own pace and can force students to use their observation, prediction, and thinking abilities.

Actually, the most important part of the conceptual change instruction of LBT was the social interaction provided by teacher-directed discussions. These discussions helped the students share their ideas and ponder them in-depth, as proposed by Renner et al. (1985). They found that many students preferred laboratory work that offered them opportunities to better direct their enquiries clearly, and discussions were found to be important in helping students to clarify their thinking. Chiu et al. (2002) used scaffolding as one principle of cognitive apprenticeship during their teaching. They found out students who were scaffolded during some experimentation constructed their mental models better that those who received direct lecturing method while doing the same experiments. The instruction typically involved intensive teacher-student, and student-student interactions during laboratory sessions. Discussions of concepts facilitate students' understanding, as well as encourage their conceptual restructuring. This type of instruction provides opportunities for greater involvement, thereby giving students more chances to gain insights and intrinsic interest, and students are assumed to focus on both the understanding and mastering of concepts. This is in agreement with the findings of Gunstone and Champagne (1990) who argued that laboratory work could successfully be used to promote conceptual change if small qualitative tasks are use. Such task aid in students reconstructing their understanding as less time is spend on interacting with apparatus, instructions and recipes, and more time gets spend on discussions and reflections.

A series of events of conceptual conflict provide students with the opportunity to challenge their own scientific concepts. Students were able to change their concepts after confrontation. However, if a concept could not be explicitly observed from an experiment, it might not be easy to change the concept ontologically, as suggested by Chiu et al. (2002). They might simply memorize them rather than understand them. Hence, students' reflection on what they see, what they do and what they explore, can promote their conceptual understanding. This provides an advantage of LBT over TBT.

The main disadvantage of LBT was the resources needed. The first category of resources includes human power. LBT does not require one instructor/educator/teacher in a class. To facilitate and have good interaction with students, more educators were needed. The educators were trained by the researcher and were also teaching chemistry in UNIFY. LBT also requires patience on the educators' part, as more time is needed to prepare the activities and have discussions with students. Unlike in TBT, wherein more demonstrations were made, in LBT the students did many experiments. It was also useful when teaching some concepts, such as constant concentration (in TBT), to use graphical representations in overcoming misunderstandings that are often associated with these concepts.

The identification of the misconceptions using the misconception identification tests (pre- and post MITs) was successful in that many of them were captured. These misconceptions were similar to those identified by other researchers worldwide (Wheeler and Kass, 1978; Johnstone et al., 1977; Banerjee, 1991; Huddle and Pillay, 1996, Voska and Heikkinen, 2000; Akkus et al., 2003). Some of the most significant misconceptions revealed by this study were:

- The rate of the forward reaction increases with time from the mixing of the reactants until equilibrium is established. This conceptual difficulty was also reported by Hackling and Garnet (1985) in their study of misconceptions of chemical equilibrium held by Year 12 chemistry students following normal instruction. It was also reported by other researchers of misconceptions in chemical equilibrium (Gorodetsky and Gussarky, 1986; Huddle and Pillay , 1996; Voska and Heikkinen, 2000).

- A simple arithmetic relationship exists between the concentrations of reactants and products at equilibrium (e.g. concentrations of reactants equals to concentrations of products). This conceptual difficulty was also reported by other researchers (e.g. Wheeler and Kass, 1978; Gorodetsky and Gussarky, 1986; Johnstone et al, 1977; Huddle and Pillay , 1996; Akkus et al, 2003) in their study of misconceptions of chemical equilibrium held by Year 12 chemistry students and University/college first entrance (Year 1) students.
- When a system is at chemical equilibrium and a change is made in the conditions, the rate of the favoured reaction increases but the rate of the other reaction decreases (e.g. when the temperature is increased the rate of the endothermic reaction increases but the rate of the exothermic reaction decreases). This conceptual difficulty was also reported by other researchers (e.g. Camacho and Good, 1989; Hackling and Garnet, 1985; Banerjee, 1991; Pardo and Pordoles, 1995; Wheeler and Kass, 1978; Gorodetsky and Gussarky, 1986; Johnstone et al, 1977; Huddle and Pillay, 1996; Akkus et al, 2003) in their study of misconceptions of chemical equilibrium held by Year 12 chemistry students and University/college first entrance (Year 1) students.

