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**Improving teaching and learning for  
*chemical equilibrium and acids and bases* in  
year 12 chemistry**

A thesis submitted in partial fulfilment of the requirements for the  
degree of Master of Education at  
Massey University, Palmerston North, New Zealand.

by

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## ABSTRACT

The aims of this action research study were to develop, implement, and test the efficacy of four strategies designed to improve the teaching and learning of *chemical equilibrium* and *acids and bases* in year 12 chemistry. The study took place in a New Zealand secondary school, with two year 12 chemistry teachers and fifteen randomly selected students taking part. Semi-structured interviews used to elicit students' pre-teaching mental models of concepts within *chemical equilibrium* and *acids and bases* revealed a range of misconceptions and a limited ability to represent the sub-microscopic level of chemistry concepts. Teachers then used information from the interviews to inform the planning of lessons for each topic. The new teaching strategies employed by the teachers centred around Johnstone's three levels of chemistry; using a macroscopic, sub-microscopic, symbolic sequence during teacher explanations of concepts. Particular emphasis was placed on modelling the sub-microscopic level of each concept with magnetic cardboard dots and student role plays.

The action research process allows teachers to improve their own understandings and teaching practices through cycles of planning, action, observation and reflection. Although the action research methodology used here was new to both teachers at the start of the study, it provided a useful structure in which to trial the new strategies. Reflection in action research is an opportunity for teachers to reflect on, and evaluate, the effects of their action.

This study demonstrates that understanding of concepts within *chemical equilibrium* and *acids and bases* is significantly improved if the sub-microscopic level of concepts is represented. For the students in this study, the preferred method of representing the sub-microscopic level was with cardboard dots rather than student role plays. Ideally, students themselves need to practise representing the sub-microscopic level with cardboard dots or other concrete models if they are to gain better understanding of the sub-microscopic level.

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Thanks to my amazing husband for his unwavering support, enthusiasm and love. I couldn't have done it without you.

Thanks to my gorgeous children for making me laugh.

Trust in the Lord with all your heart and lean not on your own understanding;  
in all your ways acknowledge Him and He will make your paths straight.

Proverbs 3: 5,6

“I love teaching.

What other job gives you the opportunity to be an actor, doctor, priest, business entrepreneur, academic researcher, banker, lawyer, lecturer, psychiatrist, coach, artist, manager, cleaner, policewoman and clerk and ....

all in one day.”

Charmaine Pountney

(2000, p.24)

*Learning our living*

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## CHAPTER ONE – INTRODUCTION

### 1.1 Introduction

The study described in this thesis has two main aims. The first is to identify and employ new teaching strategies to improve the teaching of *chemical equilibrium* and *acids and bases* in year 12 chemistry. The second is to try to establish whether these strategies help students in constructing understanding of these topics. This chapter describes the background to the study, the nature of the study, the research questions and an overview of the thesis.

### 1.2 Background to the study

Teaching chemistry is a challenge. Having spent a number of years teaching secondary school science and chemistry, I believe that many students struggle with linking the chemical equations they write, with the reactions they see in the laboratory. Some teachers find that students are frequently “turned off” to chemistry and resort to “mindlessly” memorising scientific terms, and performing laboratory experiments with “preordained right and wrong answers” instead of learning and understanding the concepts they are presented with (Stinner, 1992, p. 5). Students’ attitudes to chemistry are often amplified by their parents’ descriptions of how difficult chemistry was when they were at school. In addition to this bad reputation, many studies “reveal that students’ conceptions are often inconsistent with the scientific conceptions they are expected to learn” (Garnett, Garnett, & Hackling, 1995, p. 69). The two topics dealt with in this study, *chemical equilibrium* and *acids and bases*, are no exception. Difficulties with *chemical equilibrium* can be attributed to the “inherent abstract nature of the topic” and “the static equilibrium system so emphasised in physics teaching” (Johnstone, MacDonald, & Webb, 1977, p. 171). A year 12 chemistry assessment report produced by the New Zealand Qualifications Authority acknowledges the problems students have with *acids and bases*. The report stated that students had shown “limited understanding of the chemical principles involved in acid-base systems” in their National Certificate of Educational Achievement (NCEA) exam responses, with many failing to do correct calculations and unable “to use the related language of chemistry accurately and clearly” (NZQA, 2003, p. 2).

As chemistry teachers then, we need to examine our teaching and begin to teach for understanding. If we are to do this successfully, the literature suggests that there are a number of factors which need consideration.

### 1.2.1 Learners construct knowledge

The constructivist view of learning describes the learning process as a gradual, dynamic and active process, where learners build on their *mental model*, the ideas they already have about a concept (Greca & Moreira, 2000) taking into account their beliefs, experiences and background (Posner, 1982). Posner, Strike, Hewson and Gertzog (1982) suggest that for a learner to start to change their mental model, a new concept needs to be *intelligible*, *plausible* and *fruitful* to the learner. Intelligibility means the learner can make sense of a concept. A plausible concept needs to either have some degree of fit or to cause dissatisfaction with the learner's current conceptions. For a new concept to be fruitful, it might assist in solving problems or explaining phenomena the learner could not previously solve or explain. While these three ideas seem simple, the conceptual change process is highly complex and rarely linear (Posner et al., 1982). The mental models a learner holds are often "highly difficult to shift, and can offer a serious barrier to learning" (Tytler, 2004, p. 20).

### 1.2.2 The three levels of chemistry

Johnstone states that chemistry "exists in three forms which can be thought of as corners of a triangle" (2000, p. 11). These are:

- a) the *macroscopic*, the tangible, observable aspect. An example is a glass of water,
- b) the *sub-microscopic* aspect which represents the invisible particles within a substance. An example is the water molecules and their interactions,
- c) the *symbolic* aspect where symbols are used to represent the substance and its particles. The symbol  $H_2O$  can be used to represent one water molecule or the entire glass of water.

For most people, difficulties with the learning of chemistry can be attributed to the majority of chemistry instruction being conducted on the symbolic level, which is abstract in nature (Gabel, 1999). Students have problems with making

macroscopic observations in their practical work and then representing these with symbolic equations because they do not understand what the symbols represent. Other reports suggest that unlike their instructors, students do not have the knowledge or skill to transfer easily between the three levels and find the sub-microscopic level particularly difficult to grasp (Gabel, 1999; Johnstone, 1991; Nicoll, 2003).

### 1.2.3 Models and modelling

Recent studies suggest that students have a poor understanding of the sub-microscopic level of chemistry (Nakleh & Krajcik, 1994; Nicoll, 2003).

Gabel suggests that a reason for this could be that “many of the concepts studied in chemistry are abstract and inexplicable without the use of analogies or models” (Gabel, 1999, p. 548).

Models and analogies are examples of *expressed models*. Expressed models are the result of us translating our mental model into a new medium so that we can communicate it to others (Gilbert & Ireton, 2003). In chemistry, we often represent the sub-microscopic level with the use of ball and stick models or symbols. In this study, the sub-microscopic level of chemistry was modelled using small magnetic cardboard dots and student role-plays. To use models successfully in the representation of the sub-microscopic level of chemistry, researchers recommend:

- a) the use of multiple models so that students can realise the inadequacy of any one model to accurately represent a concept (Gilbert & Ireton, 2003; Harrison & Treagust, 2000a, 2000b),
- b) discussion of the limitations of expressed models with students (Chittleborough, Treagust, & Mocerino, 2005),
- c) acknowledgement that modelling of the sub-microscopic level relies on theory, not real observations as sub-microscopic particles are impossible to see (Chittleborough et al., 2005).

## 1.3 Nature of the study

This thesis describes the development, implementation and efficacy of teaching strategies for two topics in year 12 chemistry; *chemical equilibrium* and *acids and*

*bases*. The study took place in two year 12 chemistry classes at a girls' school with about 700 students. The two teachers of these classes, in conjunction with the author, employed action research methodology in order to develop and implement the strategies through planning, trialling, reflecting on and revisiting these strategies. Macintyre (2000, p. 1) describes action research as

“an investigation, where, as a result of rigorous self-appraisal of current practice, the researcher focuses on a ‘problem’ (or a topic or an issue which needs to be explained), and on the basis of information (about the up-to-date state of the art, about the people who will be involved and about the context), plans, implements and then evaluates an action then draws conclusions on the basis of the findings”.

Two cycles of planning, action, observation and reflection were completed with each teacher.

#### **1.4 The research questions**

In order to develop and implement effective teaching strategies for year 12 chemistry, four key questions were posed:

- What mental models do Year 12 students hold for “chemical equilibrium” and for “acids and bases”?
- What are effective teaching strategies for these concepts according to current science education literature, especially Johnstone’s three levels of chemistry?
- Can students gain a real understanding of the concepts as a result of these teaching strategies ? How do we know ?
- What are the implications for teaching and assessment of these concepts?

In using these questions as the basis of the study, it was hoped that this study would provide the author and other chemistry teachers with practical strategies that they can use to help students make sense of a subject that is often disliked and reluctantly endured.

## **1.5 An overview of the thesis**

This thesis is presented in eight chapters and fourteen appendices

Chapter One outlines the main aims and provides a background of the reasons for the study. The nature of the study is also introduced. The key research questions and overview of the study are given.

Chapter Two further explores the background for the study, by exploring and summarising relevant literature.

Chapter Three describes the theory behind the action research methodology used in this study.

Chapter Four describes how the action research methodology was employed in this context.

Chapter Five examines the results of the study in the context of the action research process.

Chapter Six describes the results of the action research process, namely the changes in the mental models of students.

Chapter Seven discusses the significance of the findings in chapters five and six in light of the literature discussed in chapter two.

Chapter eight draws together the preceding seven chapters, stating the main conclusions from the study, and recommendations and implications for teaching.

## CHAPTER TWO – REVIEW OF LITERATURE

### 2.1 Introduction

This chapter will explore recent literature which pertains to the central ideas of this study. Firstly, recent studies on students' ideas about *chemical equilibrium* and *acids and bases* will be examined, followed by an exploration of the conceptual change process. Modelling will then be discussed in terms of its role in the conceptual change process. Lastly, the role of modelling in a chemistry context will be considered.

There are numerous studies in recently published science education literature which illustrate student ideas about chemistry concepts. Interestingly, these show that the ideas students have about phenomena in chemistry are vastly different from those of scientists and are firmly held. Although Niaz & Krajcik (2001, p. 206) considers student ideas “not as mere mistakes but as conceptions that compete with scientific theories”, these conceptions often limit students' ability to really understand how chemistry works. Because some of the conceptions students hold are contrary to those accepted by the science community, many authors term the incorrect student ideas “misconceptions” (Banerjee, 1991; Hackling & Garnett, 1985). Although students are assumed to engage, construct and understand more and more complex concepts as they progress through their schooling, students at both junior and senior secondary school level and their teachers share many of the same misconceptions (Banerjee, 1991). These are outlined in the following section for the year 12 topics *chemical equilibrium* and *acids and bases*.

### 2.2 Misconceptions of chemical equilibrium

“The topic of equilibrium is recognized as one of the more difficult topics in school chemistry programmes” (Maskill, 1989, p. 57). A number of factors may contribute to this description:

- a) New Zealand students have no lessons about *chemical equilibrium* until they reach year 12, so have little or no previous experience with it,
- b) by the time they start the *chemical equilibrium* topic at year 12, students have been exposed to the term “equilibrium” in physics and economics,

confusing its meaning with the chemical equilibrium discussed in their chemistry laboratory. Chemical equilibrium is often termed dynamic and is quite different from the equilibrium students encounter in physics and economics (Johnstone et al., 1977).

- c) *Chemical equilibrium* is an abstract topic, and even the most experienced teachers will find that their students still have some difficulty with it because of its abstract nature.

The study of chemical equilibrium in year 12 is centred around four main ideas:

1. Some chemical reactions proceed to completion. This means reactants react together to form products until one of the reactants is consumed and the reaction ends. In chemical equilibrium we consider reactions which, instead of reaching completion, keep occurring because the products react to form the original reactants. In effect, when there is a forward and reverse reaction happening simultaneously and at the same rate, chemical equilibrium is reached.
2. Chemical equilibrium is achieved in a closed system, where nothing is added or leaves.
3. "If a system at equilibrium is disturbed, then the system adjusts itself so as to minimise the disturbance" (Smith, 1987, p. 270). This is known as Le Chatelier's principle and helps chemists predict a change in the concentration of reactants or products if the conditions in a system are changed in some way.
4.  $K_c$  (the equilibrium constant) is essentially the ratio of products to reactants at equilibrium.

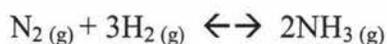
Although students appear to be able to apply Le Chatelier's principle with ease and even obtain favourable assessment scores for this topic, numerous studies have shown the real status of student understanding of chemical equilibrium. In fact, several studies have shown that not only chemistry students, but also teachers and university professors have misconceptions about how chemical equilibrium works (Johnstone et al., 1977; Quilez-Pardo & Solaz Portoles, 1995). Many studies (Bucat & Fensham, 1995; Camacho & Good, 1989; Gussarky & Gorodetsky, 1990; Huddle & Pillay, 1996; Quilez-Pardo & Solaz Portoles, 1995;

Voska & Heikkinen, 2000) provide insight into the nature of the misconceptions students hold for chemical equilibrium, and these conceptual difficulties are arranged in five main categories. These will be used as a framework to explore students' ideas and their possible origins.

### 2.2.1 Left and right sidedness

“In long term memory there already exists a wealth of knowledge and experience of equilibrium but not in a chemical sense” (Johnstone, 2000, p. 14). Students' first experience of the equilibrium concept is usually in physical rather than chemical situations. Gussarky and Gorodetsky (1990, p. 198) describe student experiences of equilibrium as “everyday life-balancing situations” involving bike-riding, kayaking, riding on a see saw or using traditional scales to measure the mass of an object. Equilibrium is seen as two-sided, stable and static once equilibrium is reached or something is balanced. To use the see saw example, equilibrium is reached when the mass at each end of the beam is manipulated so that the seesaw is eventually still. If more mass is added to one end of the see saw, then it will tilt that way. It is hardly surprising then, that students use these experiences to try and fathom the chemical equilibrium concept when they first encounter it in year 12. Unfortunately, physical and chemical equilibrium are not comparable. Chemical equilibrium is dynamic in nature with two reactions happening simultaneously and at the same rate.

In a study by Johnstone et al. (1977), students were presented with an equation showing the Haber process at equilibrium.



80% of the students compartmentalised the above system and suggested by their answers that the species on the left and right hand side of the arrow were separate entities and not existing in the same system. Garnett et al., (1995, p. 80) also report that “some students failed to perceive an equilibrium mixture as a single entity”. Johnstone, (2000, p. 15) reports similar student ideas written in exam situations with responses like “apply pressure to the reactants”, suggesting that the

student understands a reaction to have separate compartments containing reactants and products.

In the valiant attempts to help students understand chemical equilibrium, teachers might also be contributing to this inappropriate two-sided view. Johnstone et al. (1977) and Gussarky & Gorodetsky (1990) suggest that teachers need to point out differences between physical and chemical equilibrium and use the term “chemical equilibrium” while teaching rather than just “equilibrium” to distinguish it from the physics term. If the Haber process equation above is examined once more, it is easy to see another way teachers’ presentation of chemical equilibrium may contribute to the two-sided view. The use of the double-sided arrow placed in between reactants and products could promote the idea of a reaction consisting of two separate parts rather than the existence of a reaction mixture. Because it is common for teachers to start teaching chemical equilibrium by writing an equation on the board, this is students’ first experience of chemical equilibrium. One can imagine how a student could very easily liken this to a see saw.

Johnstone et al. (1977) also warn against the use of some physical analogies to describe chemical equilibrium as they also could promote the two-sided view. Many well-meaning teachers have invented analogies to try to help students understand chemical equilibrium. Carson (1999), explains a pupil demonstration which divides a class of students into two teams, one on each side of the classroom and uses balls of paper to mimic particles. Similarly, Wilson (1996), uses two teams of students with matches as particles. Russell (1988), uses a liquid transfer model as her mode of describing the properties of a system at equilibrium (figure 2.1).



Figure 2.1. The liquid transfer model

*Note.* From “Simple models for teaching equilibrium and Le Chatelier’s principle”, by J.M. Russell, *Journal of Chemical Education*, 65, 10, p. 871.

While these all may help to describe the dynamic nature of chemical equilibrium, Johnstone et al., (1977), caution that the two-sided view may only be strengthened by dividing groups of students or containers of liquid.

### 2.2.2 Dynamic or static equilibrium ?

In their study of high school students, teachers and university faculty, Camacho and Good, (1989, p. 258) found that the “perception of chemical equilibrium seemed to be a static instead of dynamic phenomenon”. Like the see saw in section 2.2.1, Maskill (1989) found that students used their life experience and physics lessons to reconcile what they thought might be happening at a sub-microscopic level in a chemical equilibrium question. For example, when asked to describe what was happening in a reversible reaction, one student said,

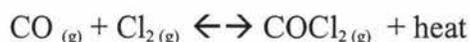
“the reaction is finished, it is stable, it will not react anymore unless you add something. Like in physics, the chemicals balance each other and become stable...” (Maskill, 1989, p. 67).

Maskill (1989) and Huddle and Pillay (1996) also found that although some students did understand the dynamic nature of equilibrium and that at equilibrium the forward and reverse reactions were of equal rates, they incorrectly assumed

that the concentrations of the products and reactants at equilibrium would also be equal. Maskill (1989, p. 66) describes this idea as an “attractive one for students because it is consistent with the familiar idea of a balance and also with most of what has been described in class”.

### 2.2.3 Problems with the application of Le Chatelier’s principle.

In their study of students’ and teachers’ misapplication of Le Chatelier’s principle, Quilez-Pardo & Solaz-Portoles (1995) found that many students had an incomplete or incorrect understanding of what happens in an equilibrium system when a stress such as increased temperature or pressure is applied or when the concentration of one of the species was changed. These authors believe the reason for this might be the misuse of Le Chatelier’s principle “in cases where its scope is limited”. Quilez-Pardo & Solaz-Portoles do not believe that Le Chatelier’s principle should be the only method of predicting the effects of changes to an equilibrium system. Helfferich (1985), Bucat & Fensham (1995) and Banerjee (1991) share this view and believe that the sole use of Le Chatelier’s principle can fool students into thinking they really know what is happening in an equilibrium system. Students memorise and use terms such as “applied stress, equilibrium position and shift to the left”, but apply them in a rote fashion only (Bucat & Fensham, 1995, p. 170). This is illustrated in a study by Banerjee (1991). Students were presented with the reaction



and a large proportion believed that increasing the temperature in this exothermic reaction would decrease the rate of the forward reaction. In fact both forward and reverse reaction rates would increase. Students are taught to use terms associated with Le Chatelier’s principle, and by predicting the reaction would shift as in Bucat and Fensham’s discussion above, students seem to automatically assume that this must mean the forward reaction slows down. Banerjee suggests that Le Chatelier’s principle should be used to interpret the extent rather than the rate of the reaction.

These authors mentioned in this section suggest that if Le Chatelier's principle is to be used, and ambiguity is to be avoided, students should learn to describe a system in terms of the relative amounts of species, rather than just stating what will happen to the position of the equilibrium.

#### **2.2.4 Rates of reaction approaching and at equilibrium**

In their review of students' alternative conceptions in chemistry, Garnett et al. (1995) summarise students' explanations of reaction rates in equilibrium systems. Although many students seem to remember that the forward and reverse reactions are of equal rate when a system is at equilibrium, it is questionable whether there is any depth to the understanding of this statement. The review reveals students believe that when equilibrium is re-established after being disturbed, the forward and reverse reaction rates are the same as those at the initial equilibrium. Students also incorrectly understood the forward reaction to be complete before the reverse reaction started, and the forward and reverse reaction rate as equal whether equilibrium was established or not. Bucat & Fensham, suggest a reason for this problem.

“Understanding the approach to equilibrium requires students to simultaneously consider how the rates of **two** reactions vary with time, as well as how the rate of the net reaction (the difference between the rates of the two opposite reactions) changes with time, until there is no net reaction. Obviously these are demanding abilities.”

(Bucat & Fensham, 1995, p. 168)

Bucat and Fensham (1995) suggest three different approaches for solving an equilibrium problem:

1. using Le Chatelier's principle
2. comparison of the reaction quotient (Q) with the equilibrium constant (K)
3. using collision theory to describe how reaction rates change during a reaction.

While these are helpful in some instances, Bucat and Fensham (1995) found all of them to have significant limitations; Le Chatelier's principle because it is usually “applied by rote”, the mathematical approach of comparing Q and K requiring a

“high level of mathematical reasoning”, (p.169) and collision theory because it is a method suitable only for “elementary reactions” (p.170).

### **2.2.5 The effects of catalysts in equilibrium systems**

Student ideas about the effects catalysts have on the rate of forward and reverse reactions appear to stem from misunderstanding of reaction rates described in section 2.2.4. Students are often told by their teachers that catalysts are used in industrial processes to increase the yield of a desired product. Garnett et al. (1995) found that students thought that a catalyst was capable of affecting the forward and reverse reactions differently so that the desired product was obtained. Similarly, Johnstone et al, (1977, p. 171) reported that students made such statements as “catalysts form a higher percentage of product in the equilibrium mixture” and “catalysts have no effect on reverse rate”. Hameed, Hackling & Garnett (1993), Wilson (1996) and Voska & Heikinnen (2000) also discovered students thought a catalyst could favour either a forward or reverse reaction.

### **2.3 Misconceptions of acids and bases**

Unlike *chemical equilibrium*, secondary students’ studies of *acids and bases* often begins much earlier than year 12; at the start of their first year of secondary school, or even in primary or intermediate school years in New Zealand. Phillips (1986, p. 121) describes primary school students as having heard “of acid rain and...probably associate acidity with the sourness of lemon juice or vinegar”. Compared with chemical equilibrium however, relatively little has been published on students’ ideas about acids and bases. Ross & Munby (1991, p. 11) express concern that although surprisingly little is known of student ideas, “chemistry curricula, textbooks, and teaching appear to proceed without this knowledge”. Recent research reports student misconceptions in the area of acids and bases, which have been arranged into five main categories. These are explored below.

#### **2.3.1 General knowledge – what are acids and bases?**

When questioned about their knowledge of acids and bases, it was found that many students were able to name lemon juice, acid rain, battery acid and stomach acid, showing that they had at least some knowledge of acids (Erduran, 1996; Phillips, 1986; Ross & Munby, 1991). By comparison, bases did not feature so

strongly. Phillips (1986, p. 121) reports that “the term base is less likely to be part of their vocabularies, but television watchers may know all about how antacids combat acid indigestion”. In another study, Ross & Munby (1991, p. 20) spoke of a senior secondary school student who stated that “acids do stick out in your mind because they are so much more powerful” and found it difficult to describe or explain bases. This is not just the case for primary and secondary school students. Ross & Munby (1991) and Zoller (1990) report that even first year university students had limited knowledge of bases. Nakleh and Krajcik (1994) found students to make statements suggesting that they thought acids were harmful whereas bases were not. If acids were thought to be coloured in students’ minds, then bases were thought to be clear. The authors speculate that “because teachers commonly explain acids and bases as having opposite chemical properties”, students think their physical properties are opposite as well (1994, p. 1090).

### **2.3.2 Neutralization**

There are many interesting statements indicating students’ misconceptions about what happens when an acid and a base combine. Garnett et al. (1995) report students’ belief that together, acids and bases form a physical mixture, but do not react. Similarly Nakleh & Krajcik (1994, p. 1089) found that some students believed that “acids and bases react additively rather than break apart and re-form as water and salt-forming ions.” Other students believed that bases were products of neutralization reactions (Ross & Munby, 1991). Ross and Munby (1991) also found that although some students could identify water as one of the products of a neutralization reaction, they did not know what a salt was or that it was a product, even if they had written a neutralization reaction correctly. In their study of senior secondary students’ ideas about acids and bases Nakleh & Krajcik (1994) found that students had some fairly surprising ideas about acid–base reactions, especially where indicators such as phenolphthalein were concerned. During an acid-base titration, students described the colour change of the indicator as being caused by the phenolphthalein adding onto the acid and base and the phenolphthalein somehow assisting with the neutralization reaction. After examining the students’ statements, the authors came to the conclusion that the

students thought that the colour change of the indicator was actually the acids and bases themselves changing colour.