It is also important to stress that:

(a) The concept “chemical equilibrium” is a concept that is liable to be misconceptualised because of the other uses of the label “equilibrium. The confusing everyday phenomena should be presented and analysed as to the common and different attributes of the concepts "equilibrium" and "chemical equilibrium". A clear distinction should be made in the use of the labels "equilibrium" and "chemical equilibrium".

(b) The misconception concerning dynamism and sidedness is deeply rooted and an explicit attempt should be made in presenting the dynamic nature of chemical equilibrium.

These findings coupled with those reported in chapter 4 under the misconceptions from pre- and post- MIT answered research question 1 of this study. Since the test instrument used in this study did not cover all the possible misconceptions held by students in the area of chemical equilibrium. This results in the weakness of the study.

The identification of misconception using the students' symbolic mental models on reactions at equilibrium was achieved. These mental models were successfully identified using selected practical activities whereby students recorded their ideas on a student self-report sheet, and then were later interviewed by the researcher. Three types of mental models were identified before and after instruction, and they were reported under section 4.3 of the results chapter. Case analysis of the students' mental models revealed similar incorrect conceptual frameworks possessed by students of both groups before exposure to learning materials. However, the majority of the incorrect concepts were removed in the course of the instruction, either by TBT or LBT. Students found the dynamic movement of the particles at equilibrium too abstract to comprehend. However, through a series of well considered experiments and prompts from the educator, students in LBT were given more opportunities to construct their mental models of chemical equilibrium than the students in TBT, thus allowing them to make more progress with developing the concepts. The mental models constructed are strictly limited to the chemical equilibrium systems adopted or used in this study.

It is also important to stress that:

- The concept “chemical equilibrium” is a concept that is liable to be misconceptualised because of the other uses of the label “equilibrium. The confusing everyday phenomena should be presented and analysed as to the common and different attributes of the concepts “equilibrium” and “chemical equilibrium”. A clear distinction should be made in the use of the labels “equilibrium” and “chemical equilibrium” avoiding abbreviations.
- The misconception concerning dynamism and sidedness is deeply rooted and an explicit attempt should be made in presenting the dynamic nature of chemical equilibrium. In presenting this scientific concepts in class possible preconceptions should be analysed and considered in the planning and teaching process.

It is clear from the results presented in Tables 1, 2 and 3 that both instructions made positive contribution to the students’ understanding of the scientific concepts investigated in this study. This is consistent with the claims of other researchers on laboratory and traditional teaching (Bates, 1978; Gunstone and Champagne, 1990; Reif and St. John, 1979). It is however noted that LBT had slightly significant contribution to the students’ conceptual understanding compared to TBT as reflected in Table 2. It is also clear from Table 3 that some concepts were still rooted in students’ minds even after instruction. For example, from Table 3 under the category of *left and right sidedness,* 81% of the students in TBT had the misconception after treatment and 58% of the students in LBT had the same misconception after treatment. These proportions of students are high (more than average number per group) and as a result the treatments were not effective. From Table 3 again under the category of the *interpretation of the reversed equilibrium arrows*, 52% of the students in TBT and 73% of the students in LBT had the misconception that equilibrium symbol of unequal lengths means that the reaction is not reversible and dynamic. This finding implies that both instructions did not have an effect on the students' understanding of this scientific concept. Lastly from Table 3 under the category of the *application of Le Chatelier 's principle*, 61% of the students in TBT and 62% of the students in LBT had the misconception that increasing the amount of a solid that is already in equilibrium with other solid product and gaseous product will affect the equilibrium system. This is evidence that both instructions failed to enhance students' understanding of this scientific concept. The implications of these findings are discussed in the next section.

5.2 Implications of the results

Implications related to classroom practice arising from this study are outlined below:

- The teaching and learning of most concepts of chemical equilibrium should be practical based (LBT) or, in case TBT is encouraged, demonstrations must be used where necessary. This will give students an opportunity to observe, measure, plan investigations, interact with each other and the environment, and communicate effectively;

- The most widely student-held incorrect concepts highlight areas within chemical equilibrium that students find most challenging. For example, most of the incorrect concepts reported in Table 3 above relate to the effect of temperature change. Thus, chemistry educators should carefully consider how they introduce and explain the effect of temperature change on an equilibrium system, especially the role that the change in enthalpy of the reaction plays in determining the direction of the shift. Furthermore, teachers should help students understand that adding or removing one or more equilibrium species at constant temperature will not change the value of equilibrium constant, so long as the temperature remains constant;
- Chemistry instructors should try to build deeper student understanding of heterogeneous equilibria. In particular, it must be clarified that adding more of a solid substance participating in an equilibrium system changes the amount of that solid substance but not the concentration of its dissolved species;
- Dealing with a complex concept such as chemical equilibrium calls for an in-depth consideration of the prerequisites for learning it. And in connection with this, both an analysis of students' misconceptions or biases and an awareness of their own responsibility are necessary. This will encourage students to reflect on their own knowledge. Providing students with opportunities to verbalise their understanding of a concept is critical if the deep-rooted (embedded) misunderstandings are to be identified, diagnosed, and addressed;
- Students must be allowed and helped to carry out adequate control of the variables during the learning process. Students should be encouraged to self-

monitor their learning by asking themselves why a particular change to an equilibrium system will cause a particular effect. They should be informed that they will be held accountable for their answers as well as their reasoning, and made to understand that providing an answer is not the same as explaining why the answer is correct;

- The role of language must be considered. We must bear in mind that the number and meaning of words used in science may impede students' competence in communicating ideas;
- The use of mathematical language and its understandings must be emphasized and clarified. For example, many students read equilibrium sign as the "equality sign" used in mathematics; and
- Application of knowledge, especially the principles of equilibrium, to new reactions, everyday life and industrial systems, must be emphasised.

5.3 Weakness of the study

The following have been identified as weaknesses of the study:

- Insufficiency of qualitative data - with reference to Table 3, under the category of the interpretation of the reversed equilibrium arrows, it is clear that students there is big difference in the students' pre test scores. Interviewing could have helped in establishing this huge difference.
- Scope of the MIT – The MIT did cover all possible misconceptions in this area. As a result the instructions might have eliminated some misconception although not identified by the MIT.

5.4 Limitations of the Study

This study has the following limitations:

- It was undertaken with foundation year students from Historically Disadvantaged Institution; and
- The chemistry content used was entirely meant for the UNIFY students. Only selected concepts of chemical equilibrium were used. Thus all the results are limited to the activities used in this study.
- Some misconceptions learned by students were not covered by the MIT used in the study.

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Student No____________________

APPENDIX 1: Misconception Identification Test

Question 1

Read the following statement:

In the familiar Haber system at equilibrium

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

the application of increased pressure to the right hand side only will drive the equilibrium to the left.
Which of the following comments about the above statement would you agree with and why?

A. It is correct.
B. It is incorrect; the equilibrium would in fact be driven to the right.
C. It is impossible to increase pressure on the right hand side.
D. It is correct as long as the nitrogen and hydrogen are continuously removed.

Give reason(s) for your choice.

Question 2

Look very critically at the following equilibria and answer the questions that follow:

(i) $C_2H_5NH_2(aq) + H_2O(aq) \; \overset{\longrightarrow}{\xleftarrow{\qquad\quad}} \; C_2H_5NH_3^+(aq) + OH^-(aq)$

(ii) $NH_3(aq) + H_2O(aq) \; \overset{\rightarrow}{\xleftarrow{\qquad\quad}} \; NH_4^+(aq) + OH^-(aq)$

2.1 Which of the following statements about the given equilibria is correct?

A. In each of them, the reverse rate of reaction is greater than the forward rate of reaction.
B. The forward rate of reaction in (i) is greater than the forward rate of reaction in (ii).
C. In reaction (i), the forward and reverse rates are greater than the forward and reverse rates in reaction (ii).
D. In each, the forward and reverse rates are equal.

Give reason(s) for your choice.

2.2 Which of the following statements about the given equilibria is correct?
A. Both systems have the same percentage of reactants and products.
B. The percentage of product in each system is the same.
C. System (i) contains a higher percentage of products than system (ii).
D. System (ii) contains a lower percentage of reactants than system (i).

Give reason(s) for your answer.