Another fundamental misconception reported by Zoller (1990) was the assumption by students that a salt formed in a neutralization reaction was always of a neutral pH, *ie.* pH 7. A salt such as sodium carbonate for example, is basic rather than neutral because hydroxide ions are formed as a result of hydrolysis.

### 2.3.3 Strength and concentration

Concentration and strength are two terms often confused by students. Concentration refers to the amount of solute in a specified volume of solution whereas strength refers to the percent molecules that dissociate and form ions in solution. While some misconceptions arose from a lack of understanding of the definitions of strength and concentration, there were also problems with how students thought strong and weak acids actually behaved in terms of dissociation. Garnett et al. (1995, p. 83) report that students believe that “more hydrogen gas is displaced from a strong acid because a strong acid contains more hydrogen bonds than weak acid”. Students also thought that strong acids performed better than weak acids. Although there might be some truth to this statement, it is really only the speed of the performance that is different. On concept maps students had constructed, Nakleh & Krajcik (1994) also noted that students closely associated the words “harmful” and “strong”. While strong acids and bases often are harmful, students also made statements such as “pH is inversely related to harmful”, *ie.* the lower the pH, the more harmful the substance was (Nakleh & Krajcik, 1994, p. 1090).

### 2.3.4 pH

“The term pH is used quite often by both students and science teachers in a metaphoric way, the hidden assumption being that ‘everybody knows what pH is’. Unfortunately this is not the case. Most students never had the opportunity to *internalise* this concept. Most commonly, the pH is used and/or manipulated by students in a ‘mechanical’ or ‘technical’ sense, without a real grasp and understanding of the concept” (Zoller, 1990, p. 1058).

The above statement provides a succinct summary of the findings of recent research on student ideas about pH. Even at university level, students with chemistry science majors do not have the depth of understanding of pH that one would expect.

Garnett et al. (1995) found that students do not think of pH in terms of hydrogen ion and hydroxide ion concentrations, but instead think of it as a measure of acidity only, disregarding basicity altogether. Although Ross & Munby's study (1991) found students' explanations of pH improved post-instruction and did include pH being a measure of how basic and acidic a substance was, their understanding of the relationship between pH and hydrogen and hydroxide ions was still limited. An example of this was one student's explanation of pH which included protons and electrons rather than hydrogen and hydroxide ions. Other studies (Wilson, 1998; Ye & Wells, 1998) found that secondary school chemistry students confused the symbols for hydrogen, hydronium and hydroxide ions ( $H^+$ ,  $H_3O^+$  and  $OH^-$  respectively). This finding was echoed in a study of student ideas which also showed students did not relate hydronium and hydroxide ions to pH in the concept maps they constructed (Wilson, 1998).

More confusion with symbols was found by Nakleh & Krajcik (1994) when they discovered some secondary school chemistry students believed pH was an abbreviation for the indicator phenolphthalein.

### **2.3.5 Problems with the symbolic**

Although students often confuse symbols and what they represent in chemistry, this problem is particularly marked when exploring acids and bases. The problem was mentioned often in the literature with many authors agreeing that a major stumbling block to understanding the abstract nature of this topic was the fact that students had a shaky comprehension of the meaning of particulate terms such as atoms, ions and molecules (Erduran, 1996).

## **2.4 Constructivism and conceptual change**

### **2.4.1 Learning as construction of meaning**

While section 2.2 and 2.3 focussed on the ideas student have about chemical equilibrium and acids and bases, there is research published in the 1980s and 1990s on the conceptions students bring to the classroom in many other science topics as well (Hackling & Garnett, 1985; Huddle & Pillay, 1996; Johnstone, 1991). Because of these, it is no longer possible to simply assume that students approach learning as “blank slates” as the classical empiricist doctrine of John Locke and Francis Bacon suggests (Posner, 1982, p. 106). The work of Kuhn (1970) acknowledges that learning is greatly influenced by prior conceptions and experiences as well as the beliefs or background the learner has (Posner, 1982). In his study of student conceptions in science, Tytler reports that as well as background, culture and language influencing the ideas students have about science concepts, students’ ideas are usually quite different to the “view of the world scientists have constructed” (2004, p. 20).

The constructivist view of learning or *constructivism* is an umbrella term used to describe “an alternative position to the traditional empiricist and positivistic positions” mentioned earlier. In a nutshell, constructivism recognises that human learning is a dynamic, constructive process. Knowledge is not simply a process of storing information but rather constructed by the learner, based on their “already existing conceptions” (Duit, 1991, p. 68). De Jong, Korthagen & Wubbels (1998) also portray constructivism as an active process and describe learners as constructing meaning “from their experiences in connection with their prior understandings and social setting” (p. 745).

### **2.4.2 Constructing meaningful knowledge – the conceptual change process**

In her review of current chemistry education research, Gabel (1999) comments on how studies on student misconceptions in chemistry have “dominated the field” (p. 548). Instead of constructing knowledge which reflects current scientific theory, students often resort to learning lists of facts, symbols and equations and hold tightly to the ideas they already have no matter what they have heard from their teacher. Duit states that “science instruction very often has limited success, that attempts to guide students from their preinstructional conceptual frameworks

to those of science very often fail” (1991, p. 65). It is useful here, therefore, to explore the process of *conceptual change*, what happens when a learner makes sense of new concepts by using their existing ideas and modifying them. Dykstra (1992, p. 41) asserts “there is no consensus within the research community about how to describe conceptual change” and several models for the process of conceptual change have been proposed (Osborne & Wittrock, 1983; Posner et al., 1982). Despite lack of consensus, Matthews (1998) suggests that many science educators do agree on a constructivist approach where the students’ ideas are the starting point of learning. In this thesis, the conceptual change model of Posner, Strike, Hewson & Gertzog will be used to explore the conceptual change process.

Posner (1982, p. 106) describes the conceptual change process as “a gradual adjustment in... conception, each new adjustment laying the groundwork for further adjustments, but where the end result is a substantial reorganization...marked by occasional retreats to older conceptions”. This is echoed in the writing of Krajcik (1991, p. 129) where he describes conceptual change as a “slow and difficult process” of learners describing, restructuring, applying and “comparing their new understanding with their previous understanding”. Posner et al. (1982, p. 212) work on the basis that “learning is a rational activity” and occurs “against the background of the learner’s current concepts”. The process of changing these concepts is described as having two distinct phases:

1. *Assimilation* where learners rely on their existing ideas to deal with new phenomena. These existing ideas are a “belief or conviction about how the world works” (Dykstra, 1992, p. 44) and are used by the learner as a starting point to question a new idea or organise an investigation. Sometimes, the existing ideas a learner has are inadequate to explain new phenomena and the second phase of conceptual change can occur.
2. *Accommodation* occurs when the learner replaces or reorganises current ideas. A change in conception occurs “which enables an event to be assimilated that could not have been assimilated under previously held conceptions” (Dykstra, 1992, p. 51). While Kuhn (1970) terms this more radical phase of conceptual change “scientific revolution” and likens it to

how scientists change their conceptions, Nussbaum and Novick 1982 (in Scott, Asoko, & Driver, 1992, p. 313) suggest that major conceptual change does not occur by revolution, “but is by nature an evolutionary process”.

Accommodation of a concept is influenced by two main factors. The first factor is the learner’s *conceptual ecology / framework* (Duit, 1991; Dykstra, 1992; Hewson, 1996; Krajcik, 1991; Posner et al., 1982). A learner’s conceptual ecology / framework is described as “concepts and the interconnections between the concepts that an individual has developed” (Krajcik, 1991, p. 120). Duit describes these concepts within the framework as “fuzzy” but “surprisingly coherent” (1991, p. 67). Hewson (1996) states that a person’s conceptual ecology “consists of many different types of knowledge” (p. 133) and these will all influence any change in meaning that takes place. Hewson (1996, p. 133) has identified important features of conceptual ecology that assist in accommodation. These are:

1. metaphysical beliefs about the world, for example the learner’s concept of the nature of time,
2. the epistemological commitments the learner holds, for example how likely it is for a learner to believe the reliability or validity of some data because of what they know of consistency or generalisability,
3. the analogies and metaphors a learner might use to help them make sense of a new idea.

Duit (1991) suggests sources of students’ conceptual frameworks. These include the experiences with natural phenomena learners have every day such as light, heat, sound, burning and growth of plants or animals. Everyday language also influences conceptual ecology. Duit uses the particular example of the statement, “the sun rises” leading learners to believe an idea contrary to the earth revolving on its axis (p. 74). Other sources of conceptual frameworks could be false information provided by teachers, textbooks, parents or the media. Lastly, Duit entertains the possibility of innate structures of our brain which help us make decisions best suited to our situation, governing which conception we include in

our framework. If this is true, it might explain the resistance to change that is true of so many student conceptions.

The second factor which influences the accommodation of a concept is the way a learner responds to the *learning conditions* for that concept. These are *intelligibility*, *plausibility* and *fruitfulness*. Posner et al. (1982, p. 223) believe that a new concept needs to be *intelligible*, *plausible* and *fruitful* for a learner if they are to accommodate it. *Intelligibility* can occur at a superficial level where the learner understands the meaning of symbols in a scientific formula or at a much deeper level where an individual can identify “a coherent representation of what a passage or theory is saying” (Posner et al., 1982, p. 216). Intelligibility of a chemistry concept often requires understanding at a number of levels. An example is making sense of what is represented by the symbols H<sub>2</sub>O. If intelligible, the learner would understand that this group of symbols can represent a beaker of water composed of many water molecules and also a single water molecule made of two atoms of hydrogen and one of oxygen. Stinner (1992, p. 9) states that if a student cannot make use of a scientific law such as  $F = ma$  “without slavishly following an algorithm” then intelligibility is not achieved and it will be useless for the student to ask questions about the plausibility of the new conception.

Posner et al. (1982, p. 216) describes initial *plausibility* of a new concept as “the anticipated degree of fit into an existing conceptual ecology”. To be plausible to the learner, the new concept either needs to be consistent with current theories and experience the learner has; or create dissatisfaction with the learner’s current ideas so that the new concept displaces the old one. To nurture conceptual change, Dykstra (1992) suggests the creation of a learning environment where students can make predictions and test their own ideas, instead of being presented with discrepant events and then being told the correct answer rather than trying to work out what is going on for themselves. Similarly, Krajcik expresses the value in giving students “opportunity to apply scientific models to explain and predict other phenomena that their prior models could not” (1991, p. 131).

Assuming a student has discovered an intelligible, plausible conception and is satisfied it is better than their prior conception, Posner et al. (1982) believe the student has one last condition to consider – the potential usefulness or *fruitfulness* of the new conception. Once the student believes the new conception is fruitful, then it may be worth accommodating. An example of a new conception might be a scientific theory which could be seen as fruitful if it can be used as an engineering or technological tool or as a theoretical basis for the development of a modern strand of science such as physics. While in theory, the idea of fruitfulness sounds a satisfying and fitting conclusion to the conceptual change process, Duit points out the complicated nature of science conceptions. The fact that science conceptions are usually much “more sophisticated” than those of students means these new conceptions are fruitful and fathomable only by those who are very familiar with science (Duit, 1991, p. 82).

Accommodation “rarely seems characterised by...a flash of insight...or a steady logical progression from one commitment to another”. Instead, it involves “much fumbling about, many false starts and mistakes, and frequent reversals of direction” (Posner et al., 1982, p. 223).

### **2.4.3 Constructivist approaches to conceptual change teaching and learning**

For the conceptual change process to occur, much thought must be given to the roles of the teacher and the learner. These roles are examined in this section.

#### Conceptual change teaching – what do teachers need to consider?

“Constructivist teaching approaches in science have emphasised the importance of monitoring students’ conceptions, of bringing them out into the open for discussion and evaluating them using evidence. The details of teaching strategies should be influenced by how we think of children’s intuitive conceptions” (Hubber & Tytler, 2004, p. 35).

Teachers need not only to have “flexible, thoughtful and conceptual understanding of the subject matter” they are exposing students to (Baker, 1994, p. 32), the teacher must be able to “bridge the gap” between current learning and

teaching theories and the content that needs to be learned (Bucat, 1999; Bucat & Fensham, 1995; Coppola, 1996). A teacher with these skills would be considered to have good pedagogical content knowledge. A teacher with good pedagogical content knowledge can consider a topic carefully, take into account its particular learning demands, then sequence and package the information in a way that will suit the learners best. This should result in students being able to relate new concepts to those they already have ideas about because the context is relevant and takes into account their life experience.

After taking into account students' ideas and experiences, Scott et al. suggest that teachers need to make pedagogical decisions at three levels (1992). Firstly the teacher needs to provide a learning environment which will be conducive to conceptual change learning with the provision of opportunities for consideration of alternative or new ideas. This environment must allow student ideas to be expressed without "fear of sanction or ridicule" (Hewson, 1996, p. 138). Dykstra (1992) and Hubber & Tytler (2004) endorse this approach.

Secondly, the overall plan guiding the teaching of a topic needs to contain learning tasks that are carefully selected and sequenced. Jones, Carter & Rua (2000, p. 156) state the importance of the teacher knowing "what prior knowledge is important for sequential concept development". This is illustrated in their example of the pointlessness of trying to teach about convection currents when students lack understanding of molecular movement. In the author's experience, it is common for students to reach year 12 chemistry with the ability to balance complex chemical equations, but little or no understanding of what the subscript and coefficient numbers actually represent. In effect, the symbols and their groupings are quite meaningless to the students because concepts have been presented in an inappropriate order.

Thirdly, important consideration needs to be given to specific learning tasks for each topic and how they fit within the overall plan. Many authors discuss the merits of planning tasks which promote cognitive conflict where student ideas are ascertained and then challenged by presenting them with discrepant events in the hope students will reconsider their existing ideas and replace them with new ones

(Dykstra, 1992; Hewson, 1996; Krajcik, 1991; Posner et al., 1982). Others promote strategies which encourage students to develop and construct their existing ideas so that they better represent the accepted science viewpoint (Scott et al., 1992, p. 316). These developments are made by the use of “bridging strategies”. After the students’ ideas are identified, the teacher uses an example which students are likely to intuitively understand to help them make connections for a more complex example. The example given by Scott et al. (1992) involves students being shown solid iodine evaporating. Because students can see the coloured gas as a result, they can see that the iodine has not simply disappeared; it has just changed state. When they are then shown colourless acetone evaporating to form an invisible gas, the students can apparently make the link that the acetone has performed similarly to the iodine. Similar strategies are used by Lawson, William, Baker, DiDonato, Verdi & Johnson (1993). Krajcik (1991) suggests a number of teaching strategies for teachers to integrate into their repertoire for promotion of conceptual change. These include using new technologies like microcomputer-based laboratories where students can use a pH probe to obtain a titration curve as an acid-base titration is occurring. Students can see how a usually obscure graph relates to what is happening in a conical flask. Computer software allowing students to simulate the behaviour of gas particles exposed to different temperatures is another way Krajcik suggests new knowledge can be built. Concept maps are suggested by a number of authors as not only helping students link concepts but also as a way of assessing student understanding or measuring conceptual change (Jones et al., 2000; Krajcik, 1991; Markham & Mintzes, 1994). Johnstone (1991) and Gabel, Samuel & Hunn (1987) recommend teaching strategies which examine chemical concepts on the molecular level so that a link can be made between the myriad of symbols and algorithms they see in chemistry texts and the chemical reactions students see happening in test tubes.

#### Conceptual change learning – an individual or social process?

In his writing about constructivist views on learning and teaching, Tytler (2004, p. 27) comments on the fact that constructivism has had “some vociferous critics” over the last decade. This criticism can, according to Tytler be attributed to the emphasis and value constructivist teaching methods place on student ideas when often they do not line up with theories accepted by the science community. A

*personal constructivist* view of learning endorsed by Duit (1991) involves the construction of knowledge by the individual, with little input from the teacher. A practical example of this view might be discovery learning, where the teacher has no content input in their lessons (Hewson, 1996) and the students make conclusions about what they observe only from their own experience. In the last decade, the *social constructivist* position seems to be taking precedence over the individualistic view of learning and the advantages of the social constructivist position are stated in recent science education literature (Basili & Sanford, 1991; Chi, 1992; Gradwohl Nash, Liotta, & Bravaco, 2000; Hewson, 1996; Tytler, 2004). Whereas a personal constructivist approach focuses on the knowledge of the individual, social constructivism views learning as “a social or cultural phenomenon” (Tytler, 2004, p. 27) and a learning environment where teachers and students can construct knowledge together is favoured. Driver, Squires and Rushworth (1994) and Posner et al. (1982) see the teacher as providing a vital role as a tutor who presents students with problems or discrepant events and then models scientific thinking and “scientific ways of viewing and dealing with the world... rather than placing most of the attention on the individual grappling with their experience” (Tytler, 2004, p. 28).

Some writings on conceptual change suggest that students also need to be able to reflect not only on what they have learned, but what thought processes they went through to reach that understanding. Baird and White (1996, p. 190) describe this cognitive ability as metacognition, “knowledge about, and awareness and control over, personal practice”. Hewson describes the conceptual change process as “explicitly metacognitive” (1996, p. 136), and goes one step further to say that students and teachers also need to be “metaconceptual” (p. 137). This skill enables students to think *with* as well as *about* the ideas they have as they compare and contrast their ideas with new concepts.

#### **2.4.4 Identifying and measuring conceptual change**

While it seems challenging to teach for conceptual change, even more challenging is assessing students to see if their ideas have changed, and if so, will they stay changed or revert to prior ideas? Testing students before (pre-testing) and after the teaching of a topic (post-testing) is a well-used technique by researchers to

elicit student ideas and see if they have changed (Basili & Sanford, 1991; Dykstra, 1992; Gradwohl Nash et al., 2000; Krajcik, 1991; Lawson et al., 1993; Markham & Mintzes, 1994). While some studies have used written pre-tests and post-tests, Dykstra warns against traditional test items because they reveal a limited view of student ideas and beliefs.

In their exploration of students' conceptual ecologies of heat and convection, Jones et al. (2000) used several assessment techniques to identify conceptual change. The students were interviewed, did card sort activities and drew concept maps before and after instruction and the researchers were surprised to find the diverse results they obtained for each assessment technique. They suggest that although the verbal methods of assessment could bring out complex ideas about the topic and their relationships, the card sort activities were more likely to prompt students to use specific terms and prior experiences related to the topic. Concept mapping, where students are given a number of terms and expected to arrange and connect them in a way that will best represent their knowledge linkages, shows "the ways the students' knowledge structure is linked for the student with the actual phenomena" (Driver, 1983). Concept mapping is a popular technique used by educators because maps "can be used as tools for negotiating meaning, making new and powerful understanding possible" (Krajcik, 1991, p. 138). Once students have learned this skill, they can construct a concept map before instruction and make new concept maps as their understanding changes. They can then compare their old and new maps and also compare maps with other students so they can see how their connection of concepts is similar or different. Cullen (1990, p. 1068) states that concept maps "have great potential for helping students "learn how to learn" chemistry. The maps are useful to teachers as well because they are a way of eliciting students' ideas before they start teaching a topic and provide a way of seeing how students are making sense of what they are being presented with in class.

Ideally then, it would seem that a range of assessment techniques including interviewing and concept mapping might help to measure or identify conceptual change. Hubber & Tytler cite one of the "components of effective science teaching" from the "Science in Schools research project" is monitoring of student

learning that is “varied, continuous”, incorporating a “range of styles of assessment tasks to reflect different types of science and types of understanding” (2004, p. 50). Markham and Mintzes (1994) report that assessment techniques such as concept mapping may actually be time-efficient for the teacher and provide a better indication of the connections the student is making. This appears however to be in a qualitative sense. One would question, in cultures where there is a demand for quantification of student achievement and “learning is typically expressed in terms of students’ relative standing in a class or in percent correct” (Markham & Mintzes, 1994, p. 92), how student understanding shown in a concept map can be quantified. Although some researchers have systems to quantitatively score the change in a student’s conceptual ecology such as the knowledge trees of Gradwohl Nash et al. (2000), these systems do not appear to have crossed the divide from research to everyday practice.

#### **2.4.5 Implications for teacher development**

So far, this chapter has focussed on the teacher’s role in assisting their students to construct knowledge. Not only will effective teachers provide a physical environment conducive to learning, they will also make themselves aware of student ideas before the teaching of a topic and plan activities in a sequence that will help students build on their existing knowledge. The ideal teacher will know how to help students “develop integrated understanding of concepts” rather than “presenting isolated pieces of information” (Krajcik, 1991, p. 143). Although the constructivist view of learning was originally developed with respect to children’s learning of science, Bell (1998), argues that this view also relates to the learning of teachers. If conceptual change strategies are to be employed in chemistry classrooms around the country, it would seem that “teachers themselves will have to undergo a process of conceptual change, a restructuring of their view of teaching” (Krajcik, 1991, p. 144). Krajcik believes that a move away from the traditional approach of “topic coverage” to a more constructivist one of “concept development” would greatly improve the reputation of high school chemistry (1991, p. 144). Marx, Freeman, Krajcik & Blumenfeld (1998) suggest four elements which may help science teachers gradually change and improve their practices.

1. collaboration - teachers have the opportunity to learn about recent information and technological advances and their application from university researchers. This element also includes opportunity for peer discussion for helping teachers to deal with difficulties and constraints within their classrooms and provides encouragement from others to try new strategies,
2. enactment - teachers plan for and conduct new practices in their classrooms and then have time set aside for reflection and refinement of the practices
3. extended effort - as well as the teacher's efforts in adopting new practices, change may also need to occur in curriculum and government policy. This all takes time,
4. reflection - teachers must have time to reflect on their teaching practices privately, possibly using a journal, or publicly with other teachers or researchers. "Teachers must reflect on teaching to extract the knowledge that leads to improved student learning" (Marx et al., 1998, p. 674).

## **2.5 Models and Modelling**

### **2.5.1 What is a model?**

The word “model” is an often and inconsistently used term in science and science education literature and is used to describe a wide range of meanings. Although basic, Duit and Glynn’s definition of models as standing for “something else, which they represent in some way” (1996, p. 167) seems to be the common thread running through the variety of writings on models. Gilbert and Ireton provide the following slightly more complex definition.

“A model is a system of objects or symbols that represents some aspect of another system, called its target. We use models every day in conversation, to learn, to experiment, and to make predictions. Model building is at the heart of learning” (2003, p. 1).

In order to make sense of the myriad of different usages of the word *model*, models will be explored here in light of:

- a) conceptual change and the learning of science
- b) their use as tools to promote conceptual change

### **2.5.2 Models and conceptual change**

In the previous section, the constructivist view of learning was described as a process of conceptual change where a learner makes sense of new concepts by using their existing ideas and modifies them so that they reflect those currently accepted by scientists. To view this process through the goggles of models and modelling, one could define the existing ideas about the world that students bring to the classroom as their *mental model* (Greca & Moreira, 2000). This mental model is constructed from the students’ interactions with their environment, what their senses have gathered, their memories of life experiences and their interactions with other people (Gilbert & Ireton, 2003; Harrison & Treagust, 1996). The process of conceptual change affects a learner’s mental model in a similar way to the renovation process of an aging house. Although the mental model already exists, some obsolete, useless or mismatching parts of it are changed or discarded as new, useful elements sympathetic with the rest of the model are incorporated. Like home renovation, the process of changing a mental model is often slow, gradual and continuous. While some authors differ on

their definition of a mental model and its similarity to (Duit & Glynn, 1996, p. 170) or dissimilarity from (Franco et al., 1999) a conception, most agree that mental models are dynamic, being generated and improved constantly as we collect information (Duit & Glynn, 1996; Franco et al., 1999; Gilbert & Ireton, 2003; Greca & Moreira, 2000; Harrison & Treagust, 1996). A mental model is the learner's "image of reality" (Gilbert & Ireton, 2003, p. 5) even though it may be "incomplete, imprecise and incoherent" (Greca & Moreira, 2000). What matters to the learner is functionality, not technical accuracy (Harrison & Treagust, 1996). Part of the mental model a student has of the nature of matter, for example might be demonstrated in their description of an atom. Harrison and Treagust (1996, p. 510) found that students described an atom as being like "a ball, a solar system, a plum and even as a structure that is able to reproduce like a cell".

The teacher's aim is to help students to modify their mental model so that it parallels the accepted *conceptual* or consensus model, "an external representation created by researchers, teachers ...that is coherent with scientifically accepted knowledge" (Greca & Moreira, 2000, p. 5). Gilbert and Ireton (2003, p. 8) approach conceptual models with an emphasis on their properties as a personal construction. They describe conceptual models as "constructs consisting of symbols, images and propositions that together characterize a certain category of events". They also comment that a "richer and more robust" (p. 8) conceptual model relies on a learner's breadth of experience and exposure to examples of concepts. It is not clear whether the richness mentioned is synonymous with accuracy, but because "scientists are professional learners" (Gilbert & Ireton, 2003, p. 86) and "modelling is central to science and...what scientists do" (Sutton, 1996, p. 143), their mental models are likely to be well developed and/or sophisticated and therefore in essence similar to the conceptual models accepted by the science community as correct. To use modelling terminology, Duit and Glynn believe learning or conceptual change to be "a process of adaptive development" that leads from learners' mental models towards conceptual models (1996, p. 171). Unfortunately, despite the teacher's best efforts, often students do not construct mental models that are consistent with the conceptual models the teacher has presented. As a result, it is common for students to resort to memorising information instead of understanding it because it does not fit with the incomplete model they still hold (Greca & Moreira, 2000).

### 2.5.3 The move from mental model to conceptual model – using expressed models

“Using models is a common form of communication. Ask someone on the street for directions and watch as his or her hands, waving and pointing, model behaviour for you to follow to reach your destination. Children on a playground will use sticks, stones and leaves to sketch out a football play or to represent dishes for an imaginary meal....In science, modelling has a similar goal – to mimic in some way the particular behaviour of a system and thus communicate a better understanding of this behaviour – both to the builder of the model and to other learners” (Gilbert & Ireton, 2003, p. vii).

So far, the word model has been used in the context of mental constructs a learner has and the learning process as a modification of one’s mental model so that it more closely represents the conceptual model accepted by the science community. In this section, the word model will be used to describe the various tools that can be employed to aid this process of learning or conceptual change. These models are termed *expressed models*. Expressed models are created when we “take in information from the outside world, translate and process it to create a mental model, and then translate that mental model into a new medium”. They are in essence “models of models” (Gilbert & Ireton, 2003, p. 9) and are “integral to our thinking and working scientifically...because models are science’s products, methods and its major teaching tools” (Harrison & Treagust, 2000b, p. 1023). Expressed models which become accepted by the scientific community become *scientific models* (Justi & Gilbert, 2000). In chemistry, examples of scientific models are the various representations of the structure of the atom (figure 2.2). As each one has been changed or improved, it has become an *historical* model (Justi & Gilbert, 2000). These scientific models are visual representations of the mental models each of the scientists wanted to express to others, although it is important to note that expressed models are not always visual in nature.

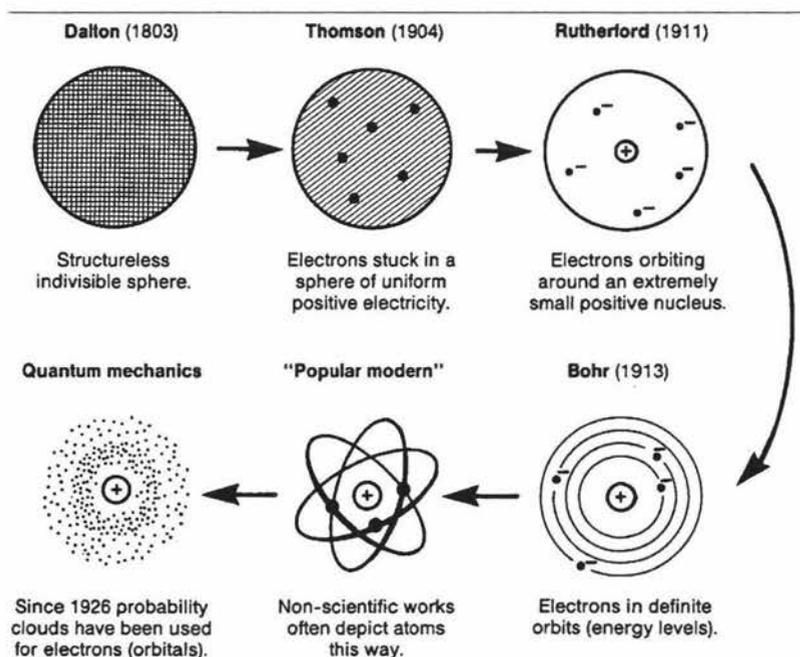


Figure 2.2 . Historical development of atomic structure.

Note. From *Conquering Chemistry* (p. 367) by R. Smith, 1987, Sydney: McGraw Hill.

Some authors have suggested other terms to describe these expressed models such as “representations” (Chittleborough, et al., 2005, p. 2), “analogical models” (Harrison & Treagust, 2000a, p. 355) and “analogies” (Duit & Glynn, 1996, p. 173) but in this instance, the term “expressed model” will be used to describe tools which help a learner modify or construct their mental model, particularly in the area of chemistry.

According to Gilbert & Ireton, expressed models can be divided into two slightly overlapping groups, *concrete models* and *abstract models* and they make the point that “most middle school students deal in the concrete 99 percent of the time” (2003, p. 10).

### Concrete models

A concrete models is designed to represent its target, “a system, an object, a phenomenon, or a process” (van Driel & Verloop, 1999), by somehow mimicking appearance or function or both. Concrete models are “tangible, material models that we can generally interpret with relative ease” (Gilbert & Ireton, 2003, p. 11). Types of concrete models include:

a) scale models which are “used to depict colours, external shape and structure” (Harrison & Treagust, 2000b, p. 355) but “seldom share functional attributes” (Gilbert & Ireton, 2003, p. 11). Harrison and Treagust (1996) categorise the 3-dimensional plastic space-filling models often used in chemistry classrooms to depict the bond angles, relative atomic sizes and overall architecture of a molecule as a scale model. However, it is important to recognise that a scale model of anything sub-microscopic in chemistry is in fact a representation of a theory (Chittleborough et al., 2005), an idea chemists have constructed from the information they have gathered about particles too small to be seen even with a microscope. This is quite different from the scale model of a space shuttle, put forward by Gilbert and Ireton (2003), an object we have witnessed on the evening news or in person. This aspect of models in chemistry will be discussed further in section 2.6.

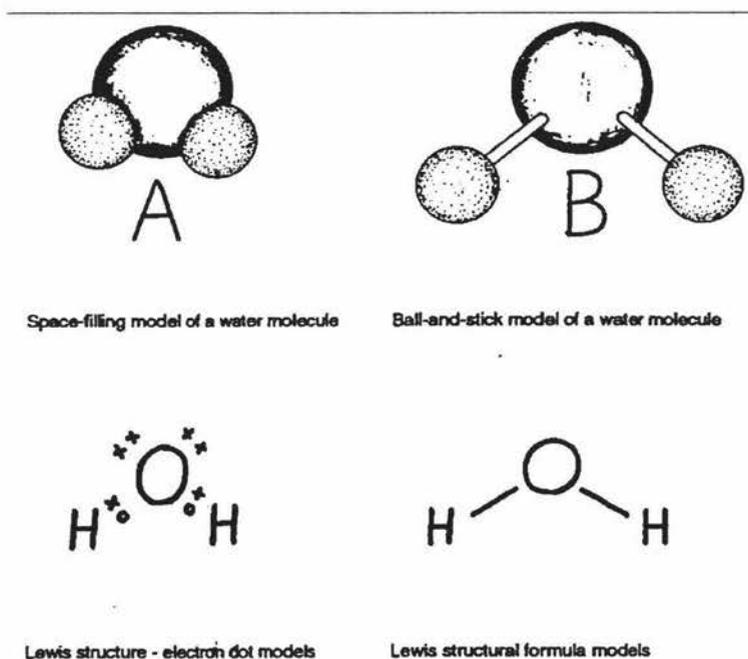


Figure 2.3. Four types of molecular models commonly used in secondary chemistry classrooms.

*Note.* From “Secondary Students’ Mental Models of Atoms and Molecules: Implications for Teaching Chemistry,” by A.G. Harrison and D.F. Treagust, 1996, *Science Education*, 80, 5, p. 513. Copyright 1996 by John Wiley and Sons. Reprinted with permission.

b) Analogical models are those which have “one or more of the target’s attributes represented in the analog’s concrete structure” (Harrison &

Treagust, 1996, p. 513) Examples of analogical models are the three dimensional plastic ball and stick models students use during their study of organic chemistry (figure 2.3). Analogical models are similar to the “functional concrete models” of Gilbert and Ireton (2003, p. 12) which concentrate less on scale and appearance and more on relative positions of the elements within them. Ball and stick models of molecules are excellent for demonstrating isomerism and the “non-rotatable nature of double and triple bonds” (Harrison & Treagust, 1996, p. 512). Other studies have found that students using ball and stick models were able to successfully increase their understanding of structure and formulae of alkanes, especially when the students were working cooperatively with other students, discussing and building structures together (Treagust, Chittleborough, & Maniala, 2003). There are, however, some disadvantages to analogical models such as ball and stick molecular models. It is suggested by Harrison and Treagust (2000b, p. 1015) that as a result of using these “oversimplified or exaggerated” models students could think that real atoms are “solid balls” and chemical bonds are “sticks joining the balls”. Similarly, Justi and Gilbert (2002) state the importance of students viewing molecular models as analogues with limitations rather than scale models reflecting the appearance of particles they represent. An example of another analogical model is the one suggested by Gilbert and Ireton (2003) in which pictorial diagrams of targets such as the solar system can be used to show the relative positions and movements of the planets in relation to the sun. However, diagrams such as these usually “distort the relative sizes and positions of the various bodies in the system in order to illustrate their arrangement” (p. 13). Some chemistry researchers have found students to believe that electron clouds and shells were “complete or semi-solid structures” because students have been “left to draw their own conclusions about analogical models” (Harrison & Treagust, 1996, p. 531). According to Gilbert and Ireton students need to be made aware of the fallibility of these types of models and their “distortions” (2003, p. 13).

- c) Mathematical models are concrete models “based on quantitative values and relationships” (Gilbert & Ireton, 2003, p. 13). In chemistry, physical properties such as  $density = mass/volume$  are represented by equations.

Titration curves (graphs which show the relationship between pH and relative volumes of acid and base during an acid-base titration) are also mathematical models. For these models to be useful to a learner, the learner must be able to interpret the graph and also “visualise the system that the graph is actually representing” (Gilbert & Ireton, 2003, p. 13).

- d) Chemical formulas such as  $\text{H}_2\text{O}$  model the makeup of chemical compounds and chemical equations such as  $\text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}$  model chemical reactions (Harrison & Treagust, 1996) in a concrete way. Often in chemistry, equations represent the “relationships between quantities of real-world things” (Gilbert & Ireton, 2003, p. 14). It is important however, that students understand what the symbols and equations actually represent. A study by Gabel, Samuel & Hunn (1987, p. 695) found that although students could use chemical formulae and balance equations correctly, further questioning revealed many did not know what the formulae meant “in terms of particles that the symbols represent”.
- e) Some science educators advocate modelling with computers as a way of expressing the scientific models teachers would like their students take on board (Ebenezer, 2001; Raghavan & Glaser, 1995; Trindale, Fiolhais, & Almeida, 2002). The use of computers in this study to present animations, three-dimensional rotatable images or video clips “offer rich sensory experiences for the learner” (Ebenezer, 2001, p. 75). Simulations to show visual representations of complex processes such as dissolving and tools which allow students to manipulate databases (Gilbert & Ireton, 2003) mean students can predict and test what happens in situations they may not have access to in the laboratory because of danger, expense or some other constraint. Ideally, however, modelling with computers can only really take place in an environment with enough computers available for student use. One computer in a laboratory with twenty eight students may not be enough.

### Abstract models

Abstract models are expressed models which are symbolic in nature and although they represent their target in some way, “have to be translated to have meaning”

(Gilbert & Ireton, 2003, p. 15). In their writing on mental modelling, Duit & Glynn (1996) discuss analogies as a form of expressed model and their value in learning science and constructing mental models. Duit & Glynn describe analogies as standing for the “mapping between two domains” (1996, p. 167). Gilbert and Ireton define analogies as propositions of “the form A is to B, as C is to D, where the A-B and the C-D system have a model-target relationship” (2003, p. 16). Rightly or wrongly, a commonly used analogy in chemistry is the description of electrons orbiting the nucleus of the atom as planets move around the sun in the solar system (Harrison & Treagust, 1996). Analogies can act as a kind of scaffolding for students to build their ideas onto, especially when the science concept they are being presented with is complex or unfamiliar. Analogies “facilitate the visualisation and understanding of abstract ideas” (Tredidgo & Ratcliffe, 2000, p. 58) and work well as long as both teacher and students recognise the limitations of the analogy they are using. An analogy is never “an exact fit between analogue and target” (Duit & Glynn, 1996, p. 173) and there are always aspects of the analogy that are different to the target idea, possibly misleading the student. It is important for analogies to be familiar to the student or they become confusing. For example, students may become confused by the comparison between the structure of an atom and the solar system because they have no clear understanding of how the solar system works.

#### **2.5.4 Implications for teaching science and chemistry – modelling in practice**

“Scientists and researchers in many disciplines frequently resort to modelling and model-based reasoning to concretise abstract ideas, to simplify and clarify complex phenomena, to predict trends, and to explain mechanisms and processes” (Raghavan & Glaser, 1995, p. 37).

However, science educators tend to, instead of making this constructive aspect of scientific endeavour known, only present students with the successful experiments or conclusions reached by scientists. Students then commit these “facts” to memory “without questioning either their development or relationship to other scientific or non-scientific knowledge”(Justi & Gilbert, 1999a, p. 164). Science educators need to provide opportunities for students to not only work with models, but also learn about the nature of science, how knowledge is built and justified and the mental struggles

of scientists as their ideas evolved (Cartier, Rudolph, & Stewart, 2001; Justi & Gilbert, 1999b; Stinner, 2001). “Modelling is central to science and should be central to pupils’ understanding of what scientists do” (Sutton, 1996, p. 143).

Recent science education literature has several suggestions for teachers keen to guide their students in construction of rich mental models in science.

- a) Ensure that multiple models are used to explain complex concepts (Gilbert & Ireton, 2003; Harrison & Treagust, 2000a, 2000b; Justi & Gilbert, 1999a; van Driel & Verloop, 1999). The presentation of several different expressed models which “co-exist for the same target” (van Driel & Verloop, 1999, p. 1147) can help the student realise that on their own, few models offer comprehensive explanation. Different models can illustrate different aspects of an idea. Students who can work with multiple models and see their complementary nature are more likely to understand science as a process, rather than just a list of facts (Harrison & Treagust, 2000b). Models also need to be clearly distinguished from their targets or the learner may concentrate on one of the weaker points of the model and “arrive at an erroneous interpretation of what the model stands for” (Gilbert & Ireton, 2003, p. 2).
- b) Encourage metacognition (Gilbert & Ireton, 2003; Harrison & Treagust, 1996). Students need to have opportunities to reflect on the way they think and how they express their mental models to others. This is more likely to take place if students spend time in group discussion with their peers, comparing their ideas with those of other students and the scientific models the teacher has presented them with (Chi, 1992).
- c) Encourage analysis of the strengths and weaknesses of expressed models (Chittleborough et al., 2005; Gilbert & Ireton, 2003; Tredidgo & Ratcliffe, 2000). Models are by nature imperfect and simplistic and cannot represent all aspects of their target. Students need the opportunity to critique the scientific models the teacher presents them with and to build and critique their own models as well. Potentially, as a result of the critique, students could modify their models so they are a more accurate representation of their target.

## 2.6 Why modelling in chemistry is unique – the three levels of chemistry

### 2.6.1 Introduction

Whereas the previous section discussed models as they relate to the teaching and learning of science, it is relevant here to focus further on models as they relate to the teaching and learning of chemistry, on which this study is based.

While it is easy to view chemistry as a process of observing physical and chemical reactions and representing them with chemical equations, Chittleborough, Treagust & Mocerino (2005, p. 2) describe chemistry as “unique” because it is based on one central theory which assumes that matter is made of largely invisible, sub-microscopic particles; the atomic theory of matter. A chemist explains the reactions they see in the laboratory by employing this theory to describe the interactions between the particles they cannot see, even with the help of the latest advances in nanotechnology. These authors suggest that the mental model students and teachers hold for matter and its particulate nature forms the basis for future learning in chemistry.

### 2.6.2 The three levels of chemistry

Johnstone (1991) suggests that learning chemistry requires understanding at several levels – the macroscopic, the symbolic and the sub-microscopic (figure 2.4).

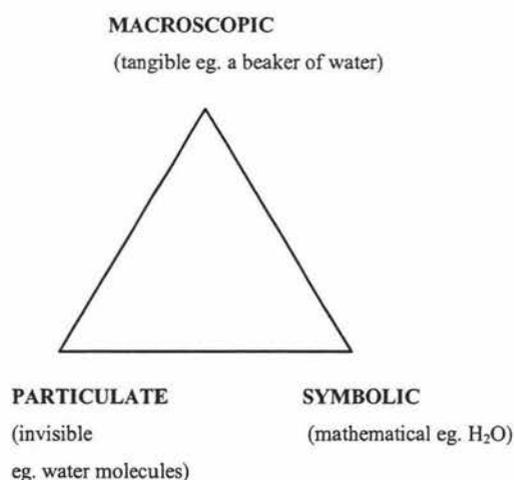


Figure 2.4. Three levels of chemistry.

*Note.* Adapted from “Why is Science so Difficult to Learn? Things are Seldom What They Seem” by A.H. Johnstone, 1991, *Journal of Computer Assisted Learning*, 7, p. 78. Adapted with permission.

These three levels can be described using the rusting process as an example. The macroscopic level could be represented by observation of a rusting iron nail or car, possibly with flakes of orange-brown solid visible. This is a “tangible and visible” phenomenon (Johnstone, 1991, p. 78). The symbolic level uses symbols to summarise this process in a chemical equation which represents the production of the orange-brown solid (rust) with symbols such as Fe, H<sub>2</sub>O and O<sub>2</sub> combining to form Fe<sub>2</sub>O<sub>3</sub>.xH<sub>2</sub>O. An equation containing these symbols would also state the proportions in which the reactants and products should exist. The sub-microscopic dimension of rusting could be described by examining the interactions between iron, water and oxygen particles as rust forms, taking into account the breaking of the bonds within oxygen molecules and the formation of bonds between iron and oxygen atoms (Chittleborough et al., 2005, p. 6). Often concrete models such as diagrams, ball and stick models or computer animations can be useful in representing this level.

While many authors discuss these three levels and their relevance to the teaching of chemistry (Chittleborough et al., 2005; Gabel, Briner, & Haines, 1992; Johnstone, 1991; Treagust et al., 2003), one would question whether the word “level” is appropriate as it suggests a kind of hierarchy. Because the macroscopic, sub-microscopic and symbolic aspects of chemistry can all help in the construction of our mental model of a chemistry concept, the current author shares the view of Nicoll (2003, p. 205), who describes the three levels as “realms” and “worlds”. It should be noted that in this thesis, use of the word *level* as it relates to the three aspects of chemistry, does not indicate hierarchy. Rather, it is used for convenience because many other authors refer to the three aspects in this way. All three aspects are mental models with the potential to contribute to the construction of the learner’s mental model of a chemistry concept. While the macroscopic realm is “real” and can be observed by a learner, Pavlinic & Buckley (2002, p. 16) emphasise the imaginary or “dream world” nature of the symbolic and sub-microscopic realms. In the sub-microscopic world, describing molecular interactions during a reaction relies on what *we think* is happening because of what we know of the atomic theory of matter and how particles move in relation to each other. Similarly, Chittleborough et al. (2005) state that the sub-microscopic level of chemistry is based on real observations, but needs theory to

explain what is happening at the particle level and uses “representations of theoretical models” (p. 4). We rely on theory because while technology such as electron microscopy allows us to see the particles within a substance, it is still almost impossible to see how they interact (Chittleborough et al., 2005).

The symbolic level of chemistry should also be treated as representation of reality rather than reality itself (Chittleborough et al., 2005; Pavlinic & Buckley, 2002). While “chemistry instruction occurs predominantly at the most abstract level, the symbolic level” (Gabel, 1999, p. 549), symbolic representations such as chemical equations do not provide information describing the motion of particles within a substance during a reaction and only represent the reaction that has taken place as a result of successful collisions between particles. Unsuccessful collisions are not displayed and cannot be communicated to students if only the symbolic level of chemistry is used to describe a chemical reaction. There are many times when students are asked to interpret macroscopic observations from practical work by writing a symbolic reaction and this is a major reason students find chemistry so difficult (Gabel, 1999; Johnstone, 1991). While Johnstone argues that “perfectly respectable chemistry” such as thermodynamics can be done using only the macroscopic and symbolic levels, many authors believe that explanation of a chemistry concept at all three levels is essential for student understanding (Chittleborough et al., 2005; Ebenezer, 2001; Gabel, 1999; Krajcik, 1991; Nicoll, 2003; Treagust et al., 2003).

### **2.6.3 How do students cope with the three levels of chemistry?**

While expert chemists can move between the three levels of chemistry with ease, recent studies have shown that novices usually only operate using one of these realms at a time (Nicoll, 2003; Treagust et al., 2003). Nicoll labels the three levels as “three distinct languages”, the macroscopic being the only one fathomable to a novice because it is the only that can be directly observed (2003, p. 205).

Johnstone (1991) and Nicoll (2003) suggest that students fail to learn to integrate the three levels of chemistry because they are not clearly represented in their chemistry lessons. Teachers tend to move unconsciously from one level to another

when they are teaching, imposing all three levels on students at once. Many studies support these statements, and problems with linking the three levels are demonstrated constantly in research literature. These are described below.

On the macroscopic level, the study by Lee, Eichinger, Anderson, Berkheimer & Blakeslee, (1993) found students equated the evaporation of water with its disappearance. Osborne and Cosgrove's study (in Gabel et al., 1987) found that 25% of the 17 year old chemistry students questioned thought that the bubbles in boiling water were composed of air.

On the sub-microscopic level, Renstrom, Andersson & Marton (1990) and Driver, Squires & Rushworth (1994) were interested to find that many students thought the particles comprising a substance expand when the substance is heated, rather than the particles moving further apart. Students often assume sub-microscopic particles have the same properties as the macroscopic substance they comprise. Students thought sulfur atoms were yellow because sulfur is yellow. (Chittleborough et al., 2005). Garnett et al. (1995) also reported problems with student perception of how particles are represented in a liquid. Many students (and teachers!) appear convinced that there is considerable space between these particles. Lee et al. (1993) and Gabel (1999) found students did not have the ability to imagine molecules as smaller than microscopic and in a study done by Schollum (1982), students tended to give explanations indicating that they had little or no understanding of what was happening at the particle level during rusting. Student explanations included water "eating away at metal", rust "evaporating" and water getting into the "ingredients" of steel.

The symbols and formulae identified with the symbolic level of chemistry can seem to be less of a problem for students. Many students are able to memorise at least the first 20 elements on the periodic table and appear to manipulate chemical formulae with ease. However, the failure to understand how chemical symbols and formulae actually represent the macroscopic and sub-microscopic levels is common (Gabel et al., 1987). For example the fact that the symbol for iron, Fe, could be used to describe a piece of iron metal, or an iron atom is a complete mystery to some. In fact, "students often perceive a chemical formula as representing one unit of substance rather than a collection of molecules" (Gabel et

al., 1987, p. 695). Krajcik (1991) contrasts chemists' understanding of chemical equations with those of chemistry students. When presented with a chemical equation, chemists have the ability to visualise a chemical reaction in terms of:

1. structure – what the symbols represent, the states of matter (solid, liquid or gas) and how the particles are moving in relation to each other,
2. interaction of species and the breaking and forming of bonds,
3. the dynamic nature of the particles,
4. relative quantities of reactants and products.