Question 3

Consider an equilibrium mixture of CO, Cl_2, $COCl_2$ at 200 °C and 1 atmosphere pressure present in chemical equilibrium:

$$CO\,(g) + Cl_2(g) \rightleftharpoons COCl_2\,(g) + \text{heat}$$

3.1 The mixture is cooled to 150 °C while the volume is kept constant. When the new equilibrium is established,

3.1.1
A. The concentration of $COCl_2$ (g) is the same as in the first equilibrium.
B. The concentration of $COCl_2$ (g) is less than in the first equilibrium.
C. The concentration of $COCl_2$(g) is greater than in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.1.2
A. The rate at which $COCl_2$ (g) is being formed is greater than that in the first equilibrium.
B. The rate at which $COCl_2$ (g) is being formed is less than that in the first equilibrium.
C. The rate at which $COCl_2$ (g) is being formed is the same as that in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.1.3
A. The equilibrium constant is less than in the first equilibrium.
B. The equilibrium constant is greater than in the first equilibrium.
C. The equilibrium constant is the same as in the first equilibrium.
D. Data insufficient for conclusion.
.
Give reason (s) for your choice.

3.1.4

A. The concentration of CO(g) is greater than in the first equilibrium.
B. The concentration of CO(g) is less than in the first equilibrium.
C. The concentration of CO(g) is the same as in the first equilibrium.
D. Data insufficient for conclusion

Give reason (s) for your choice.

3.2 The volume of the system is reduced by increasing the pressure at constant temperature. When the new equilibrium is established:

3.2.1

A. The mass of COg) is greater than in the first equilibrium.
B. The mass of CO(g) is the same as in the first equilibrium.
C. The mass of CO(g) is less than in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.2.2

A. The concentration of COg) is greater than in the first equilibrium.
B. The concentration of CO(g) is the same as in the first equilibrium.
C. The concentration of CO(g) is less than in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.2.3

A. The concentration of $COCl_2$(g) is less than in the first equilibrium.
B. The concentration of $COCl_2$(g) is greater than in the first equilibrium.
C. The concentration of $COCl_2$(g) is the same as in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.2.4

A. The mass of $COCl_2$(g) is less than in the first equilibrium.

B. The mass of $COCl_2(g)$ is greater than in the first equilibrium.
C. The mass of $COCl_2(g)$ is the same as in the first equilibrium.
D. Data insufficient for conclusion.

Give reason(s) for your answer.

3.2.5

A. The rate at which $COCl_2(g)$ is being formed is less than that in the first equilibrium.
B. The rate at which $COCl_2(g)$ is being formed is the same as that in the first equilibrium.
C. The rate at which $COCl_2(g)$ is being formed is greater than that in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.2.6

A. The equilibrium constant is greater than in the first equilibrium.
B. The equilibrium constant is less than in the first equilibrium.
C. The equilibrium constant is the same as in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.3 Some $Cl_2(g)$ is removed from the system, the volume and the temperature being kept constant. When the new equilibrium is established:

3.3.1

A. The mass of $COCl_2(g)$ is less than in the first equilibrium.
B. The mass of $COCl_2(g)$ is greater than in the first equilibrium.
C. The mass of $COCl_2(g)$ is the same as in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.3.2

A. The equilibrium constant is greater than in the first equilibrium.

B. The equilibrium constant is less than in the first equilibrium.
C. The equilibrium constant is the same as in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.3.3

A. The rate at which $COCl_2(g)$ is being formed is greater than that in the first equilibrium.
B. The rate at which $COCl_2(g)$ is being formed is the same as that in the first equilibrium.
C. The rate at which $COCl_2(g)$ is being formed is less than that in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.3.4

A. The concentration of CO(g) is greater than in the first equilibrium.
B. The concentration of CO(g) is less than in the first equilibrium.
C. The concentration of CO(g) is the same as in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.4 The catalyst is added to the reaction mixture of CO, Cl_2, $COCl_2$. When the new equilibrium is established:

3.4.1

A. The rate at which $COCl_2(g)$ is being decomposed is greater than that in the first equilibrium.
B. The rate at which $COCl_2(g)$ is being decomposed is less than that in the first equilibrium.
C. The rate at which $COCl_2(g)$ is being decomposed is the same as that in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

Student No___________________

3.4.2

A. The concentration of $COCl_2(g)$ is less than in the first equilibrium.
B. The concentration of $COCl_2(g)$ is greater than in the first equilibrium.
C. The concentration of $COCl_2(g)$ is the same as in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.4.3
A. The concentration of $Cl_2(g)$ is less than in the first equilibrium.
B. The concentration of $Cl_2(g)$ is greater than in the first equilibrium.
C. The concentration of $Cl_2(g)$ is the same as in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.4.4

A. The rate at which $Cl_2(g)$ is being used up is greater than that in the first equilibrium.
B. The rate at which $Cl_2(g)$ is being used up is less than that in the first equilibrium.
C. The rate at which $Cl_2(g)$ is being used up is the same as that in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.4.5
A. The equilibrium constant is greater than in the first equilibrium.
B. The equilibrium constant is less than in the first equilibrium.
C. The equilibrium constant is the same as in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

3.5 Some students in the chemistry class wanted to relate the equilibrium concentrations of the reactants and products by formulating the equilibrium constant expression for the CO(g), Cl_2 (g) and $COCl_2$ (g) equilibrium mixture represented as follows:

$$CO\,(g) + Cl_2(g) \rightleftharpoons COCl_2(g) + \text{heat}$$

Four students put down their opinions on equilibrium constant expressions as follows:

A. The equilibrium constant will be calculated using the following expression:

$$Kc = \frac{[CO(g)]+[Cl_2(g)]}{[COCl_2(g)]}$$

B. The equilibrium constant will be calculated using the following expression:

$$Kc = \frac{[CO(g)][Cl_2(g)]}{[COCl_2(g)]}$$

C. The equilibrium constant will be calculated using the following expression:

$$Kc = \frac{[COCl_2(g)]}{[Cl_2(g)][CO(g)]}$$

D. The equilibrium constant will be calculated using the following expression:

$$Kc = \frac{[COCl_2(g)]}{[CO(g)]+[Cl_2(g)]}$$

With which student do you most closely agree?

Give reason(s) for your choice.

3.6 Some students in the chemistry laboratory collected the following experimental data on equilibrium constant and temperature for the equilibrium reaction:

$$CO\,(g) + Cl_2(g) \rightleftharpoons COCl_2\,(g) + \text{heat},$$

Experiment No.	Temperature	Kc
1	273 K	130

2	298 K	17
3	373 K	0.1

3.6.1 The students started the arguments about the proportions of reactants and products at equilibrium as follows:

A. In Experiment 2, the equilibrium mixture has more reactants than products as compared to the other two experiments.
B. In Experiment 3, the equilibrium mixture has more products than reactants as compared to the other two experiments.
C. In Experiment 1, the equilibrium mixture has more reactants than products as compared to the other two experiments.
D. In Experiment 3, the equilibrium mixture has more reactants than products as compared to the other two experiments.

With which student do you most closely agree?
Give reason(s) for your choice.

3.6.2
A. The highest Kc value in experiment 1 indicates that its reaction rate is faster than the reaction rates in Experiments 2 and 3.
B. In Experiment 2, the reaction proceeds at a moderate rate compared to Experiments 1 and 3.
C. The lowest Kc value in Experiment 3 indicates that its reaction rate was slower than the reaction rates in Experiments 1 and 2.
D. None of the above answers is correct because high Kc value does not imply faster rate and also low Kc value does not imply slower rate.

Give reason(s) for your choice.

3.6.3
A. The experimental results are incorrect because the Kc must always increase with an increase in temperature.
B. The experimental results are incorrect because the Kc does not depend on the temperature (i.e. Kc must be the same for the same reaction).
C. The experimental results are correct because Kc must decrease with an increase in temperature.
D. Data insufficient for conclusion.

Elaborate on your choice.

Student No_______________________

Question 4

Consider the following equilibria,

$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

4.1 Which of the following equilibrium constant expression for the given reaction would you agree with and why?

A. $Kc = \dfrac{[CaO(s)][CO_2(g)]}{[CaCO_3(s)]}$

B. $Kc = \dfrac{[CaCO_3(s)]}{[CaO(s)][CO_2(g)]}$

C. $Kc = [CO_2(g)]$

D. $Kc = \dfrac{[CaCO_3(s)]}{[CaO(s)] + [CO_2(g)]}$

Give reasons for your choice.