All of these aspects require understanding and integration of at least two of the three levels of chemistry and all require understanding at the sub-microscopic level. Because chemistry students do not have the wealth of knowledge and experience chemists do, Krajcik explains that students “do not visualise chemical reactions as a process involving bond breaking and bond formation; rather, students visualise chemical reactions as the reactants adding together to form the products” (1991, p. 122). Even if students can successfully balance equations, many have limited understanding of what subscripts or coefficients really mean (Krajcik, 1991).

Similarly, Stinner (1992) focuses attention on the gap between student ideas about science and the ‘scientific fact’ and formulae they encounter in textbooks. Stinner’s LEP model also has three aspects which relate to how conceptual change might take place; logical, evidential and psychological (LEP) (figure 2.5). The *logical* plane is where the mathematics, algorithms, theories and principles of science exist. Johnstone’s symbolic level of chemistry parallels this plane. The *evidential* plane is described as the students’ experimental data, experience and intuition – this being similar to the macroscopic or observable aspect of chemistry Johnstone describes. Stinner describes the *psychological* plane as the link between the logical and evidential planes. In this context, the psychological plane is a place to explore chemical reactions at a sub-microscopic level in order to make a link between what students have observed in the laboratory or everyday

life and the symbols the teacher has written on the board. This is to ensure fruitful learning has occurred rather than a simple memorising of facts.

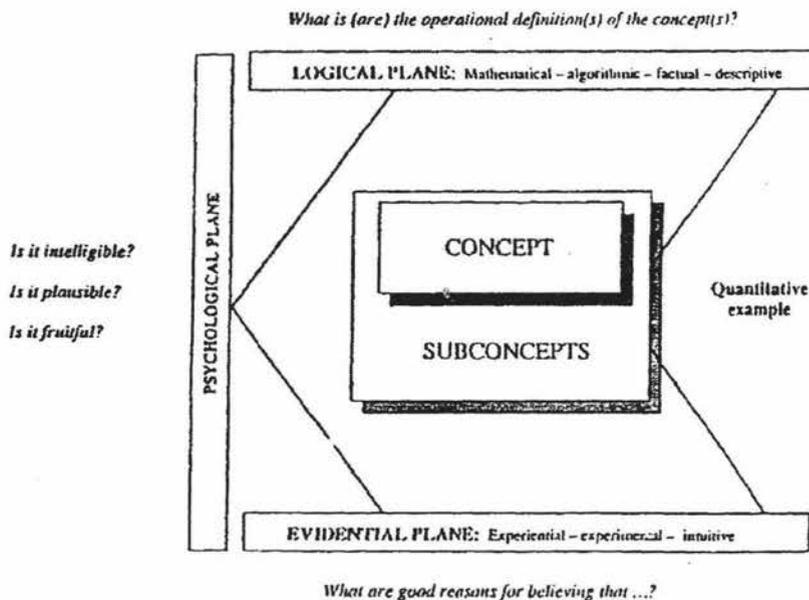


Figure 2.5. A model for concept acquisition in science. *Note.* From “Science Textbooks and Science Teaching: From Logic to Evidence” by A. Stinner, 1992, *Science Education*, 76, p. 9. Copyright 1992 by John Wiley & Sons, Inc. Reprinted with permission.

#### 2.6.4 Implications for teaching chemistry.

According to Gabel (1999), the ability to make sense of matter at the sub-microscopic level is essential if students are to explain phenomena they encounter at the macroscopic level and then meaningfully represent these phenomena with appropriate symbols and formulae. Without the sub-microscopic level, chemical equations become an “algorithmic exercise” and although they are commonly used in assessment tasks, “provide little evidence of students’ meaningful understanding” (Chittleborough et al., 2005, p. 11). The value of presenting the sub-microscopic level becomes apparent, especially for female chemistry students, in a recent study by Bunce & Gabel (2002). When the teachers presented chemistry concepts using first a macroscopic demonstration, followed by an explanation at the sub-microscopic level, followed by explanation at the symbolic level, female students achieved significantly better understanding of the concepts than female students in classes where only the macroscopic and symbolic levels were mentioned. Similar success was achieved in another study

(Gabel et al., 1992) when students were encouraged to model sub-microscopic particles with small magnets. Students who modelled the sub-microscopic level achieved significantly higher test scores than their peers who were only presented with the macroscopic and symbolic levels, even on test items only mentioning the symbolic level. The success of this approach was attributed to the fact that teachers continually related the sub-microscopic particle models to the content of the beaker or test tube and the symbolic formula of the substance. Gabel (1999) suggests that helping students relate the three levels of representing chemistry “has potential for improving conceptual understanding” (p. 548). Several authors however, caution teachers to consider several factors which may influence how students construct their understanding of the three levels and their linkage (Chittleborough et al., 2005; Grosslight, Unger, & Jay, 1991; Nicoll, 2003).

1. Students’ ability to model.

The scale developed by Grosslight et al. (1991), suggests that students’ ability to understand and construct models to explain a target falls into three main categories. Students in the first category “think of models only as little copies of real-world objects” (1991, p. 819). The second and slightly more sophisticated category means students can differentiate between ideas behind the construction of the model and the model itself. Operating in the third category involves viewing models as a way of testing and refining ideas and theories. These authors suggest that modelling is not an innate skill and that students need to be taught explicitly how to model, and about the nature of models, rather than being taught indirectly as needed to explain a concept. Ideally, in order for students to learn from models, students need to be operating at the highest modelling level and using models to predict, describe and explain phenomena.

2. Students’ background in chemistry.

In their study of university chemistry students, Chittleborough et al. (2005) found that the chemistry experience of students greatly influenced their ability to model and understand the sub-microscopic level and link it with

the other levels. Students with little or no chemistry background did not have accurate mental models of the sub-microscopic level of chemistry (Chittleborough et al., 2005; Nicoll, 2003), and misconceptions at this level actually hindered understanding of chemistry concepts. According to Stinner (1992) teachers must explore students' prior scientific knowledge so they can know how to effectively help students make the link between the logical and evidential planes. In this context, interviewing students or having them complete a diagnostic test which indicates their mental models for the sub-microscopic realm seems impractical but very important. Teachers cannot know if the presentation of the sub-microscopic level of chemistry is 'plausible, intelligible or fruitful' for the student unless they know of the student's "readiness to accommodate" this abstract and sometimes confusing level (Stinner, 1992, p. 8).

Chittleborough et al. (2005) recommend "The Rising Iceberg" as a theoretical framework for teaching chemistry (figure 2.6).

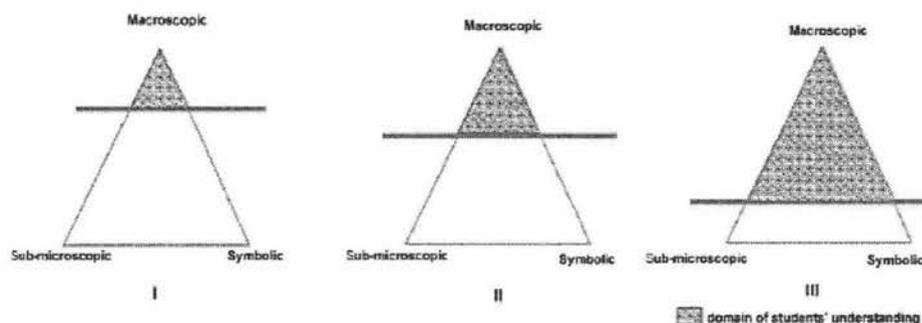


Figure 2.6 The Rising Iceberg – A Theoretical Framework for Learning Chemistry. *Note.* From "The Modelling Ability of Non-Major Chemistry Students and their Understanding of the Sub-microscopic Level," by G. Chittleborough et al, 2005, *National Association for Research in Science Teaching Conference* (April 1-3), p. 37.

Constructivist in nature, this framework means starting with student understanding of a concept and helping students build on this understanding with an emphasis on the real and observable macroscopic level. It is suggested to begin with that the more abstract sub-microscopic and symbolic levels should be "introduced on an 'as needed' basis" (Chittleborough et al., 2005, p. 38). As a

student's modelling ability and understanding of the sub-microscopic level gradually grows, the teacher can present more information using the abstract levels at the base of the triangle to help the student build more complex mental models of chemistry concepts. This is demonstrated by the downward movement of the horizontal line in figure 2.6. Strengths and limitations of the models at the sub-microscopic level also need to be pointed out to students.

From the point of view of the learner, learning and understanding is a process of conceptual change where learners gradually constructs, modifies and refines their mental model by taking on new pieces of information or changing current ideas. The information that is taken on board by the learner depends on their conceptual ecology and whether the new idea is intelligible, plausible and fruitful to the learner. From the teacher's viewpoint, the success of teaching for conceptual change depends on the presence of a number of factors. Being informed of the ideas students have when they reach the classroom, providing a safe learning environment, and good pedagogical content knowledge so that classroom activities are well-planned and sequenced, are all imperative if teaching for conceptual change. While teachers are encouraged to take into account the idea that chemistry exists in three realms, the macroscopic, the sub-microscopic and the symbolic, the sub-microscopic is often neglected and students are forced to try to make the link between what they see in a test tube and the symbols that represent it, with no intermediate step. The literature cited in this section suggests that explanation of the sub-microscopic realm and clear and gradual linkage of the three realms can be helpful for student understanding as long as the teacher ascertains whether students have satisfactory mental models of the sub-microscopic realm to begin with. The use of tools or concrete models such as molecular models or computer simulations can be helpful for constructing mental models as long as the limitations of these tools are discussed with students.

## **2.7 Conclusion**

The literature cited in this section provides the basis for the study described in this thesis. Eliciting student ideas about chemistry concepts is imperative if teachers are to plan activities which can help students change their erroneous mental models. Conceptual change is a complex, gradual process and new ideas will

only be incorporated into a learners' mental model if they are intelligible, plausible and fruitful (Stinner, 1992). Conceptual change in chemistry may be aided by recognising that chemistry exists on three levels, the macroscopic, the sub-microscopic and the symbolic (Johnstone, 1991). To avoid student confusion, teachers must be careful to move between these levels cautiously in their explanations of concepts. Provided their limitations are discussed, expressed models may be useful in modelling the sub-microscopic level of chemistry, enabling students to make more sense of the observations they make in laboratory activities.

## CHAPTER THREE - METHODOLOGY

### 3.1 Introduction

Action research is a qualitative research methodology which is used to study “a social situation with a view to improving the quality of action within it” (Elliot, 1991, p. 1).

In an educational context, on which this thesis will focus, action research means groups of teachers, parents, students or others taking steps to improve or change problematic issues within their school or classroom. Issues could be improving classroom management, optimising student learning and understanding for a particular topic, or even improving communication between staff.

Although McNiff & Whitehead (2002, p. 1) described action research as “still struggling for legitimacy” in 1988, it is now recognised as “a valid form of enquiry with its own methodologies and epistemologies, its own criteria and standards of judgement”. This statement is evidenced by the development of action research support networks such as PA-ARN (Pennsylvania Action Research Network) in the USA and CARN (Collaborative Action Research Network). These networks indicate the willingness of teachers and educators to “manage change with confidence and purpose, actively participating in the process, to ensure the best possible effects” (Reiff, 1996, p. 5).

“Action research directly addresses the problem of the division between theory and practice” (Noffke & Somekh, 2005, p. 89). Whereas some approaches rely on researchers from outside the school environment, solely controlling and conducting research inside the school, action research allows teacher participation in all aspects of the research, even if an external researcher is involved. The development of new knowledge resulting from the research process and the improvement of practice are intertwined, “reducing the time-lag between the generation of new knowledge and its application in the classroom”(Feldman & Minstrell, 2000, p. 429). However, because the teacher and researcher are one and the same in action research, personal and procedural bias may be seen as a weakness of the approach. Employing

triangulation in data collection can address issues of validity and reliability when participating in an action research study.

Since its beginnings in the 1940s, action research has evolved in response to changes in the nature of research and changes in social and political climate. While some (Stenhouse, 1975) would argue that the purpose of action research is to “observe and describe individuals’ actions in order to understand how they behave”, others (Whitehead, 1993) would say that the primary role of action research was to change social structures through individuals examining, reflecting on and explaining their own practices within the classroom or school (McNiff & Whitehead, 2002, p. 40).

This chapter will:

- a) serve as an introduction to the development of and key features and principles of action research, focussing on its role in an educational context,
- b) explore the procedures of action research,
- c) discuss issues of validity and reliability in action research, and
- d) consider the ethical issues associated with action research studies.

### **3.2 What is action research?**

McNiff & Whitehead (2002) describe early action research taking place in Native American communities in the United States in the early 1940s with the help of a politician of the time named John Collier. Collier encouraged a democratic method amongst the native communities to work through education and social issues. Social psychologist Kurt Lewin, who shared similar ideas with Collier, developed and applied action research over a number of years in a series of community experiments in post World War II America (Lewin, 1946). This was to try and formulate solutions to difficult social situations of the time such as integrated housing and equality in employment opportunities. Fundamental to Lewin’s and Collier’s work were the ideas of “group decision and commitment to improvement” (Kemmis & McTaggart, 1989, p. 6). These men recognised that those affected by an unfavourable situation would be much more committed to formulating steps towards improving the situation if they themselves stood to reap the benefits of any improvement. After identifying a problem or issue that needed improvement, participants had to commit to work collectively, take responsibility for planning a course of action, and then evaluate the resulting changes.

In the field of education, action research had its beginnings in curriculum reform (Scott & Usher, 1999). By the early 1950s, Stephen Corey (1953) had started to translate the ideas of Lewin to suit the education context and a movement whereby teachers were encouraged to reflect on their own practices in their classrooms, was born (McNiff & Whitehead, 2002). During the 1970s, British curriculum theorist Lawrence Stenhouse and educator John Elliot (1978) concluded that teaching and research were almost inseparable and believed teachers were the ones best equipped to evaluate their own work. Stenhouse (1975) deduced that in order for curricula to develop, teachers must develop, also and the importance of development of knowledge as well as improvement of practice was recognised.

Stephen Kemmis and Wilf Carr were probably the most significant players in the further development of action research in the late 1980s. Carr and Kemmis (1986) encouraged the use of the term “educational action research” (McNiff & Whitehead, 2002, p. 45) and have adopted and expanded the ideas of Lewin to form the action research spiral (figure 3.1) where self-reflective planning, acting, observing and replanning take place “as the basis for understanding how to take action to improve an educational situation” (McNiff & Whitehead, 2002, p. 46).

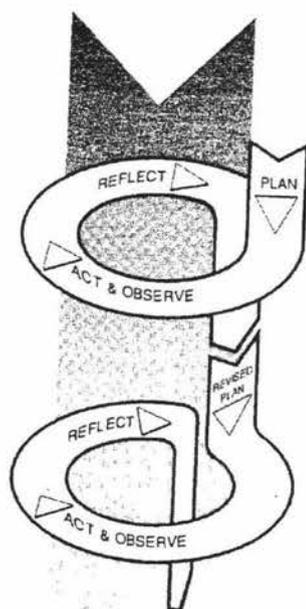


Figure 3.1. The action research spiral

Note. From *The Action Research Planner* (3<sup>rd</sup> edition) (p. 11), by S. Kemmis and R. McTaggart, 1989, Victoria: Deakin University Press.

As action research has been influenced by many different philosophies, theories and the contexts or cultures in which it was used, it seems appropriate that Marsh describes action research as an “umbrella term for a number of approaches”, all dependent on a group of participants or researchers taking “responsibility for researching solutions to their problems” (1992, p. 118). The group of researchers (in this context, teachers, students and/or parents) may start off with only a small number of people but can gradually grow to include more and more of those people involved in the practice or issue being explored. Syrjala (1996) recognises the way in which action research brings together different perspectives on the same situation and the integration of individual findings into a group discussion. Action research is a type of qualitative research which produces holistic understanding of situations rather than statistics that can be generalised. This kind of research is increasingly employed in educational research and professional development of teachers (Kemmis & McTaggart, 1989).

A cycle of four phases or “moments” (Kemmis & McTaggart, 1989, p. 9) of research (planning, action, observation, reflection) are implemented to try to address the concern a group has. The moments of research are not designed to be a single series of four steps. The group goes through planning, action, observation, and reflection, several times and not necessarily in that order as shown in figure 3.1 – the Action Research Spiral. In this way they grow to understand the situation being researched and gradually refine the action so that long term improvement is achieved. These moments are described in detail by Kemmis & McTaggart (1989) and a summary is provided below.

### **3.2.1 Planning**

This involves producing a forward-looking and flexible plan of critically informed action designed to address the concern or issue the action research group is interested in. Once this concern is identified, then a reconnaissance begins where data are gathered so that the concern can be better understood. This may involve researching relevant literature, investigating perceptions of people involved in the situation eg. parents, students, staff by interviewing or informal discussion or analysing documents such as lesson plans, student work or teacher notes. Much discussion amongst the group takes place during this phase. The plan must be

able to be adapted to unpredictable circumstances or constraints. It is critically informed because it takes into account the material and political constraints in a social situation and empowers practitioners to rise above these constraints so they can be more effective educators.

Collaboration and discussion within the action research group is of course very important in the planning process so that the members of the group have a shared language by which they can analyse how the research situation is progressing.

### **3.2.2 Action**

The plan is then carried out. It should be noted that the plan is used as a guide only and the action research group is not completely controlled by it. Because the plan is implemented in a social situation, it will have to be flexible in order to deal with changes in circumstances. Compromise and negotiation with people involved in the situation being studied are inevitable and only modest improvements in the situation may take place early on. The action phase must take into account the ways things were done previously but should not be bound by this factor.

### **3.2.3 Observation**

All activities during the action phase are documented as they occur and this provides a basis for reflection by the action research group. Observation must be planned but at the same time open-minded so all the unexpected constraints that could not be predicted in advance can be taken into account. In a classroom situation, Southward and Conner (1999) suggest the following in order to observe effectively.

1. looking at how children go about their work; not just the work they produce,
2. listening to pupils' ideas in order to gain an understanding of their reasoning,
3. discussing problems, responses and interpretations with children in order to reveal their thinking.

Southward & Conner (1999) suggest interviews, questionnaires and analysing assessment information were also methods for observing students or teachers and

their perception of a situation. These techniques will be described further in the chapter four of this thesis.

The main purpose of observation is to find the effects of the action research process and to record the expected and unexpected issues that arise. Observation is always guided by the need for critical self-reflection because this reflection eventually leads to replanning and hopefully improvement in the situation under investigation.

#### **3.2.4 Reflection**

Action research group participants then closely examine the observations and reflect on and evaluate the effects of their action. Again, the group aspect of action research is important because at some point in the process reflection needs to take place in the form of group discussion. The reflection process addresses problems, issues and constraints that have arisen as a result of the planned action and researchers have to decide whether these effects are desirable and then start the process of revising the plan. Reflection is very important for building a realistic picture of the situation and to consider what is realistically possible for the group to eventually achieve.

### **3.3 Approaches in action research methodology**

It can be seen then, that action research relies on participants focussing on issues that need improvement. They then plan a course of action, observe the action in progress, reflect on their observations and change the plan if necessary. As mentioned earlier however, action research spans a broad range of philosophies which have given rise to a number of different approaches to the methodology. The three main approaches in action research methodology are summarised below.

#### **3.3.1 Technical action research**

Carr & Kemmis (1986) and Marsh (1992) describe this type of action research as one initiated and directed by an external researcher or expert. Although the group of teachers or practitioners is involved in all aspects of the process, because the research is not initiated by the group involved in the research, this approach to

action research can sometimes be viewed as inadequate, manipulative and only useful to the researcher who initiated it in the first place. Carr & Kemmis describe technical action research as a way to develop and extend research literature rather than develop teachers' own practices "on the basis of their own collaborative and self-reflective control" (1986, p. 202). It applies within the current constraints and structures of the environment and under criteria which may be imposed on the research group by the outside researcher or expert. Similar to Lewin's approach, technical action research, however, is not all bad and in many cases is appropriate and beneficial for those involved. Technical action research studies can be very beneficial because teachers are encouraged to improve and reflect on their practices, something they may not have had the opportunity to do previously. Because technical action research often has the aim of repeating other studies in order to validate the findings, it can also help teachers to "see how their own practices are shaped by ideological conditions in society at large" (Carr & Kemmis, 1986, p. 203).

### **3.3.2 Practical / participatory action research**

McKernan describes this model of action research as a trading off of "some measurement and control for human interpretation, interactive communication, deliberation, negotiation and detailed description" (1996, p. 20). It seems then that practical action research may allow more freedom for researchers because although an expert or outside researcher may be involved, it is in a facilitatory role only. Marsh (1992) and Carr & Kemmis (1986) describe practical action research as being directed by a group of teachers with the aim of developing new practices, using the facilitator as a kind of consultant, helping the research group to plan, observe the plan in action and reflect on the effects of the changes that have taken place. Practical action research is termed such because it "develops the practical reasoning of practitioners" and helps teachers to be more self-reflective (Carr & Kemmis, 1986, p. 203). It is different from technical action research because the aim is to develop new practices as perceived by the research group, rather than an outsider. Scott & Usher describe Elliott's form of action research as practical action research because it is concerned with "what is possible", *ie.* it is limited by current systems and "what is desirable" (1999, p. 39). The research group has freedom to make decisions about what needs to be

improved or changed but must work within the structures that already exist in the school.

More recently this approach to action research has been termed *participatory action research*. The term *participatory* places emphasis on issues of power within the research process, with “all those participating in the action research process being regarded as action researchers”, not just the facilitator from outside the organisation (McTaggart, Henry, & Johnson, 1997, p. 123). As researchers, teachers can have the opportunity to work on a shared project, and improve their personal practice at the same time. In practice, a participatory approach to action research may mean the initiator losing some control of the process as it proceeds (Noffke & Somekh, 2005).

### **3.3.3 Emancipatory action research**

Martin aptly describes Carr & Kemmis’ more recent emancipatory form of action research as enabling the researcher to “escape the straightjacket of the status quo” (2000, p. 3). Martin, a religious educator, employs action research to ask questions such as ‘how can we help people of all ages enjoy learning in our congregation?’ In this project, the researchers, after identifying their concern, read widely about educational issues and reflected critically upon their own educational practices. Then, drawing upon theoretical knowledge and observations, and reflections, the researchers collaboratively devised and implemented a plan and observed the results. The plan was then revised and the whole process repeated a number of times. Martin describes action research as giving him the opportunity to “reflect upon and grow in (his) understandings of (himself) as an individual, as a religious leader, and as an educator” (2000, p. 3). While this statement could be described as the essence of emancipatory action research, it is suggested that emancipatory action research is very uncommon. This is because a “critical mass of radical participants” are required to stay committed to the project for a significant period of time (Marsh, 1992, p. 118). In a study by Atweh, Christensen & Dornan (1998), secondary school students, a teacher and university researchers collaborated in a project aimed at increasing participation of low socio-economic backgrounds in higher education. The project took over three years and considerable commitment by all involved.

Nevertheless, Carr & Kemmis' passion for emancipatory action is clear. They describe teachers being able to take joint responsibility for the development of new practices and understandings, thus uniting "theory and practice, individual and institution" free from constraints (1986, p. 202).

### 3.4 Strengths and limitations of action research

"One of the greatest strengths of action research is being able to choose a relevant, timely topic, and another is the facility to react to the context and the findings as they unfold" (Macintyre, 2000, p. 7). The perceived strengths and weaknesses of action research will be discussed in a classroom context in this section. Macintyre describes action research as a favourable approach because it is:

- contextualised – the plan is created or co-created by teachers in their own setting and therefore is likely to cause minimum disruption in the classroom,
- realistic – because of the teachers' intimate knowledge of their classes, they set realistic goals for what can be achieved,
- flexible – because it can be changed to accommodate unforeseen circumstances such as student absence,
- illuminating – because it is possible for researchers to describe *why* something occurred as well as *what* occurred in a classroom.