4.2 Some solid calcium oxide (CaO) is added to the system, the volume and the temperature being kept constant. When the system reaches the new equilibrium:

4.2.1

A. The concentration of $CaCO_3$ (s) is less than in the first equilibrium.
B. The concentration of $CaCO_3$ (s) is greater than in the first equilibrium.
C. The concentration of $CaCO_3$ (s) is the same as in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice.

4.2.2

A. The equilibrium constant is greater than in the first equilibrium
B. The equilibrium constant is less than in the first equilibrium
C. The equilibrium constant is the same as in the first equilibrium
D. Data insufficient for conclusion

Student No____________________

Give reason (s) for your choice.

4.2.3

A. The rate at which $CaCO_3$(s) is being formed is greater than that in the first equilibrium.
B. The rate at which $CaCO_3$(s) is being formed is the same as that in the first equilibrium.
C. The rate at which $CaCO_3$(s) is being formed is less than that in the first equilibrium.
D. Data insufficient for conclusion.

Give reason (s) for your choice

APPENDIX 2: Results of the proportion of students on each item of the MIT.

	TBT Pre Test					LBT Pre Test					TBT Post Test					LBT Post Test			
	A	B	C	D	Correct Key	A	B	C	D		A	B	C	D		A	B	C	D
1	57	23	**10**	10	**C**	61	16	**10**	13		52	15	**19**	15		27	27	42	4
2.1	27	7	3	**63**	**D**	39	35	3	**23**		37	11	4	**48**		46	23	4	27
2.2	40	7	**40**	13	**C**	33	17	**30**	20		37	15	**30**	19		33	21	25	21
3.1.1	33	37	**20**	10	**C**	37	13	**27**	23		67	19	**7**	7		31	35	27	8
3.1.2	27	**43**	23	7	**B**	29	**48**	10	13		11	**67**	19	4		8	73	8	12
3.1.3	33	**20**	40	7	**B**	23	**13**	48	16		44	**19**	37	0		12	20	68	0
3.1.4	13	**17**	67	3	**B**	19	**13**	61	6		11	**15**	63	11		19	42	35	4
3.2.1.	20	33	**37**	10	**C**	35	39	**23**	3		22	44	**26**	7		4	50	42	4
3.2.2	**20**	53	20	7	**A**	**43**	30	23	3		**33**	37	19	11		27	46	27	0
3.2.3	37	**20**	40	3	**B**	19	**35**	39	6		26	**7**	59	7		4	54	38	4
3.2.4	28	**24**	34	14	**B**	23	**26**	39	13		33	**30**	37	0		8	42	42	8
3.2.5	27	37	**30**	7	**C**	23	23	**48**	6		33	37	**30**	0		19	23	46	12
3.2.6	17	17	**57**	10	**C**	45	16	**35**	3		22	19	**59**	0		19	27	50	4
3.3.1	**77**	3	13	7	**A**	**77**	0	16	6		**70**	15	7	7		73	8	15	4
3.3.2	10	47	**33**	10	**C**	10	55	**29**	6		19	19	**59**	4		8	27	62	4
3.3.3	30	7	**47**	17	**C**	32	19	**35**	13		22	37	**33**	7		23	23	42	12
3.3.4	**13**	27	57	3	**A**	**19**	3	74	3		**11**	11	74	4		35	8	58	0
3.4.1	**53**	13	30	3	**A**	**68**	6	10	16		**70**	7	22	0		77	8	12	4
3.4.2	3	20	**70**	7	**C**	19	3	**74**	3		19	11	**67**	4		8	12	81	0
3.4.3	20	13	**60**	7	**C**	13	10	**74**	3		11	11	**70**	7		12	4	85	0
3.4.4	**40**	27	20	13	**A**	**61**	6	26	6		**56**	11	26	7		65	15	19	0
3.4.5	13	13	**63**	10	**C**	10	10	**77**	3		22	4	**74**	0		19	4	77	0
3.5	17	7	**50**	27	**C**	0	10	**68**	22		4	7	**63**	26		0	0	88	12
3.6.1	18	18	39	**25**	**D**	3	17	45	**34**		0	22	30	**48**		4	15	4	77
3.6.2	17	0	10	**72**	**D**	26	10	3	**61**		4	4	7	**85**		0	4	8	88
3.6.3	17	20	**27**	37	**C**	10	23	**35**	32		22	15	**30**	33		4	15	58	23
4.1	17	13	**53**	17	**C**	19	29	**42**	10		26	11	**52**	11		23	12	62	4
4.2.1	13	67	**20**	0	**C**	3	52	**35**	10		7	48	**41**	4		4	50	46	0
4.2.2	43	20	**30**	7	**C**	40	10	**40**	10		33	0	**63**	4		23	8	65	4
4.2.3	39	**18**	32	11	**B**	23	**37**	37	3		41	**37**	22	0		38	31	27	4