The contextualised nature of action research can also be perceived as a disadvantage because of concerns with the reliability and validity of the approach. Stringer (2004, p. 20) provides a succinct description of each of these factors. Reliability is "the extent to which similar results may be obtained from different samples, settings and times." It refers to the accuracy of the data obtained. Internal validity is "the extent to which results might be attributed to experimental variables." In other words, whether the data accurately represent the phenomena they claim to. External validity is "the extent to which results apply to the broader population from which the sample was drawn". According to Feldman & Minstrell (2000, p. 432), there are two main issues surrounding validity and reliability in action research.

1. It is almost impossible to completely eliminate personal and procedural bias because the teacher and researcher are one and the same. By nature, "action

research is inquiry into one's own practice" (Feldman & Minstrell, 2000, p. 435) and for this reason may be difficult to generalise to other situations.

2. The research is difficult to reproduce because no two classes are alike and variables are difficult to control.

Although these concerns seem to indicate that action research cannot be a legitimate research approach, it is helpful here to re-examine the main goal of an action research study. It is to seek an "improvement of teaching and learning and a better understanding of the researcher's educational situation" (Feldman & Minstrell, 2000, p. 432). A teacher conducting an action research project in their classroom is not aiming to demonstrate that what they have learned is viable for *all* classroom situations, rather, to show that "what they have learned is true in the particular case of their teaching in *their* classrooms" (Feldman & Minstrell, 2000, p. 435). To achieve this, action researchers most often use triangulation (Sagor, 2005). Stringer, (2004, p. 57) describes triangulation as researchers using many "different sources, methods and perspectives to corroborate, elaborate, or illuminate the research problem and its outcomes". Consistent data collected by the researcher using a number of different data collection methods, for example interviewing, classroom observation, questionnaires, will be more reliable than the claims made from data collected using only one method. In a classroom situation, reliability issues should also be addressed by anticipating aspects of the action plan which could influence the way teachers or students react in the classroom. For example, if collecting data by interviewing students, this data should not be gathered as students are rushing out to lunch, as students may give hasty answers which do not accurately reflect their reaction to the classroom situation. If an action research study is reliable, repetition of the study in that context, should produce similar results. Procedures for the research should be clear so that it could be repeated by another researcher.

Validity can be a problem in action research because studies are usually relatively small-scale and the data are not subject to statistical analysis. It is therefore imperative that there is a depth and richness in how the data are collected. This could be achieved by collecting data from a number of different sources and methods, for example interviewing students, observing classes, and reviewing documents such as assessment tasks. In order to avoid the subjectivity that could

occur if data were collected by only one person, data also needs to be collected by different people. In a school situation, this might mean recording the viewpoints of teachers, external researchers and students so that bias is reduced as much as possible.

No research method can be truly objective, value-free or equalising. Research methods are affected by political and social factors and the world view of the researcher. Nevertheless, action research “has a wide range of applications in classroom, school and community contexts” and “provides the basis for formulating effective solutions to highly significant classroom and school problems” (Stringer, 2004, p. 6).

### **3.5 Ethical considerations**

Southward & Conner (1999) state the importance of spending time on considering the implications of how data are collected, and how they are going to be used when planning an action research project. It is important that no distress is caused to any of the participants in the school or community (Macintyre, 2000). Macintyre states a number of steps which can be taken to address ethical issues.

1. Observe school protocols and work within procedures in the school.
2. Construct a detailed plan and provide all the people involved in the research with a clear picture of what the plan is and how data will be collected. This could also involve getting written permission from the school, teacher, students and possibly parents, all who are to take part in the research.
3. Be realistic and considerate when calling on teachers' and students' precious time to collect data.
4. Consider the stress and demands the research will put on those involved.
5. Ensure confidentiality by making a person's unprocessed data only available to that person or the people directly involved in the research.
6. Preserve anonymity by changing names and locations in reporting.

### **3.6 Conclusion**

Action research is a simple yet valuable tool. It empowers practitioners to undertake a field of action, develop a specific plan, implement it and reflect upon it in their own situation (Marsh, 1992). The cyclical nature of action research means it is flexible and allows for continual refining of a plan of action so that eventually a situation or issue that needs improvement is changed for the better. It relies on group participation, and discussion and brings together the ideas of a group of people with a shared concern.

Action research exists in a spectrum ranging from a technical, researcher-directed position to practical/participatory and emancipatory action research. Emancipatory action research is the ideal because it provides opportunity for change for the benefit of those inside and outside the research group. It also removes existing constraints, but requires much commitment possibly over an extended period of time. In reality, technical and practical/participatory action research are commonly used to improve processes and situations in educational environments, working within some existing constraints and recognising that researchers bring their values to the research situation.

All research methodologies are affected by political and social factors and the world view of the researcher, and no methodology can provide completely unbiased and objective data. In many situations, however, action research has proven to be a simple and useful tool for improvement in the educational context. The next section will describe the process of an action research study carried out in a secondary school chemistry context.

## CHAPTER FOUR – METHOD

### 4.1 Introduction

This chapter records the process of action research as it occurred in this study.

The following aspects will be described:

- a) contacting and approaching the research site,
- b) setting up the action research process,
- c) data collection procedures,
- d) dealing with ethical issues.

While the primary focus of this chapter is to describe the process of action research, it is inevitable that the content pertaining to the chemistry concepts and to the learning and teaching models used will be mentioned as they relate to the procedures.

### 4.2 Setting up the study

#### 4.2.1 Contact with potential research sites

Before this study commenced, the author had developed a keen interest in the area of chemistry education and improving teaching strategies for year 12 and 13 chemistry especially. After deciding to adopt an action research methodology to test some of these strategies, twelve secondary schools were contacted in February 2004 by way of a letter to the principal and board, inviting them to take part in the research (Appendix 1). Although many principals and school boards were keen for the research to proceed in their school, the heads of most science departments were concerned that the significant workload of their staff should not increase further. At the time, staff were implementing the introduction of the National Certificate of Educational Achievement (NCEA), a new standards based assessment system for senior high school, and did not have any surplus time to spend participating in an action research study. The head of science at only one of the schools was happy to have information sheets about the study sent to their chemistry staff.

#### 4.2.2 Recruitment of teachers

Two female teachers of year 12 chemistry read the information sheet for teachers (Appendix 2) and agreed to meet with the writer in the staffroom of the school to discuss the possibility of an action research study proceeding in their classrooms. Although both teachers were a little apprehensive about what the study would

involve, both had recently attended *ChemEd 2003*, a New Zealand Chemistry Teachers' Association Conference and had attended a presentation on Johnstone's three levels of chemistry, as discussed in section 2.6 of this thesis (Johnstone, 1991). Both teachers recognised the potential merits of using this model in their classroom but without some help did not see how they would have the time and resources to implement it or to incorporate it into their present teaching styles. The teachers were keen to participate in the study, knowing that while the writer would be present to provide advice or suggestions during the action research process, they would be in control of what happened in their classrooms.

Early in term 2, 2004, both the principal and teachers signed consent forms (Appendices 3 and 4), agreeing to take part in the study and then students were recruited.

#### **4.2.3 Recruitment of students**

Midway through term 2, 2004, the author visited the class taught by each of the chemistry teachers and distributed an information sheet (Appendix 5) explaining the study. Students were to be observed and audiotaped during chemistry classes and interviewed in pairs before and after two chemistry topics were taught. This is explained in section 4.4.3 of this chapter. Students had the opportunity to ask any questions about the study and were left to consider the information sheet for one week. The author returned one week later, ready to select from each class the students who would be part of the study. It was intended that ten students be randomly selected from each class using the following process. All students were given a small piece of paper and the students wishing to take part in the study wrote their name on the paper and folded it in two. Students not wishing to take part in the study were asked to leave the paper blank and to fold it in two also in order to remain anonymous. All papers were then collected and placed in a container. It was intended that the first ten names drawn, who agreed to sign consent forms, would be part of the study. Ten students were recruited in one of the classes but only five in the other. This was because there were only twelve students in the class, some of these did not wish to be part of the study and some others were not available because of long term absence. Names not drawn were destroyed. All students then had a further opportunity to ask questions about the study, and signed consent forms

(Appendix 6). Parental consent was not required as all students were sixteen years or older. All students were year 12 chemistry students, and some were planning to continue with year 13 chemistry the following year as a prerequisite for their chosen course of university study. Some of the students did not intend to continue with chemistry and had chosen the subject for interest only.

The study was limited to a small number of students, although this number constituted almost 50% of each class, so as to focus on each “student’s breadth and depth of knowledge” (Nicoll, 2003, p. 205) and understanding of the chosen chemistry topics.

#### **4.2.4 Teacher education – preparing the teachers for the action research study.**

Neither teacher had heard of action research or had had any experience of doing research in the classroom. Before the action research study could proceed then, the author met with both teachers involved, for two after school sessions in the staffroom at the end of term 2, 2004. During these sessions, the author provided material to help describe action research and the teachers had the opportunity to ask questions and explore examples of action research projects. To begin with, the type of action research used in this study is best termed *technical action research*, as described in section 3.3.1, because it was initiated by an outside researcher. However, as the study progressed, a gradual evolution into *participatory action research* (section 3.2.2) occurred as the teachers became fully involved in all aspects of the process as well as having the opportunity to reflect on their own practices. Although two one hour sessions seemed somewhat inadequate for the teachers to achieve a full understanding of action research methodology, once they had the basic ideas, the teachers both indicated their enthusiasm for learning more about the process on the job. The teachers were familiar with Johnstone’s triangle (Johnstone, 1991), which illustrates the three levels of chemistry. One after school session was spent brainstorming and discussing how Johnstone’s ideas could be incorporated into their teaching and the author provided the teachers with reading material to study privately before commencing planning sessions for the classes.

At this stage, opportunity was given for the teachers to feed back any concerns or queries they had with the study. The author noted that although both teachers were already very busy at school with teaching, deaning and extracurricular activities, both were very willing to test new strategies and were looking forward to reflecting more on their teaching.

### **4.3 Culture of the school and classrooms**

#### **4.3.1 Culture of the school**

The study was conducted at a well-established girls' school of about 700 students, catering for year 7 to year 13 students, priding itself on an inclusive and family environment, as well as academic, sporting and musical excellence. In order to familiarise herself with the school environment and make students in the study feel more at ease, the author spent five hours observing each of the classes of the teachers taking part in the study, interacting with students as they did laboratory work, or working through written chemistry problems, when appropriate. The author also spent about two hours in the staffroom during morning tea or lunchtimes, learning more about the school culture from staff. The school's website was also a useful way of getting to know more about the school. It was the author's perception that expectations of staff and students were high and that strengths of students, whatever form they took, were to be fostered and encouraged. The school provided a very positive environment for its students.

#### **4.3.2 Culture of the classrooms**

As mentioned above, the author spent several hours sitting at the back of each of the classrooms as a non-participating observer in order to gain knowledge about the nature of each classroom culture before the study started. This helped to inform the planning process and also helped the students and teacher become familiar with the presence of an outsider in the classroom.

The first classroom (class 1) was a pleasant, well-equipped, bright modern science laboratory with movable desks, data projector and well-maintained equipment. There were 24 students in this class, so when all were present, the room was quite full. Overall the classroom environment was positive and relaxed and students had an obvious rapport with their teacher. At times though, even while the teacher was

explaining a concept, many students were quite “chatty” and did not appear to be concentrating on what was going on. Other students however, were very focused on the chemistry content of their lessons. These two groups of students tended to sit separately from each other, the focussed ones at the front, near the teacher and the “chatty” ones towards the back.

The teacher, an experienced chemistry teacher with chemistry as her primary teaching subject, was a very organised teacher with well-planned lessons and clear ideas about what would take place during her lessons each day. Most lessons were teacher-directed, the teacher explaining a concept to the class and then the class copying the notes about the concept off the board. Sometimes a video would be shown or laboratory work would be carried out by pairs of students.

The second classroom (class 2) was also a pleasant, well-equipped chemistry laboratory, almost identical in appearance to the room of class 1. The teacher was an experienced science teacher, although she did not see herself as a chemistry teacher because it was not her primary teaching subject. This teacher also had a good rapport with her students and there was a relaxed atmosphere in the laboratory. This class was a small class with only 12 students and overall, students were quiet as lessons proceeded. It was the author’s perception that several of these students were not focussed on what was being taught because they were writing notes to each other or doodling in their homework planning books. Lessons were primarily teacher-directed, with the teacher explaining a concept using the whiteboard or a demonstration and then the students copying notes about that concept into their books. Again, laboratory work was sometimes used as were video tapes.

#### **4.4 The action research process**

The following is a description of how the action research process was carried out in this study. It was intended that two cycles of planning, action, observation and reflection would take place with each teacher, but in fact many extra informal instances of reflection and re-planning took place, face to face after classes, and by email. Sometimes, entire lessons had to be reworked because students were not responding to particular strategies or ideas presented by the teacher. It was a flexible

process which also had to accommodate school trips, student absences and many other unexpected happenings along the way.

#### **4.4.1 Planning**

It was intended that two topics would be taught by the two teachers involved in the study, each topic being the subject of a cycle of action research with each teacher. The two topics were *chemical equilibrium*, and *acids and bases*. At the end of term 2, 2004, diagnostic interviews were conducted with pairs of students selected from each class. The data collected from the diagnostic interviews were important for helping to plan lessons effectively and selecting teaching strategies deemed helpful for the students. Details of how interviews were conducted can be found in section 4.4.3. After the writer had presented a summary of student knowledge of the first topic to the teachers, the teachers and the author considered these data and spent time planning an introductory lesson. They also informed the students about what the study was designed to achieve, and explained Johnstone's triangle and its three levels. As well as the two chosen topics, the teachers and author considered it important for students to understand the existence of the particulate nature of matter in particular, because it forms the basis of many other chemistry concepts (Chittleborough et al., 2005; Krajcik, 1991) so a lesson was planned for this topic. The lesson focussed on revising and exploring particle behaviour in solids, liquids and gases. A sequence of lessons on chemical equilibrium was planned to follow this. The lessons incorporated strategies from recent science education literature, focussing on Johnstone's three levels of chemistry. This process was repeated for acids and bases mid-way through term 3, 2004.

#### **4.4.2 Action**

At the beginning of term 3, 2004, both teachers presented the introductory lesson and then started teaching a series of five or six lessons on chemical equilibrium as planned at the end of the previous term. More planning and replanning took place in the form of brief informal discussions between the teacher(s) and the author after classes and by email during the action phase. Changes in lesson plans were common due to students reacting in a particularly negative or positive way to a teaching strategy or because the teachers were finding some strategies were too far removed

from their usual teaching style and needed to use less radical strategies to start off with.

#### **4.4.3 Observation**

According to Southward & Conner (1999) effective strategies for observation and collection of data in the action research process involve:

1. looking at how children go about their work, not just the work they produce,
2. listening to pupils' ideas in order to gain an understanding of their reasoning,
3. discussing problems, responses and interpretations with children in order to reveal their ways of thinking.

The strategies relevant to this study are described in this section.

##### **a) Open observation**

The author took the role of non-participant observer most of the time and sat at the back of each classroom during the lessons and noted what struck her as being interesting or important during the lesson (Southward & Conner, 1999, p. 38). Examples are a comment by a student to the teacher or another student, or notes describing student behaviour and body language for example (Appendix 7). All activities in the classroom were recorded on audio tape. The data collected provided a basis for reflection by the teacher(s) and the author. Although students were sometimes questioned during, or at the end of the lesson in order to clarify a statement they had made, this was kept to a minimum so as not to cause disruption for the teacher. Lessons were observed at the beginning, middle and end of each chemistry unit for each teacher. This was so the nature of student interactions with each other and their teachers and student behaviour and work habits could be recorded.

##### **b) Structured observation**

“Structured observations usually employ systems to record activities in some kind of quantitative form” (Southward & Conner, 1999, p. 40). In this study, observation of the involvement of students during chemistry lessons was noted every five minutes according to a set of predetermined criteria. This information

was collected in order to establish whether or not there was any link between on-task or off-task behaviour and the strategies employed. Criteria were coded in the following way:

A= on task, listening or discussing with teacher,

B= on task, completing written questions,

C= talking to friend about topic,

D= off task behaviour,

E = on task group work,

F = writing notes in book.

An example of the recording sheet for structured observation is found in Appendix 8.

### c) Interviewing

The randomly selected students from each class were interviewed in pairs during class time at the beginning and end of each topic. The interviews were audiotaped, transcribed by the researcher and the transcripts made available to the students for checking and in order to satisfy ethics guideline requirements and to establish whether the statements were correctly transcribed as accurate. Questions about the chemistry content for each topic were asked as were questions about how the students perceived their understanding and if it had changed during the course of the study. Students also were given opportunity to comment on the teaching strategies their teachers had used. Interview questions can be found in Appendices 9, 10, 11 and 12. The interviews were conducted in a room across the hall from the classrooms and were limited to twenty minutes. Although the author had focussed interview questions prepared to present to the students, questions were open-ended and the interviews were relaxed and conversational in style. This allowed flexibility for the author to add in extra questions to clarify student understanding if necessary. Students were also asked to arrange and connect terms to form a concept map each time they were interviewed. They were also asked to manipulate models or draw diagrams to help illustrate their understanding of a particular concept. Although it was valuable to collect data indicating students' perceptions of their understanding, perceptions of student understanding from the viewpoint of the teachers were also important. For this reason, each teacher was interviewed in order to obtain, for example, their

perceptions of how appropriate were the planned activities, whether students were “on task”, and if they thought student understanding was enhanced by the lessons. Similar data collected from a variety of sources (teachers, students and observer) using a variety of methods (interview, observation) are more likely to be valid and reliable data (Stringer, 2004) than data collected from just one source.

#### **4.4.4 Reflection**

In this study, reflection was very important for building an accurate picture of the classroom situation and what was realistically possible to achieve as the study progressed. Each teacher and the author spent time reflecting on each lesson at its conclusion. This reflection took the form of an informal chat, discussing the good and bad points of the lesson, how comfortable the teacher felt with the activities during the lesson and how they thought the students responded. This was all written down by the author so that any issues affecting the planning of future lessons would be available for reference. An example of author notes can be found in Appendix 13. Sometimes one of the teachers or the author, due to reflection some time after the lesson, would email or phone each other, discussing ideas for future lessons. Problems, issues and constraints that arose as a result of the planning and teaching were addressed and the planning for the next lesson or the second topic was adjusted accordingly. Teachers reflected in a more formal way when they were interviewed on audiotape by the author at the conclusion of each topic. These questions are also available in Appendix 14. Students were given an opportunity to reflect in their interview times, as mentioned in the previous section.

#### **4.5 Ethical considerations**

Southward and Conner (1999) state the importance of spending time on considering the implications of how data are collected, and how they are going to be used when planning an action research project. It is important that no distress is caused to any of the participants in the school or community (Macintyre, 2000). Macintyre emphasises a number of steps which can be taken to address ethical issues and each of these is addressed as it is relevant to this study.

- a) School protocols and procedures were observed. Although the school did not appear to have any particular protocols or procedures which set it apart

from any other secondary school, it was important for the author to be well-presented and polite at all times.

- b) A detailed plan was constructed so as to inform all the people involved in the research and give them a clear picture of what the plan was and how the data would be collected. This included distributing detailed information sheets to the principal and board of the school, the teachers and the students. Information forms were also available for parents if requested. Written permission was obtained from the school, the teachers and the students involved in the study.
- c) Data collection and planning were as organised and efficient as possible so as to avoid cluttering the already busy schedules of teachers and students. It was important to remember the stress and demands the research would put on the teachers and students involved and be realistic about what could be achieved in a relatively short-term study. Anonymity was preserved by avoiding the use of names and locations in reporting.

## CHAPTER FIVE – RESULTS

### THE ACTION RESEARCH PROCESS

#### 5.1 Introduction

This action research study involved participating in a process of planning, action, observation and reflection as well as looking toward a product; that is the implementation of new strategies in teaching year 12 chemistry. The outcomes of this study will therefore be reported by firstly exploring the process of the two action research cycles and effects on the teachers and their teaching of *chemical equilibrium* and *acids and bases*. Secondly, the outcomes will be explored in terms of changes in student ideas about these two topics over the course of the study.

#### 5.2 The action research process

Two cycles of action research took place in this project. The first cycle focussed on deciding which strategies would be used to improve the teaching of the two chemistry topics, *chemical equilibrium* and *acids and bases*. During the first cycle, the teaching of *chemical equilibrium* was undertaken. The second cycle focussed on using the selected strategies to plan for and teach *acids and bases*. The two cycles will be examined in the light of three questions:

1. How did the action research process help to make changes?
2. What was the effect of the process on teaching practice?
3. Was the process useful in implementing change?

##### 5.2.1 How did the action research process help to make changes?

Although action research was a methodology completely unfamiliar to both teachers at the start of the study, once introduced, they saw the process as a potentially realistic and non-invasive way to enact change in their classrooms. Both teachers were busy with teaching and other extracurricular commitments and saw the action research as fitting in well with their day-to-day teaching. In fact, the action research process seemed to provide confidence, a “kickstart” and a structure for trialling new teaching strategies which the teachers had heard about at a conference but had not managed to implement. This is reflected in the comments of Teacher 1 below.

“It’s the kind of thing that actually it’s good to have a go at it. I think that’s what stops you from having a go at it, because you think, what if it goes wrong? ... We had been to that conference, where a lot of ideas were discussed and then not had time to just quite see how we would change what we were doing. It sort of gave us an incentive” (T01INT, 11/08/04).

Similarly, Teacher 2 commented on the way the action research process helped her to start making changes.

“We actually did that little bit of planning like professional development which was enough to get us started... it was really good to have that time to put together what we’d learnt at the conference and put all our ideas together” (T02INT 11/08/04).

After the teachers had read the chemistry education literature about constructivism, the three levels of chemistry and modelling, the author and teachers decided on the general strategies that would be implemented in order to improve the teaching of *chemical equilibrium* and *acids and bases*. It was very important for the teachers to choose strategies they thought would be manageable in their classrooms. These were:

- Strategy 1 using the information from pre-teaching student interviews (and sometimes literature) to inform planning for each topic,
- Strategy 2 using the three levels of chemistry sequentially, exploring the macroscopic level, then sub-microscopic level, and lastly the symbolic level of a concept, and making this process explicit to students during lessons,
- Strategy 3 modelling the behaviour of particles at the sub-microscopic level using magnetic cardboard dots or student role plays during lessons,
- Strategy 4 drawing students’ attention to the limitations of these concrete models, or any others, used during lessons.

Once these strategies had been decided upon, the author and teachers discussed preliminary lesson plans which included these strategies for the first few lessons of chemical equilibrium. Each teacher then planned the detail of their lessons individually to accommodate their personal teaching style. More detail of how these strategies were implemented by the teachers can be found in lesson observation notes recorded by the author in tables 5.1, 5.2, 5.3, and 5.4.

### **5.2.2 What was the effect on each teacher's practice in each cycle?**

#### Cycle 1 – *chemical equilibrium*

##### Implementation of strategy 1

The most obvious changes to teacher practice brought about by the first cycle of the action research process were in the area of planning for lessons and thinking about how the new strategies would be employed. Planning sessions allowed time for teachers to discuss and synthesise ideas from the conference they had attended, strategies from chemistry education literature and the ideas from student interviews and then try to plan meaningful lessons for their students. In this case, student misconceptions from chemistry education literature were also considered because the students in the study had so few ideas about *chemical equilibrium*. Both teachers indicated the positive effects the planning stage had for them and their teaching.

Teacher 1 focussed on the way the group planning process helped her to fully develop ideas she already had, but may not have had the chance to implement.

“We actually had enough time together planning and talking about it that we had worked it out enough ahead of time, whereas, if you were going to do it yourself, you might not get to the point where we were when we started” (T01INT, 11/08/04).

Teacher 2 enjoyed the opportunity to think about the words she would use and the pedagogy in her lessons.

“I think my class did respond positively because I had to really think and plan what I was going to say, rather than just make up the words as I went along” (T02INT, 11/08/04).

Whereas in previous years, both teachers had written the symbolic equation for a reversible reaction on the whiteboard as a start to this topic, this time they wanted to take a different approach because they knew that students only considered equilibrium as static or like a balanced see saw. The teachers and the author focussed on ways to help students to see chemical equilibrium as dynamic, with movement of particles represented by concrete models. The teachers and the author were also aware of the way students in the literature compartmentalised reactants and products and planned to again use concrete models to promote the idea of reactants and products in the same system instead.

#### Implementation of strategy 2

The second major area of change to teacher practice involved the events that took place in the classroom. From the author’s perspective, changes in the way the teachers conducted their classes were modest in this cycle, but it is important to note that both teachers introduced strategies and tools they had never used before, even if to a limited degree. Rather than launching straight into the content of chemical equilibrium, the teachers made their intended teaching *process* explicit to the students at the start of the topic. During the first lesson of the chemical equilibrium topic, Teacher 1 explained to the students how she would normally teach and how that would change.

“What I have done and what other chemistry teachers have done when teaching chemistry is go straight into writing something like this (a chemical equation), which is our symbols, our chemical equations....so the tendency is to go straight from what we see in the test tube to writing the symbolic equation...but does that give you a picture in your mind? Not really....We need to have a picture of what is happening to individual molecules so we can explain ideas that we’re talking about because we’ve got this mental picture in our minds” (FN0101, 06/08/04).

Similarly, Teacher 2 talked to students about the three levels of chemistry and compared the sub-microscopic level to the microscopic cells studied in biology classes.

“When we watch a reaction with our eyes; that’s called the macroscopic level, then we usually try and write an equation to go with it and that’s called the symbolic level. Now what we’re going to do from now on is try and know what’s happening to the particles. In biology, it’s easy to look at cells under the microscope, but because in chemistry the particles are so small, we can’t do that, so we use models and things to try and show what the particles are doing” (FN0501, 10/08/04).

The author observed that in this cycle, both teachers did tend to order class activities to start with the macroscopic level, then to the sub-microscopic level, then the symbolic, although usually not making the moves between levels explicit to the students. An example is the activity sequence 6, 7, 8 of Teacher 1 in table 5.1. Teacher 2 tended to move from the macroscopic to the sub-microscopic level, but only introduced the symbolic level very briefly near the end of the lesson (table 5.2, activity 10).

Table 5.1. Lesson observation Teacher 1– *chemical equilibrium* lesson 1 (FN01, 06/08/04)

Activity	Notes and observations
1. Brainstorm	Teacher encourages students to give ideas about what they think equilibrium is and writes ideas on whiteboard.
2. Teacher explanation	Teacher explains three levels of chemistry and describes each level, giving examples.
3. Student role plays	Students are divided into groups of four or five and encouraged to work together to show behaviour of particles in a solid, liquid and gas in a container. Desks were arranged to mimic the container. Teacher stimulates discussion with students about <ul style="list-style-type: none"> <li>• what happens to particles when substance is heated</li> <li>• what is in between particles</li> <li>• how particles move in relation to each other</li> <li>• how particles are positioned in relation to their container</li> <li>• the size of particles as phase changes occur</li> </ul> Teacher draws pictures on whiteboard to show how students arrange themselves. Students indicate large spaces in between particles of a liquid.
4. Cognitive conflict activity with syringes	Students stay in their groups and are provided with syringes with ends blocked. Some are full of air. Some are full of water. Students are questioned about compressibility of syringes and what this show about spaces between particles.
5. Student role play	Students are encouraged to change their role play if needed because of information from syringe activity.
6. Teacher demonstration	Teacher sets up water to boil on a tripod over a Bunsen, first without lid and then with. Introduction and discussion of closed and open system
7. Role play	Students in groups again and modelling water molecules in demo.
8. Notes to copy	Teacher writes notes about equilibrium and closed and open systems as it relates to the demonstration. Teacher draws water molecules and symbols and indicates their movement in diagrams
9. Teacher demonstration	Dissolving sodium chloride in water until solution is saturated. Discussion with students about saturated solutions and equilibrium. (dissolving → recrystallisation → dissolving)
10. Magnetic dots	Demonstration by teacher of saturated solution on board with dots
11. Teacher explanation with magnetic dots	Teacher compares complete reactions ( $KI + PbNO_3 \rightarrow KNO_3 + PbI_2$ ) with equilibrium reactions ( $A + B \rightleftharpoons C$ ) using dots on board. No demonstration with actual chemicals. Aim is to try and show that in an equilibrium reaction: <ul style="list-style-type: none"> <li>• reactants and products are present at the same time</li> <li>• at equilibrium the reactions are proceeding at equal rates</li> <li>• reactants and products are not in two separate compartments. Teacher draws a beaker on board and puts reactant and product dots inside it.</li> <li>• At equilibrium concentrations of reactants and products are usually not equal.</li> </ul>
12. Notes to copy	Teacher writes notes describing demo with dots and symbols
13. Teacher explanation	Introduction of K as a ratio just to whet appetite for next time

Table 5.2. Lesson observation Teacher 2 – *chemical equilibrium* lesson 1 (FN05, 10/08/04)

Activity	Notes and Observations
1. Brainstorm	Teacher encourages students to give ideas about what they think equilibrium is and writes ideas on whiteboard.
2. Teacher explanation	Teacher explains three levels of chemistry and describes each level, giving examples.
3. Student role plays	Students are divided into groups of four or five and encouraged to work together to show behaviour of particles in a solid, liquid and gas in a container. Desks were arranged to mimic the container. Teacher stimulates discussion with students about <ul style="list-style-type: none"> <li>• what happens to particles when substance is heated</li> <li>• what is in between particles</li> <li>• how particles move in relation to each other</li> <li>• how particles are positioned in relation to their container</li> <li>• the size of particles as phase changes occur</li> </ul> Teacher asks students to draw pictures on whiteboard to show how students arrange themselves. Students indicate large spaces in between particles of a liquid.
4. Cognitive conflict activity with syringes	Students stay in their groups and are provided with syringes with ends blocked. Some are full of air. Some are full of water. Students are questioned about compressibility of syringes and what this show about spaces between particles.
5. Student role play	Students are encouraged to change their role play if needed because of information from syringe activity.
6. Teacher demonstration	Teacher sets up water to boil on a hot plate, first without lid and then with. Introduction and discussion of closed and open system.
7. Student role play	Students in groups again and modelling water molecules in demo.
8. Notes to copy	Teacher writes notes about equilibrium and closed and open systems as it relates to the demonstration. Teacher draws water molecules and indicates their movement in diagrams
9. Brainstorm	Teacher asks students to brainstorm and try to remember reactions from other science lessons which go to completion and reactions which are reversible. Students do not really respond.
10. Teacher demonstration	Teacher goes back to water boiling demo, pointing out liquid and gas phases of water and draws a symbolic equation on board with double arrows to show that the liquid and gas phases are present at the same time.
11. Notes to copy	<ul style="list-style-type: none"> <li>• reactants and products are present at the same time</li> <li>• at equilibrium the reactions are proceeding at equal rates</li> <li>• reactants and products are not in two separate compartments. Teacher draws a beaker on board and puts reactant and product dots inside it.</li> <li>• At equilibrium concentrations of reactants and products are usually not equal.</li> </ul>

### Implementation of strategy 3

Other changes in the classroom involved the introduction of teaching pedagogies such as student role plays and magnetic cardboard dots to represent particles in substances (see tables 5.1 and 5.2). Neither teacher had used student role plays or magnetic dots on the whiteboard with their chemistry classes to demonstrate

particle behaviour, but after having the opportunity to plan and discuss the ideas, they were happy to give them a try. Again the planning aspect of the action research process seemed to give the teachers confidence to try something new.

“It sort of gave us an incentive to spend a little bit more time planning and making the dots, and having done it now, you’re more likely to use it again...you can improve it and modify it but you’ve got the basic thing” (T01INT, 11/08/04).

In this cycle, role plays were used by both teachers in their first lesson. The author observed that each role play took about 15 minutes (table 6.8 and 6.9) and required significant organisation. Each teacher had to group students, and explain each step of the role play. Role plays were not used again in this cycle by either teacher.

In this cycle, both teachers used the magnetic dots mostly in five to ten minute teacher-directed explanations of a concept (table 6.10, and section 6.11) and often in conjunction with a symbolic equation on the whiteboard (figure 5.1 and 5.2).

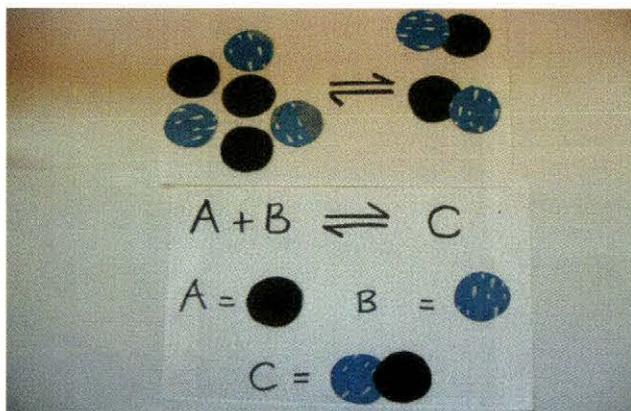


Figure 5.1. Dots and symbolic equation at beginning of cycle 1 (FN0107, 06/08/04)

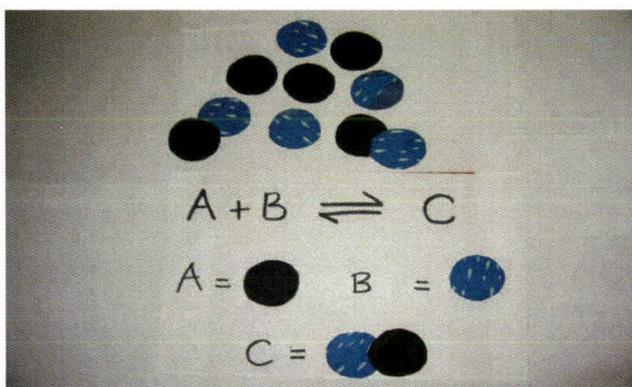
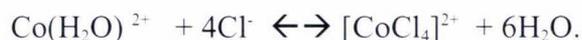


Figure 5.2. Dots and symbolic equation at end of cycle 1  
(FN 0201, 13/08/04)

In the last lesson of this cycle, the students of Teacher 2 were given opportunity to manipulate the dots on the board (FN0602, 13/08/04). Students had completed a practical activity where they observed the effect of temperature change on the colour of a cobalt chloride solution



None of the students involved in this study took the opportunity to move dots around and try to represent at a sub-microscopic level what they had seen in their test tubes.

In interviews with the author, students indicated the changes they had noticed in their classroom activities and there was a mixed response to the use of the magnetic dots and student role plays.

“It (the role play) was kind of silly, but then it really stuck with me and I remembered it. You think back to it. Normally she (Teacher 1) just teaches off the board. We’ve never really like, had visual examples. No, it was good” (S15INT, 27/08/04).

“I thought that the things, the cardboard dots were quite good, but I guess they just could have been drawn instead. The role plays were kind of like, a waste of time” (S06INT, 27/08/04).

Students of Teacher 2 also commented on the changes their teacher had started to make. The majority of the students were complimentary about the dots and did not like the role plays because they had to move out of their seats (FN0501, 10/08/04). One student felt the opposite way:

“The role plays were really different! They were actually quite good because I felt more likely to remember it...The dots I found confusing at the beginning. I think I cope with symbols better” (S05INT, 27/08/04).

#### Implementation of strategy 4

Although both teachers briefly mentioned the limitations of using dots and role plays in their introduction to this topic, neither was observed to refer to limitations of these models during the first cycle.

The reflective aspect in the action research process was a catalyst for change in teacher practice. Although reflections on classroom practices were recorded by the author in interviews with the teachers, the most valuable reflections in terms of enacting change were those stated in an informal manner at the conclusion of lessons. The two teachers reflected on their lessons with the author, tentatively at first;

“Mmmm, I guess it went alright” (FN0505, 10/08/04).

“I’m not really sure what they (students) thought” (FN0108, 06/08/04).

They then reflected together more and more about how the classes went and the success of the strategies whether the writer was present or not. By the end of the *chemical equilibrium* topic, the teachers saw reflection as an integral part of the way they planned and replanned their lessons. It helped them to adjust aspects of the lessons which did not suit them or their students.

“Between the two of us, we worked it out. Teaching next door to each other was great because you could compare notes have a quick chat about what to do and what not to do” (T02INT, 28/10/04).

“I was one class ahead of (Teacher 2) so I could tell her what I’d done and what had worked” (T01INT, 28/10/04).

### Cycle 2 – acids and bases

#### Implementation of strategy 1

Planning for the *acids and bases* topic was quite different to planning for *chemical equilibrium* because teachers were more familiar with the action research process, and had tried some new teaching strategies using magnetic dots and student role plays in the first cycle. At the beginning of the first cycle, the teachers had used the same strategies as each other in their classrooms but in this cycle, teachers used student feedback about the strategies to help them decide which ones suited them and their students better and which ones they would discard. The reflections about the first cycle informed the planning for the second cycle. Teacher 1, for example, decided not to use role plays when teaching *acids and bases*.

“I think with the role plays; I’ve never really liked role plays anyway, but I think to sell the role play, that would be something I’d need to do differently or not use at all” (T01INT, 11/08/04).

Teacher 1 also thought that the students did not respond well to or benefit from the role plays.

“Some of them it might have helped a little bit, but the majority, it didn’t work so well...their reaction to the role play was negative so they didn’t see that as having helped them” (T01INT, 11/08/04)

On the other hand, Teacher 2 planned to use role plays again when teaching *acids and bases*.

“From my point of view, it looked like it (the role play) made them (the students) think and consider how they really thought particles worked (T02INT, 11/08/04).

Both teachers thought that using the magnetic dots helped their students and both planned to use them throughout the teaching of *acids and bases*.

Student ideas about *acids and bases* collected from interviews also greatly influenced the planning of lessons for the *acids and bases* topic. For example, knowing that many students thought of neutralisation as a simple mixing of acids and bases, made teachers try to think of ways to model how acids and bases interact with each other and water at a sub-microscopic level.

#### Implementation of strategy 2

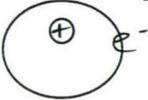
In this cycle, both teachers used concrete models quite extensively to represent the sub-microscopic level of chemistry concepts but differed in the order they presented the macroscopic, sub-microscopic and symbolic levels. Teacher 1 tended to move between the sub-microscopic and the symbolic in her explanations, sometimes mentioning the macroscopic aspect (table 5.3). Teacher 1 indicated the way the dots had become part of her teaching in the following reflection.

“With the dots, we’d never used them before. We had to consciously fit those in, but I think that if you incorporate it into your teaching, then you could just go without really thinking you were going between them. Once I had worked out how I was going to do things, I don’t remember thinking about moving between the levels too much” (T01INT, 28/10/04).

Table 5.3. Lesson observation teacher 1 – *acids and bases* lesson 1 (FN03, 19/08/04)

Activity	Notes and observations
1. Teacher explanation	Review of acids and bases as described by their pH (common student idea from interviews).
2. Teacher / student discussion	Introduces strong acids and bases as proton donors and proton acceptors by talking about how they behave in water. Example is HCl. Uses dots on board to show hydrogen ion from HCl forming hydronium ion with water. Students ask questions to clarify what would happen with a base eg $\text{Cl}^-$ . Teacher also introduces the terms conjugate acid and conjugate base and also water as an amphiprotic substance.
3. Notes to copy	Students copy down definitions of acids and bases and also are very keen to copy down dots even though teacher has said that it is not necessary.
4. Teacher answers individual student questions as students write notes	Teacher uses dots on board or writes symbolic equations on board or in student notes to clarify questions students have.
5. Written questions	Students are told to complete questions from their workbooks (all in symbolic format). The questions require the students to write the formula of conjugate bases for acids such as HCl, $\text{HSO}_3^-$ . Teacher goes through answers on board, sometimes using dots to clarify.
6. Teacher explanation	Teacher introduces neutralization and shows dissociated HCl and NaOH in water with dots. Shows hydronium ions and hydroxide ions interacting to produce water and the sodium and chloride ions as spectator ions (sodium chloride solution). Teacher writes symbolic equation $\text{H}_3\text{O}^+ + \text{OH}^- \rightarrow 2\text{H}_2\text{O}$ and puts dots alongside and moves dots to show how symbols represent dots and vice versa. Teacher talks about limitations of dots as a model ie. too few of them, too big, flat cardboard, difficult to demonstrate movement.
7. Written questions	Students are told to complete questions from their workbooks (all in symbolic format). The questions require the students to complete neutralisation reactions eg. $\text{HCl} + \text{NaOH} \rightarrow$ Teacher roams and answers questions from students if needed.

Table 5.4. Lesson observation teacher 2 – *acids and bases* lesson 1 (FN07, 18/08/04)

Activity	Notes and Observations
1. Brainstorm	Students are asked about their knowledge of acids and bases. Ideas are written on white board. Students express similar ideas to those in interviews.
2. Teacher demonstration	Teacher passes around molymod molecular models of water and HCl and talks about them as discrete molecules. Teacher does demonstration with conductivity apparatus (light bulb and electrodes). Explains how it works if ions are present and then asks students to predict conductivity of sodium chloride solution and water. Conductivity test is carried out. Water doesn't conduct and sodium chloride does.
3. Teacher / student discussion with magnetic dots	Teacher and students interact about demonstration. Teacher asks students to predict whether pure HCl would conduct. Students think it will but teacher explains that the HCl solution we have in the lab is not pure and only conducts because of the interaction of the HCl and the water. Teacher demonstrates this interaction with dots on board and then writes symbolic equation $\text{HCl} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^-$ Teacher also weaves limitations of particle dots into discussion ie. too few of them, too big, flat cardboard, difficult to demonstrate movement.
4. Notes to copy	Students ask the teacher for time to copy down symbolic equation and dots before the lesson moves on.
5. Student role play	Students are told to get themselves into pairs or triplets with arms linked within groups and act out the hydrochloric acid solution. Pairs are hydrogen chloride and triplets are water. Initially students swap an H from the water with an H from the HCl but teacher points out what has happened with dots and students correct their model so that $\text{H}^+$ from HCl joins with water to make $\text{H}_3\text{O}^+$ .
6. Notes	Students write down what they did on the role play and also copy the explanation teacher has put on the board.
7. Teacher explanation	Teacher reviews structure of hydrogen atom by drawing a very simple model on the board ie. one proton in nucleus and one electron. Teacher asks students to come up with limitations of this model.  eg.   Teacher explains how proton and hydrogen ion are the same thing.
8. Notes to copy	Notes on hydrogen ion and proton being the same thing.
9. Teacher explanation/ discussion with students / student modelling with dots	Teacher explains neutralisation. Teacher draws large diagrams of beakers on the board and gets students to arrange dots inside each to represent NaOH solution and HCl solution. Teacher then tells students to mix contents of beakers and try to model neutralisation with the dots. Remainder of lesson is spent discussing this and moving dots around.

In the lessons the author observed, Teacher 2 mostly referred to the macroscopic level first in her lesson activities in this cycle, then modelled the sub-microscopic aspect and lastly presented the symbolic aspect. An example of this can be seen in table 5.4, activity 2, 3 and 4 where Teacher 2 tested the conductivity of solutions, then modelled particle behaviour in role plays and lastly wrote the

symbolic equation on the board. Teacher 2 indicated that this had been her intention in the following reflection.

“Because I was prepared, I was trying to make sure I started with macro and then really tried to keep the symbolic ‘til last” (T02INT, 11/08/04).

Once she had moved through the macroscopic, sub-microscopic, symbolic sequence, Teacher 2 also tended to repeat the sub-microscopic → symbolic sequence (table 5.4, activity 5). Both teachers made the move between levels explicit about 50% of the time in this cycle.

### Implementation of strategy 3

Whereas reflection in the first cycle helped the teachers to know which strategies were useful or successful, reflection in the second cycle by teacher 2 in particular seemed to be more focussed on fine tuning the use of strategies and the magnetic dots and role plays. An example of this reflection is a comment made by Teacher 2 to the writer at the end of an *acids and bases* lesson (FN0704, 18/08/04). The teacher reflected that the representation of a liquid by putting dots inside a drawing of a beaker would be better, if the beaker was at an angle (figure 5.4) rather than having a flat bottom (figure 5.3), so the students could see that a liquid takes the shape of its container.

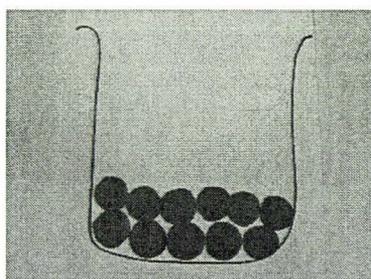


Figure 5.3  
Representation of a liquid  
with cardboard dots by  
Teacher 2

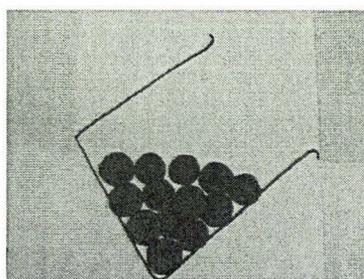
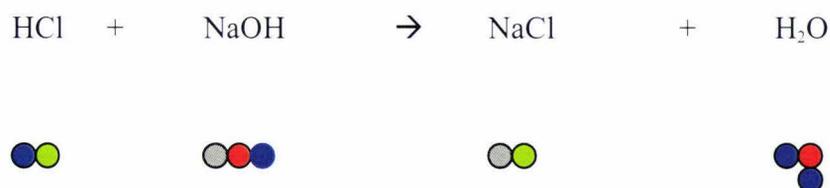


Figure 5.4  
Representation of a liquid  
with cardboard dots by  
Teacher 2

Students of Teacher 2 were encouraged to come to the whiteboard and move the dots around and some took the opportunity to do this (FN0703, 18/08/04). An

example of this is when the teacher tried to get students to model the behaviour of ions in the neutralisation process (table 5.4, activity 9). Most of the students, many of whom were involved in the study were hesitant to do this and instead copied the formation of the dots into their notes once another student or the teacher had arranged them. Teacher 2 also used short role plays up to three times per lesson by the end of this cycle (FN0802, 26/08/04), particularly when movement of particles needed to be modelled.

The lessons of Teacher 1 tended to be more teacher-directed than those of Teacher 2. Teacher 1 used the dots frequently during explanation of a concept but the writer did not observe students being given the opportunity to use the dots. In her lessons, Teacher 1 tended to use the dots to help describe the symbols in a chemical reaction. An example is an acid-base reaction she wrote on the whiteboard with the magnetic dots underneath (FN0302, 18/08/04).



The effects of the action research process have been ongoing for these teachers. When they were interviewed in August, 2005, Teacher 1 said that she planned to use the dots albeit a slightly more sophisticated version, labelled with complex ions to teach chemical equilibrium and acids and bases in September, 2005. Teacher 2, even though not timetabled to teach chemistry at the time, indicated that her experiences in the process had made her more aware of how she planned and taught some topics in junior science and year 12 biology.

“In planning, I have to make sure I make room for lots of visual models both for them (students) to use and for me to have during explanations. Actually, it was quite funny as I was a lot more adventurous with my year 10 during genetics...and in some ways again, I was aware of not jumping

into the symbols without them (the students) having a good grasp of links (between levels). We used coloured counters” (T02INT, 27/07/05).

#### Implementation of strategy 4

Both teachers referred to the limitations of the concrete models they were using far more in this cycle. For example, the author observed that Teacher 1 talked about the limitations of the dots when explaining the concept of neutralisation (table 5.3, activity 6). Teacher 2, as well talking about the limitations of the dots, talked about the model of the atom and its limitations and encouraged students to think of the problems with showing particle movement using student role plays (table 5.4, activities 3 and 7). Comments about the use of the magnetic dots made by students in section 6.5.2 also indicate an awareness of the limitations of using flat discs of cardboard to represent particles.