Appendix 3: Example of the student material and probing in the establishment of chemical equilibrium.

1(a) What would be observed if we put one of the three $Co(H_2O)_6^{2+}$ solution tubes into hot water?

Your prediction: ______________________

Why: ______________________________

(b) Put one test tube of $Co(H_2O)_6^{2+}$ solution into hot water.

What do you observe? ________________________

Please explain: ____________________________

Question 1: What kind of colour change occurs? Physical or chemical change?

Question 2: What kind of equilibrium occurs? Open system or closed system?

Question 3: What influences the chemical reaction?

2(a) What will the colour change be if the heated tube is cooled down to room temperature?

Your prediction: _________________________

Why: _____________________________________

(b) Now allow the heated tube to cool down to room temperature, what colour change occurred?

What do you observe: ______________________

Please explain: ________________________

3(a) What would be observed if we put another tube of the $Co(H_2O)_6^{2+}$ solution into cold water (below 15 °C)?

Your prediction: ______________________

Why: _______________________________

(b) Put one test tube of $Co(H_2O)_6^{2+}$ solution into cold water.

What do you observe? ________________________

Please explain: ____________________________

Question 1: What kind of colour change occurs? Physical or chemical change?

Question 2: What kind of equilibrium occurs? Open system or closed system?

Question 3: What influences the chemical reaction?

4(a) What will the colour change be if the cold tube is warmed up to room temperature?

Your prediction: _________________________

Why: _____________________________________

(b) Now allow the cold tube to warm up to room temperature, what colour change occurred?

What do you observe: ______________________

Please explain: ________________________

Why: ____________________________________

5. (a) If we add Cl^- ion and water to the pink solution ($Co(H_2O)_6^{2+}$), what colour change will occur?

Your prediction: _________________________

Why: ___________________________________

(b) Now add hydrochloric acid solution (contains Cl^- ions and H^+ ions) to the pink solution ($Co(H_2O)_6^{2+}$),

What colour change do you observe: ________________________

Please explain: _____________________

6. Please summarise briefly what you learned about the chemical equilibrium in this series of activities. _________________________________

7. Please describe what you still do not know in this activity: ________________

Appendix 4: An example of a self report worksheet

Group Number/ Name ___________

Theoretical Task - Effect of concentration: Ethanol, CH_3CH_2OH, react with ethanoic acid, CH_3COOH, to form ethylethanoate, $CH_3COOCH_2CH_3$ and water, H_2O. In a 1L solution, 2 moles ethanol were added to 2 moles ethanoic acid at 15 °C. After establishing the equilibrium, 0.5 mole ethylethanoate was formed.

(a) Give the reaction equation for this reaction.

(b) If more ethanoic acid is added to the equilibrium mixture, what will happen to the amount of ethylethanoate? Explain!

(c) Will the value of equilibrium constant be the same as before the additional ethanoic acid was introduced into the equilibrium mixture? (do not calculate, just predict with justification).

(d) Will the new equilibrium be the same (i.e. contain the same amounts of reactants and products) as the initial equilibrium?

(e) Elaborate on your answer to (f)?

Lets consider the same task given above under initial conditions:

(f) If more ethyl ethanoate is added to the equilibrium mixture, what will happen to the amount of water? Explain!

(g) Will the value of equilibrium constant be the same as before the additional ethanoic acid was introduced into the initial equilibrium mixture? (do not calculate, just predict with justification).

(h) Will the new equilibrium be the same (i.e. contain the same amounts of reactants and products) as the initial equilibrium?

(i) Elaborate on your answer to (h)?

* What we don’t understand about this problem/concept is: ________________________