#### **5.2.3 Was the action research process useful in implementing change?**

From the experiences of the author, teachers and students in this study, the action research process seems to provide a manageable, flexible structure in which to make gradual changes to teaching practice. To begin with, it seemed that the teachers had the huge task of learning about and implementing the action research process as well as the new teaching strategies, but by the end of the second cycle, the process and the inclusion of the new strategies in the classroom became almost inseparable, the reflection process in particular making a significant impact on planning for future classroom activities. The teachers in this study also saw the action research process as potentially helpful to their science teacher colleagues so that a unified approach to the teaching of some chemistry concepts could be achieved across the science department. Ideally, the teachers thought that these strategies should be employed in all science classrooms in the school. Although the action research process was aimed at improving teaching strategies for chemical equilibrium and acids and bases in year 12 chemistry, both teachers indicated that improvements in strategies used as early as year 9 science would be ideal, particularly when teaching about the nature of matter. This is illustrated in a comment by one of the teachers.

“I think we could make sure that everybody (in the department) is doing the same thing, with the liquid particles touching each other... because (the students) get confused with ionic, covalent and melting and boiling points. They have trouble with that” (T01INT, 11/08/04).

Although, participating in the process required extra work for the teachers, they did seem to enjoy the process as it provided an opportunity for them to improve their teaching practice in a way that was manageable for them and without disrupting their classes.

## CHAPTER SIX – RESULTS

### THE PRODUCT

#### 6.1 What preinstruction mental models did students have for chemical equilibrium?

The following data are collected from interviews with students from the classes of both chemistry teachers. Firstly, students were asked what ideas they had about *chemical equilibrium* and *dynamic equilibrium*. All students referred to the terms *equilibrium* and *dynamic* separately and never in the context of chemistry. For this reason, the author did not ask students more complex questions about chemical equilibrium until after the teaching of the topic was taught. Representative responses of the students interviewed are provided below. The author has grouped similar responses.

##### 6.1.1 “Equilibrium” is related to physics

“It’s the sort of thing you hear in physics” (ST04INT, 17/06/04).

“Equilibrium is if something’s balanced or all the forces are equal, like in physics” (ST14INT, 15/06/04).

“Equilibrium means balanced sort of, it’s like two things balancing and they have the same amounts of energy or weight” (ST15, 17/06/04).

“I think it’s (equilibrium) like when you have even amounts of weight and it stops moving” (ST13INT, 17/06/04).

“Equilibrium is where the forces are always balanced” (ST08, 17/06/04).

“When you have equilibrium it means things are all equal and balanced and nothing is moving (ST05, 15/06/04).

##### 6.1.2 “Dynamic” has a wide variety of meanings

“You can have a dynamic person” (ST03INT, 15/06/04).

“Dynamic means powerful” (ST12INT, 15/06/04).

“Well, it suggests two things because it has ‘di’” (ST15INT, 15/06/04).

“It has something to do with music” (ST14INT, 15/06/04).

“Dynamic stretches from soccer training” (ST08INT, 15/06/04).

When the students were asked to observe water boiling, in a closed system and describe orally what was happening in the system and model the behaviour of the water molecules with drawings or cardboard dots, the author observed:

a) All fifteen students were able to offer a plausible explanation of what they saw happening in the beaker. All students recognised that the water changed from liquid to gas and also from gas to liquid and attributed this to the heat energy from the Bunsen burner, or the cooling effect of the glass lid. Students gave responses similar to the following example.

“The water gets hot because of the Bunsen and the water boils and turns into steam. The steam hits the lid and turns into liquid again” (ST05INT, 15/06/04).

In addition to this type of explanation, nine of the fifteen students were able to use the terms, boiling, evaporation and condensation correctly, to enhance their explanation, similar to the statement below.

“When the water boils it like, evaporates and becomes steam. When the steam cools down on the glass it condenses back into liquid again and dribbles down the sides of the beaker” (ST09INT, 15/06/04).

b) In addition to their verbal explanations, the students attempted to use aids to help communicate their ideas. Two of the students elected to model the behaviour of the water molecules by drawing them on paper. These are pictured in figure 6.1 and 6.2.

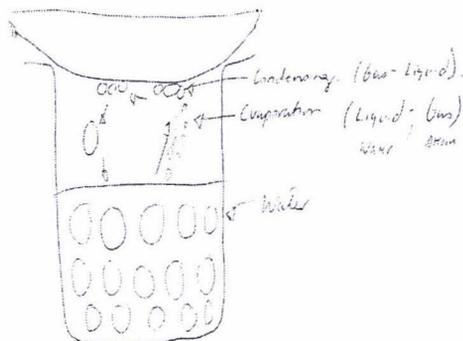


Figure 6.1. Student drawing of behaviour of particles during boiling of water before instruction (ST15INT, 15/06/04).

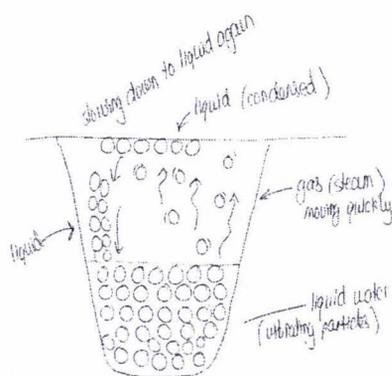


Figure 6.2. Student drawing behaviour of particles during boiling of water before instruction (ST12INT, 15/06/04).

Thirteen students elected to manipulate cardboard dots to demonstrate particle movement. Ten of these students gave up after a very short time, and indicated that they were not sure what the particles were doing.

“I just can’t really think what the waters would do” (ST08INT, 15/06/04).

“I have absolutely no idea. It’s not something I really think about” (ST13INT, 17/06/04).

The remaining three students used the dots with the results similar to those pictured in figures 6.3, 6.4 and 6.5.

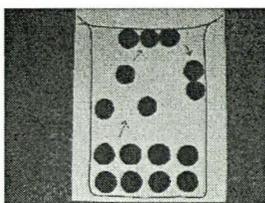


Figure 6.3. Student model of behaviour of particles during water boiling before instruction ST01INT, 15/06/04.

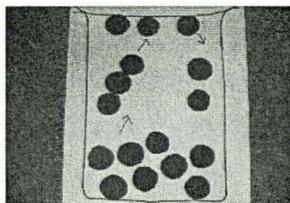


Figure 6.4. Student model of behaviour of particles during water boiling before instruction ST10INT, 15/06/04.

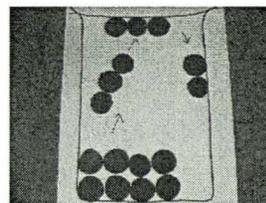


Figure 6.5. Student model of behaviour of particles during water boiling before instruction ST14INT, 15/06/04.

## 6.2 How did students' mental models change?

Student responses in post-teaching interviews about chemical equilibrium are as follows. The responses are representative of the students interviewed. Sometimes interview questions have been included in bold print to show the context of the student's answer. The author has grouped responses according to the key concepts involved in understanding *chemical equilibrium* and where possible has tabulated pre and post instruction responses. Although students were asked to create concept maps before and after the teaching of each topic, these are not applicable as no valid results were obtained.

### 6.2.1 Chemical equilibrium is dynamic

“The reaction doesn't go to completion. The rates of backwards and forwards are the same. It seems like there's no further reaction but there still is reaction going on” (ST07INT, 27/8/04).

It's when a reaction doesn't go right to the end and there's a balance between reactants and products and it's not necessarily half way” (ST09INT, 27/08/04).

### 6.2.2 Chemical equilibrium is not like physics

Table 6.1. Students' mental models of equilibrium before and after instruction

Before instruction	After instruction
“Equilibrium means balanced sort of, it's like two things balancing and they have the same amounts of energy or weight”(ST15, 17/06/04).	“(Physics) is kind of the opposite really. Physics is like a see saw, but chemistry, it looks like it's (the reaction) stopped, but it hasn't really” (ST15INT, 27/08/04).
“I think it's (equilibrium) like when you have even amounts of weight and it stops moving” (ST13INT, 17/06/04).	“In physics , it's more static, like if things are balanced, it just stops” (ST13INT, 27/08/04).
“Equilibrium is where the forces are always balanced” (ST08, 17/06/04).	“In physics it's equilibrium of forces and stuff. Yeah they don't necessarily keep changing. It's static and the forces are equal” (ST08INT, 15/10/04).
“When you have equilibrium it means things are all equal and balanced and nothing is moving (ST05, 15/06/04).	“The reactions are occurring all the time, even though it looks like it's stopped, like in physics” (ST05INT, 27/08/05).

### 6.2.3 Double arrows

“It shows that the reaction can go forwards and backwards at the same time. It shows that those reactants go together to make those products and at the same time, some products are breaking up to become reactants” (ST12INT, 27/08/04).

“The reaction can go either way” (ST13INT, 27/08/04).

“It shows that there’s a forwards and backwards reaction” (ST02INT, 27/08/04).

### 6.2.4 Relationship between concentration of reactants and products at equilibrium

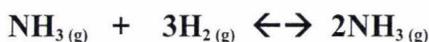
“Just because the reactions are going at the same rate doesn’t mean you have the same concentrations of things on each side of the equation” (ST04INT, 27/08/04).

“Even though it’s at equilibrium you could have, like, 90% that and 10% that (pointing to reactants and products)” (ST08INT15/10/04).

### 6.2.5 The effect of stresses on a system

#### Pressure

Interviewer – “Which side of the reaction should I apply pressure to in order to increase the production of ammonia in the Haber process?”



“But aren’t you applying pressure to the whole thing? They are all in there together. It’s not like a left and right hand thing like a see saw. Whatever you do affects the whole system” (ST15INT, 27/08/04).

“Well, you’re not really doing it to either side, are you? Those things (reactants and products) are actually together in the same system, so you’re making pressure more for the whole thing” (ST13INT, 27/08/04).

“Well, you apply it everywhere. There’s no two different chambers. The pressure gets applied to the whole thing” (ST10INT, 27/08/04).

“It can be confusing because the reaction makes it look like there’s two separate sides but all those things are in the one system” (ST09INT, 27/08/04).

“Well, you can’t just really increase it on one side, it really affects everything. Those things are all together in the same container” (ST05INT, 27/08/04).

## Temperature

Interviewer – “If the temperature of the system increases, what will be favoured, reactants or products?”



“I think you need to know whether the reaction is endothermic or exothermic, you know, whether the reaction makes or takes in heat. I just know that if you try and heat up a system, it will try and cool down and vice versa, ‘cause it always tries to oppose the change” (ST05INT, 27/08/04).

“Well, you’d have to know whether this was an endothermic or exothermic reaction” (ST07INT, 27/08/04).

“Oh, if it was endothermic, which means it takes in heat, the left to right will be favoured” (ST12INT, 27/08/04).

“I really don’t know” (ST04, 27/08/04).

### **6.2.6 The equilibrium constant (Kc)**

“It’s the concentration of products divided by the reactants. Large K means more product than reactant, small K means it’s opposite; more reactant. K is really just a ratio, so instead of having eight divided by four, you might just have ten divided by five when it reaches equilibrium again” (ST11INT, 27/8/04).

“K is the rate. I don’t really know. I just know how to do them (equilibrium expressions)” (ST12INT, 27/08/04).

“There’s like, a formula. I can’t remember which way it goes ‘round, but you put the ‘power of’ outside the brackets and you put in the reactants and products and stuff and work out K. K shows you the ratio of products to reactants” (ST06INT, 27/08/04).

“Something to do with where the equilibrium is and it kind of tells you whether you have lots of products or lots of reactants and which way it is” (ST05INT, 27/08/04).

### **6.3 What preinstruction mental models did students have for acids and bases?**

Student responses to the interview questions revealed the following ideas. The author has grouped responses based on the key concepts involved in understanding *acids and bases*. Representative responses of the students interviewed are provided below.

### **6.3.1 Acids and bases are defined by their pH**

“Acids and bases are on the pH scale. Acids are one to four and bases are the other end, close to fourteen. Seven is the middle of the scale like water” (ST15INT, 17/06/04).

“Acids have a pH number below seven and bases are above seven and seven is neutral” (ST01INT, 18/06/04).

“Acid has a higher pH than base. Seven is neutral” (ST011INT, 17/06/04).

### **6.3.2 Neutralisation is a physical reaction**

“When an acid and base mix together, they neutralise” (ST07INT, 17/06/04).

“If it’s a base, you add an acid. If it’s an acid, you add a base” (ST12INT, 17/06/04)

“You add more of one or other, like if it’s more acidic, you add base and vice versa. Like for a titration, you put indicator in and wait ‘til it turns whatever colour so that you know there’s equal amounts of...mmm, not sure” (ST13INT, 18/06/04).

### **6.3.3 Concentrated means more solute and less solvent, dilute means less solute, more solvent.**

“A concentrated acid has more acid, less water and vice versa” (ST04INT, 18/06/04).

“Dilute is... there’s less particles of acid in proportion to whatever it’s dissolved in” (ST01INT, 18/06/04).

Table 6.2 contains examples of student drawings of concentrated and dilute solutions. These are arranged into three main categories and examples of each category are pictured.

### **6.3.4 Strength and concentration mean the same thing**

“Strong acid is high concentration. Weaker acids are more dilute” (ST12INT, 17/06/04).

“Concentration is specific, like you know exactly how many moles per litre or something whereas strong, you’d just say like... it’s more of a general thing. There’s not really a difference” (ST13INT, 18/06/04).

“A concentrated acid is more strong ‘cause it’s got more acid particles and less water” (ST05INT, 18/06/04).

When asked to draw strong and weak solutions, there were three main responses from students;

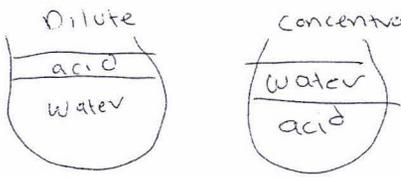
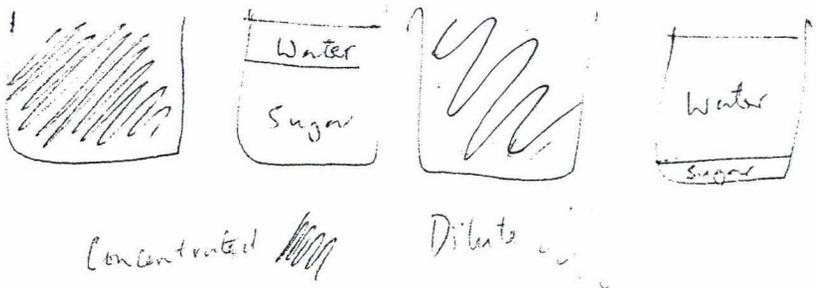
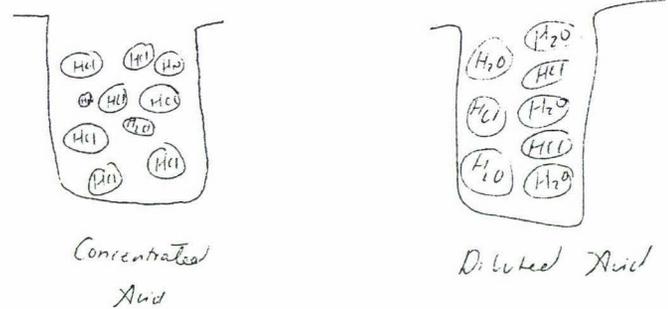
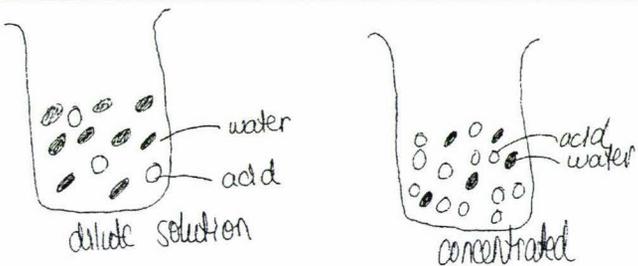
1. students did not attempt to draw them because they were unsure,
2. students pointed to their drawings of concentrated and dilute solutions and indicated that they would be the same for strong and weak,
3. students attempted to draw strong and weak solutions. These are pictured in table 6.3.

### **6.3.5 Proton transfer**

“The acid already has the proton and needs to get rid of it. The protons collide or something when the acid and base react” (ST15INT, 17/06/04).

“Protons do not transfer, only electrons” (ST07INT, 17/06/04).

Table 6.2. Students' presinstruction mental models for dilute and concentrated acids

Category	Example 1
No particles pictured	 <p>ST03INT, 18/06/04</p>
	<p>Example 2</p>  <p>ST13INT, 18/06/04</p>
Category	Example 1
Particles pictured but no dissociation of acid	 <p>ST15INT, 18/06/04</p>
	<p>Example 2</p>  <p>ST12INT, 18/06/04</p>

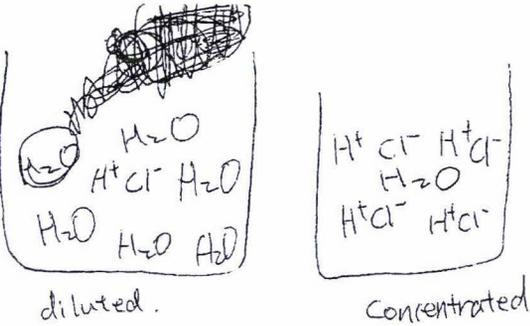
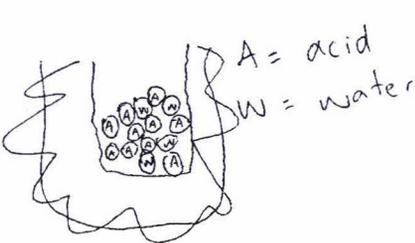
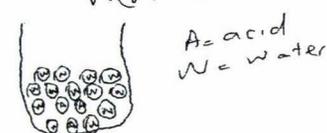
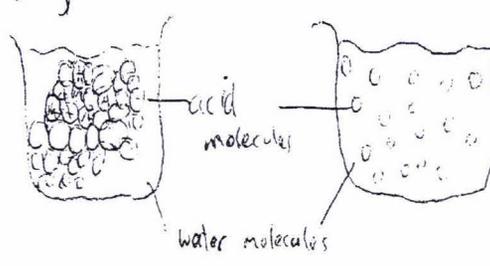
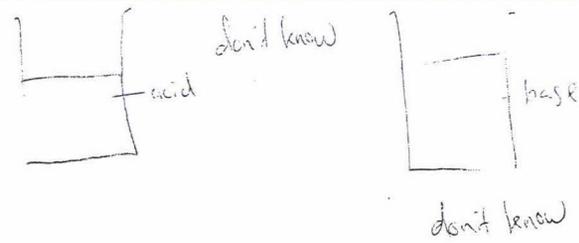
Category	Example 1
Particles pictured and indication of acid dissociation	 <p data-bbox="550 526 675 564">diluted.</p> <p data-bbox="877 515 1046 564">concentrated</p> <p data-bbox="471 581 728 614">ST10INT, 18/06/04</p>
	<p data-bbox="471 643 620 676"><b>Example 2</b></p>  <p data-bbox="520 931 704 968">concentrated</p> <p data-bbox="902 953 1031 990">dilute</p> <p data-bbox="471 1008 728 1041">ST01INT, 18/06/04</p>

Table 6.3. Students' presinstruction mental models for strong and weak acids

Category	Example 1	Example 2
Strong and weak are the same as concentrated and dilute	<p style="text-align: center;">strong acid</p>  <p style="text-align: center;">weak acid</p>  <p>ST14INT, 17/06/04</p>	<p style="text-align: center;">strong acid                      weak acid</p>  <p>ST08INT, 17/06/04</p>
Category	Example	
No idea	 <p>ST05INT, 18/06/04</p>	

#### 6.4 How did students' mental models change for acids and bases?

Tables 6.4, 6.5, 6.6 and 6.7 contain information about the changes in the students' mental models of students for acids and bases. The examples used are representative of the students interviewed.

Table 6.4. Students' definitions of acid and/or base before and after instruction

Before instruction	After instruction
"When something's acidic it turns red" (ST03INT, 18/06/04).	"Acids contain hydrogen ions" (ST03INT, 15/10/04).
"They have a pH between two and fourteen" (ST06INT, 18/06/04).	"An acid is a proton donor and a base is a proton acceptor" (ST06INT, 15/10/04).
An acid is between one and seven on the pH scale and bases are between seven and fourteen (ST09INT, 18/06/04)	An acid has a pH less than 7 and base has one more than seven (ST09INT, 14/10/04)

Table 6.5. Students' mental models of neutralisation before and after instruction

Before instruction	After instruction
"If you add them (acid and base) together, you can make water (ST09INT, 18/06/04)	A strong acid and a strong base neutralise each other, whereas a strong acid and a weak base, it would still be slightly acidic"(ST09INT, 14/10/04)
"When an acid and base mix together, they neutralise (ST07INT, 17/06/04)	"The H comes from the hydrochloric acid and because it's an acid, it gives protons to water. Water is like, amphiprotic, but this time it reacted as a base (ST07INT, 14/10/04)

Table 6.6. Students' pre and post-instruction mental models of dilute and concentrated solutions

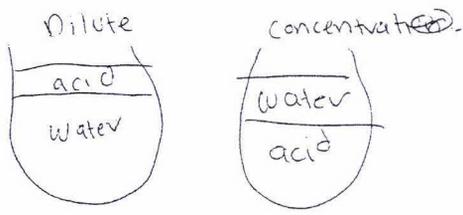
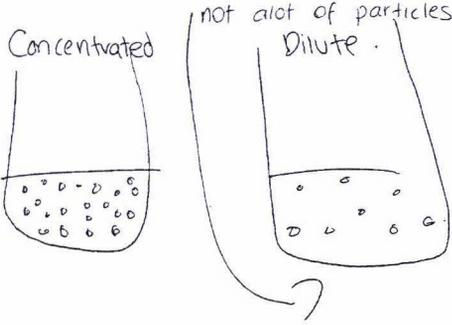
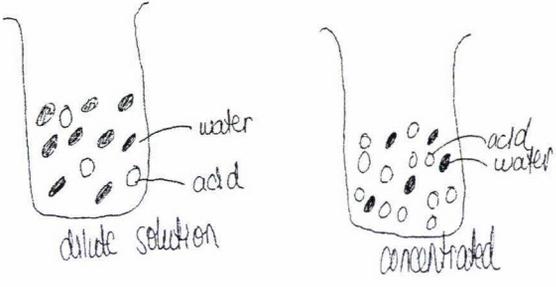
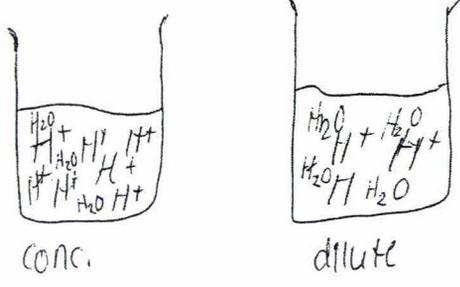
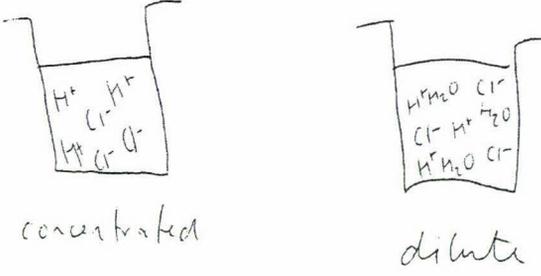
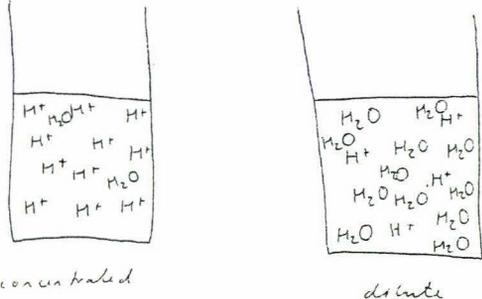
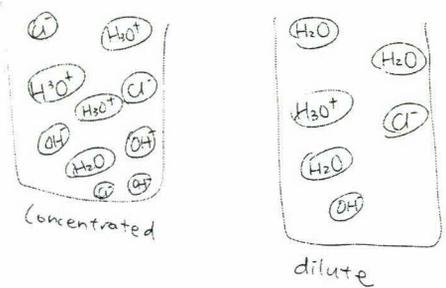
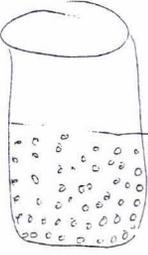
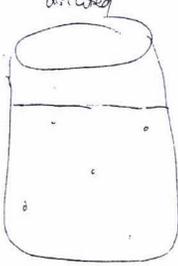
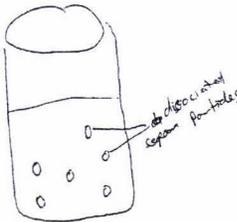
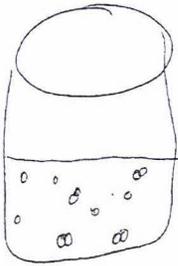
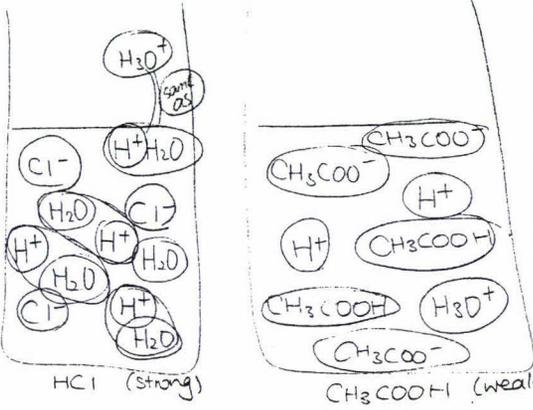
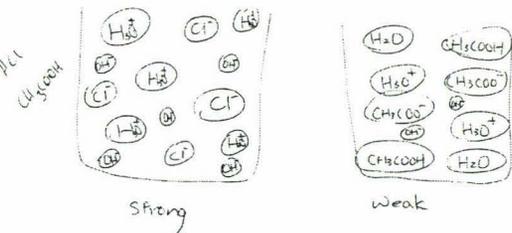
Before instruction	After instruction
 <p>ST03INT, 18/06/04</p>	 <p>ST03INT, 15/10/04</p>
 <p>ST12INT, 17/06/04</p>	 <p>ST12INT, 15/10/04</p>
 <p>ST05INT, 18/06/04</p>	 <p>ST05INT, 15/10/04</p>
<p>“Less acid and more water is dilute. Less water and more acid is concentrated”.</p> <p>ST07INT, 17/06/04</p>	 <p>ST07INT, 14/10/04</p>

Table 6.7. Students' pre and post-instruction mental models of strong and weak acids

Before instruction	After instruction
<p>Concentrated</p>  <p>diluted</p>  <p>ST02INT, 18/06/04</p>	<p>Strong acid</p>  <p>Weak acid</p>  <p>ST02INT, 15/10/04</p>
<p>"I'm not really sure".</p> <p>ST11INT, 17/06/04</p>	 <p>ST11INT, 15/10/04</p>
<p>"Don't know"</p> <p>ST07INT, 17/06/04</p>	 <p>ST07INT, 14/10/05</p>
<p>"I think strong and concentrated just means the same" ST06INT, 18/06/04.</p>	<p>"With a strong acid, you could have the same concentrations of two different acids but one can be stronger than the other because of the rate of dissociation" ST06INT, 15/10/04.</p>

#### **6.4.1 Strong acid vs weak acid performance in chemical reactions**

During the teaching of acids and bases, both classes carried out a laboratory activity, where they reacted two identical pieces of magnesium ribbon with ethanoic and hydrochloric acid of the same concentration. In post-teaching interviews, ten students (nine of them from the class of Teacher 1) indicated that hydrochloric acid and ethanoic acid of the same concentration would react with the same mass of magnesium, but that the weak acid would take longer. They reasoned that the ions from the strong acid were immediately available whereas the rate of dissociation in the weak acid was much slower. Five students (four of them from the class of Teacher 2) indicated that the ethanoic acid could not perform as well as the hydrochloric acid and would not react completely with the magnesium, even though they had seen the magnesium completely dissolve in both acids in the laboratory. Out of these five students, one was absent for the laboratory activity.

#### **6.5 Student feedback on strategies used in chemical equilibrium and acids and bases**

When asked if they had noticed any changes in their lessons over these two topics, students commented on two aspects of their lessons; the role plays and the magnetic cardboard dots their teachers had used on the whiteboard. Feedback on these tools is reported below.

##### **6.5.1 Role plays**

The first role play for each class was in the beginning lesson of chemical equilibrium. Initially, students in both classes were quite reluctant to take part in role plays. At the suggestion of doing a role play for the first time, students in the class of Teacher 1 “moan about doing role play and look fairly disinterested” (FN0109, 6/08/04). Students in the class of Teacher 2 “are giggly and distracted” (FN0503, 10/08/04). The author observed the activities of students during these beginning lessons and recorded what each of the students was doing every five minutes. This information can be found in table 6.8 for the class of Teacher 1 and table 6.9 for the class of Teacher 2. Time spent involved with the role play is indicated by bold type.

Table 6.8. Student activities in beginning lesson of chemical equilibrium (Teacher 1). Time spent involved in role play is indicated by bold type (FN0115, 06/08/04)

Student	Time elapsed (min)									
	5	<b>10</b>	<b>15</b>	<b>20</b>	<b>25</b>	30	35	40	45	50
06	D	<b>A</b>	<b>D</b>	<b>E</b>	<b>A</b>	F	C	A	A	F
07	A	<b>A</b>	<b>D</b>	<b>E</b>	<b>A</b>	F	C	A	A	F
08	A	<b>A</b>	<b>D</b>	<b>E</b>	<b>A</b>	F	F	A	A	F
09	A	<b>A</b>	<b>D</b>	<b>E</b>	<b>A</b>	F	C	A	A	F
10	A	<b>A</b>	<b>D</b>	<b>E</b>	<b>A</b>	F	F	A	A	F
11	A	<b>A</b>	<b>D</b>	<b>E</b>	<b>A</b>	F	C	A	A	F
12	A	<b>A</b>	<b>D</b>	<b>E</b>	<b>A</b>	F	C	A	A	F
13	D	<b>A</b>	<b>D</b>	<b>D</b>	<b>A</b>	F	D	A	A	F
14	A	<b>A</b>	<b>D</b>	<b>E</b>	<b>A</b>	F	D	A	A	F
15	A	<b>A</b>	<b>D</b>	<b>E</b>	<b>A</b>	F	C	A	A	F

A= on task, listening or discussing with teacher, B= on task, completing written questions, C= talking to friend about topic, D= off task behaviour, E = on task group work, F = writing notes in book

Table 6.9. Student activities in beginning lesson of chemical equilibrium (Teacher 2). Time spent involved in role play is indicated by bold type (FN0506, 10/08/04)

Student	Time elapsed (min)									
	5	10	<b>15</b>	<b>20</b>	<b>25</b>	30	35	40	45	50
01	A	A	<b>E</b>	<b>E</b>	<b>E</b>	A	A	F	F	A
02	D	A	<b>D</b>	<b>E</b>	<b>E</b>	D	A	D	F	A
03	D	A	<b>E</b>	<b>E</b>	<b>E</b>	A	A	F	F	A
04	D	A	<b>E</b>	<b>E</b>	<b>E</b>	A	A	F	F	A
05	A	A	<b>E</b>	<b>E</b>	<b>E</b>	A	A	F	F	A

A= on task, listening or discussing with teacher, B= on task, completing written questions, C= talking to friend about topic, D= off task behaviour, E = on task group work, F = writing notes in book

Teacher 2 went on to use role plays for the acids and bases topic. On average, subsequent role plays were only about four minutes long and although one of the students observed was usually off task during the role play, students were less reluctant to take part than they had been initially. Student activities have not been recorded in a table for subsequent role plays because of their brevity. Teacher 1 did not use role plays at all after the first attempt.

Student ideas about role plays were expressed in interviews with the author and some of these are recorded below. Responses from students from both classes were similar. Some students were positive about the role plays and some were not. Similar responses have been grouped based on similar ideas within the responses.

#### Role plays were too strenuous

“Introducing new things in the afternoon probably wasn’t that good – like role plays. If she did it in the morning, it would have been better. In the afternoon, you just want to sit there” (ST10INT, 27/08/04).

“Couldn’t be bothered with the role plays. We’d rather sit and do nothing” (ST03INT, 27/08/04).

#### Students perceived role plays helped them to remember concept

“The role plays kind of helped me to remember it, but it doesn’t help you to understand it” (ST06INT, 27/08/04).

“Well, I thought it (the role play) was quite fun actually. I remembered it” (ST15INT, 27/08/04).

#### Students perceived role plays helped to them to increase their understanding

“When we did the particle stuff right at the beginning with the role plays, that was easy to understand. That was different and fun, ‘cause, and then she had her little counters and stuff”(ST12INT, 27/08/04).

Interviewer – “*Did you understand what the role plays were trying to show?*”

“Yeah, the micro thing in the triangle. It helps explain why the symbols are written like that” (ST15, 27/08/04).

### 6.5.2 Cardboard dots

Examples of the way students reacted to the use of dots in their lessons are shown in the tables below. The author observed the activities of students during an acids and bases lesson for each teacher where the cardboard dots were used and recorded what each of the students was doing every five minutes. This information can be found in table 6.10 for the class of Teacher 1 and table 6.11 for the class of Teacher 2. Time spent using the dots is indicated by bold type.

Table 6.10. Student activities in an acids and bases lesson (Teacher 1). Time spent using dots is indicated by bold type (FN0306, 19/08/04).

Student	Time elapsed (min)									
	<b>5</b>	<b>10</b>	15	20	25	<b>30</b>	<b>35</b>	40	45	50
06	<b>A</b>	<b>F</b>	F	F	E	<b>A</b>	<b>A</b>	F	C	D
07	<b>A</b>	<b>F</b>	F	E	F	<b>A</b>	<b>A</b>	F	F	A
08	<b>A</b>	<b>F</b>	F	F	E	<b>A</b>	<b>A</b>	F	C	D
09	<b>A</b>	<b>F</b>	F	E	F	<b>A</b>	<b>A</b>	F	F	D
10	<b>A</b>	<b>F</b>	F	F	F	<b>A</b>	<b>A</b>	F	F	A
11	<b>A</b>	<b>F</b>	F	E	F	<b>A</b>	<b>A</b>	F	F	A
12	<b>A</b>	<b>F</b>	F	F	F	<b>A</b>	<b>A</b>	F	C	D
13	<b>D</b>	<b>F</b>	F	F	D	<b>A</b>	<b>D</b>	F	D	D
14	<b>A</b>	<b>F</b>	F	F	E	<b>A</b>	<b>A</b>	F	F	D
15	<b>A</b>	<b>F</b>	F	E	F	<b>A</b>	<b>A</b>	F	F	D

A= on task, listening or discussing with teacher, B= on task, completing written questions, C= talking to friend about topic, D= off task behaviour, E = on task group work, F = writing notes in book

Table 6.11. Student activities in an acids and bases lesson (Teacher 2). Time spent using dots is indicated by bold type (FN 0705, 18/08/04)

Student	Time elapsed (min)									
	5	10	15	20	25	30	35	<b>40</b>	45	50
01	A	<b>A</b>	<b>A</b>	<b>A</b>	E	E	F	<b>A</b>	E	E
02	D	<b>D</b>	<b>A</b>	<b>A</b>	D	D	F	<b>A</b>	D	D
03	D	<b>D</b>	<b>A</b>	<b>A</b>	D	E	F	<b>A</b>	E	D
04	A	<b>A</b>	<b>A</b>	<b>A</b>	D	E	F	<b>A</b>	E	D
05	A	<b>A</b>	<b>A</b>	<b>A</b>	E	E	F	<b>A</b>	E	E

A = on task, listening or discussing with teacher, B = on task, completing written work, C = talking to friend about topic, D = off task behaviour, E = on task group work, F = writing notes in book

The author also observed in the class of Teacher 1, that students asked the teacher to leave the dots on the board after they had been used to explain a concept so that the students could copy down the arrangement of the dots in their notes (FN0303, 19/08/04). Student ideas about the use of dots were expressed in interviews with the author towards the end of the second cycle. Representative responses of the students interviewed are provided below.

“You can imagine how they combine together. It just makes more sense. Even though they’re not really like atoms ‘cause they’re flat, they do help a lot” (ST09INT, 27/08/04).

“The thing with the dots on the board, with the equilibrium and stuff, that really helped me because we could see what was present at a particular time” (ST08INT, 15/10/05).

“I found the role plays not so useful but the dots very useful. You could see the action” (ST11INT, 27/08/04).

“Instead of telling you that there are three molecules and two molecules in a chemical equation, you can actually see, even though atoms don’t really look like little flat pieces of cardboard and there are millions and millions of molecules rather than just five or six” (ST07INT, 27/08/04).

“I didn’t find them (the dots) very helpful. It just didn’t work for me. It was too much of a distraction. ‘Cause she was busy doing this (moving dots around), I was like, what’s going on?” (ST13INT, 26/08/04).

None of the students elected to use the dots to demonstrate their post teaching ideas about *chemical equilibrium* or *acids and bases*. Instead, students tended to use symbolic equations or drew pictures of particles.

## CHAPTER SEVEN - DISCUSSION

### 7.1 Introduction

This study had two main objectives. The first was to improve the teaching of year 12 chemistry by implementing four strategies, and the second was to establish whether these strategies helped students to change their mental models for acids and bases. This section discusses the action research process and products and their significance in light of the literature in chapter two.

### 7.2 The action research process

The action research process gave teachers a flexible structure in which to plan, action their plan, observe the action, and reflect so that replanning could occur. The success of the process will be examined in the following section.

#### 7.2.1 Did the teachers employ the new strategies?

“Teachers in schools today are constantly confronted with change. They are being asked to change their practices, their beliefs about the purposes of education and how they are to be represented as professionals in society” (Sachs, 1997, p. 449).

In this study, teachers were challenged to change the way they taught chemistry by employing four new strategies they had not tried before in their classrooms. These were:

- Strategy 1      using the information from pre-teaching student interviews (and sometimes literature) to inform planning for each topic,
  
- Strategy 2      using the three levels of chemistry sequentially, exploring the macroscopic level, then sub-microscopic level, and lastly the symbolic level of a concept, and making this process explicit to students during lessons,
  
- Strategy 3      modelling the behaviour of particles at the sub-microscopic level using magnetic cardboard dots or student role plays during lessons,

Strategy 4 drawing students' attention to the limitations of these concrete models, or any others used during lessons.

The action research process was the structure within which teachers could trial and refine these strategies. It appeared to be successful as teachers reflected that the action research process of planning, action, observation and reflection gave them the opportunity to try implementing new strategies which might never have been trialled otherwise. Teachers also seemed relieved to have the freedom to try new things without the fear of having to get it right the first time. This is evidenced in a comment by Teacher 1, who said,

*"I think that's what stops you from having a go at it, because you think, what if it goes wrong?"* (T01INT, 11/08/04).

During this study, both teachers employed all the strategies at some stage (see section 5.2.2) and continue to use several of the strategies after the action research project. Strategy 1, which relied on the idea that learners construct meaning "from their experiences in connection with their prior understandings and social setting" (De Jong et al., 1998, p. 745), influenced the planning of both teachers greatly during this study. Both teachers changed not only the way they began a topic with their students, but also could plan activities to try and help students overcome misconceptions. An example of these activities is the syringe activity in tables 5.1 and 5.2. Because the students' mental models of liquids and gases were known to the teachers (figure 6.1, 6.2, 6.3, 6.4, 6.5), they designed this activity to help students confront their ideas about the distance between particles in liquids and gases. Because of the discrepant events they encountered during this activity, students were challenged to rethink the *plausibility* of their mental models. Another example of where students' ideas influenced the planning of lessons is the teachers' decision to use dots as illustrated in figure 5.2. Because the students' two-sided view of equilibrium was known to the teachers, they planned to use the dots in a way that would challenge this idea.

Ironically, one year later, neither teacher uses strategy 1. Because the process of interviewing students to elicit their pre-teaching ideas took many hours, busy

teachers do not see this method as practical or possible. Implementing effective, less time-consuming methods of eliciting students' ideas in year 12 chemistry could be the subject of a further action research study.

While planning for the implementation of strategy 2 was fairly straightforward, teachers need several more action research cycles to become proficient with using this strategy in their classrooms. Although both teachers started off with the intention of presenting concepts in the macroscopic → sub-microscopic → symbolic sequence, both teachers need more time to put this strategy into practice as well as making the moves between these three levels explicit.

Overall, use of the macroscopic → sub-microscopic → symbolic sequence improved over the course of the two cycles. Compared with the first cycle, Teacher 2 in particular was far more proficient in using the sequence in the second cycle (table 5.4). This may reflect her conscious decision to adhere to this sequence, illustrated in her comment,

*“I was trying to make sure I started with macro and then really tried to keep the symbolic ‘til last” (T02INT, 11/08/04).*

In cycle 2, Teacher 1 tended to move only between the sub-microscopic and symbolic (table 5.3). This may reflect her more relaxed approach to the use of the sequence.

*“Once I had worked out how I was going to do things, I don't remember thinking about moving between the levels too much” (T01INT, 28/10/04).*

Since many authors believe that explanation of a chemistry concept at all three levels is essential for student understanding (Chittleborough et al., 2005; Ebenezer, 2001; Gabel, 1999; Krajcik, 1991; Nicoll, 2003; Treagust et al., 2003), it is hoped that both teachers will continue to use this strategy in the future.

By the end of the second cycle, both teachers were becoming more proficient at making their moves between the levels explicit to the students. Again, teachers

need time to get used to teaching in this way; emphasising process to the students, as well as chemistry content. In effect, this study was not only about the chemistry students changing their chemistry ideas, it also required teachers to change the teaching methods they have been using for years. Posner's description of conceptual change as "gradual adjustments" to current conceptions over time (Posner, 1982, p. 106) reinforces the point that strategy 2 cannot be implemented overnight. Teachers need time to become familiar with new strategies as well as assess their plausibility if the strategies are to be employed long term.

Of all the strategies, strategy 3 has had the most lasting effect on teacher practice. Positive responses (section 6.5.2) and on-task behaviour (table 6.11) from students during the use of dots appeared to play a large part in teachers' decisions to continue using this strategy. Teacher 1 currently uses the dots to represent the sub-microscopic level at year 12 and a more complicated version of them in year 13 chemistry. Teacher 2, although not teaching chemistry this year, has carried the concept of modelling the invisible into her biology classes, helping students to build a mental model of cells or chromosome behaviour, for example.

*"Actually, it was quite funny as I was a lot more adventurous with my year 10 during genetics...and in some ways again, I was aware of not jumping into the symbols without them (the students) having a good grasp of links (between levels). We used coloured counters" (T02INT, 27/07/05).*

On reflection, both teachers saw the need for modelling the sub-microscopic level as early as year 9 science classes, so that students became familiar with, and better at, modelling,

*"I think we could make sure that everybody (in the department) is doing the same thing, with the liquid particles touching each other..." (T01INT, 11/08/04).*

Use of role plays during the study appeared to be influenced by the teachers' attitudes toward role plays and the by students' response to them. The fact that there was mixed student response to the use of role plays (section 6.5.1) and hesitation to use them by one teacher in particular, this strategy was implemented with varying degrees of success. While Teacher 2 perceived that the role plays helped her students build understanding,

*"From my point of view, it looked like it (the role play) made them (the students) think and consider how they really thought particles worked"* (T02INT, 11/08/04),

Teacher 1 did not have the same opinion. As well as not feeling completely comfortable with the strategy to start off with,

*"I've never really liked role plays anyway, but I think to sell the role play, that would be something I'd need to do differently or not use at all"* (T01INT, 11/08/04),

she did not think role plays were helpful for her students.

*"Some of them, it might have helped a little bit, but the majority, it didn't work so well...their reaction to the role play was negative so they didn't see that as having helped them"* (T01INT, 11/08/04).

From the author's perspective, the students in both classes did not respond well to role play activities to start with. During the first cycle, field notes indicate that students in the class of Teacher 1

*"moan about doing role play and look fairly disinterested"* (FN0109, 6/08/04),

and that students in the class of Teacher 2

*"are giggly and distracted"* (FN0503, 10/08/04).

In fact, it appears that one of the biggest problems with the implementation of student role plays was that the students did not really want to move from their seats.

While Teacher 1 did not use student role plays in cycle 2, Teacher 2 streamlined her use of role plays in the second cycle, weaving them into her explanations of the sub-microscopic level (table 5.4). From the author's perspective, students in the class of Teacher 2 were less reluctant to take part in role plays by the end of cycle 2, possibly indicating that they were becoming more comfortable with them, or that the teacher was becoming more skilled at facilitating role plays. Students' perceptions of role plays are discussed in section 7.4.3.

Similar to strategy 2, strategy 4 could have been implemented more effectively over several more cycles. Ideally, the teachers would have had more time to come to terms with the limitations of models *per se* and in hindsight, strategy 4 probably should have been introduced later in the study because teachers already had enough new strategies to cope with. It appeared that teachers seemed so involved in trying to implement strategy 2 and 3, they forgot to talk about strategy 4. The fact that students had such limited ideas about the sub-microscopic level at the beginning of the first cycle (figures 6.1, 6.3, 6.4 and 6.5) also would have made it difficult for teachers and students to discuss the limitations of the models used. Students could not analyse the models unless they understood what the models were supposed to represent. There was increased success with the implementation of strategy 4 in the second cycle, with teachers drawing attention to limitations of the models they used in class (tables 5.3 and 5.4) and students showing in post-teaching interviews that they had considered the limitations of the dots as models for the sub-microscopic level (section 6.5.2).

### **7.2.2 Did the teachers become more reflective?**

“Reflection in participatory action research where the research participants examine and construct, then evaluate and reconstruct their concerns. Reflection includes the pre-emptive discussion of participants where they

identify a shared concern or problem” (Seymour-Rolls & Hughes, 1995, p. 1).

The teachers’ tendency to spend time reflecting increased as the action research process progressed and was very helpful in the implementation of the four strategies. During the first cycle, the teachers would offer brief statements about their lessons, for example:

*“Mmmm, I guess it went alright”* (FN0505, 10/08/04).

*“I’m not really sure what they (students) thought”* (FN0108, 06/08/04).

By the end of the study, the teachers appeared to see reflection as an integral part of the way they planned and replanned their lessons. Informal reflection at the end of lessons became common.

*“Between the two of us, we worked it out. Teaching next door to each other was great because you could compare notes and have a quick chat about what to do and what not to do”* (T01INT, 28/10/04).

Because reflection is one of the four main parts of the process, teachers seemed to place more value on thoughts they had about their lessons. Teachers increasingly shared information about the success of activities they had used. For example, the influence of reflections about the use of dots and role plays in the first cycle influenced if and how these strategies would be used in the second cycle. This was similar to teachers interviewed in a study by McTaggart, Henry & Johnson (1997, p. 134) where teachers commented that action research “drew people together...people were always looking out at others. It led to more talking between staff and teaming up”.

It is the author’s belief that the reflection phase of further action research cycles would be even more valuable if the teachers developed the skill of metacognition. Baird and White (1996) describe metacognition as, “knowledge about, and

awareness and control over, personal practice” (p. 190). Because “people in Western cultures are not typically reflective or introspective”, it is more likely for them to think about the *products* of their learning than the *thought processes* they went through to reach that understanding; the danger being that action research projects become “boring exercises in fine-tuning” (McTaggart et al., 1997, p. 130). If lasting changes are to be made to teacher practice, teachers may need to practice metacognition as Hewson describes the conceptual change process as “explicitly metacognitive” (1996, p. 136).

### **7.2.3 Was the action research process practical?**

Although the action research process provided a flexible structure within which teachers could try new things, teachers would have benefited from more education about the action research process and more time to participate in it. Feldman & Minstrell suggest that teachers need a year to learn the process and a second year to “look critically and systematically at their teaching” (2000, p. 452). It is hoped that the teachers in this study will continue to use the process so that their understanding of the process and the ability to assess their teaching practice improves.

In spite of time limitations, the action research methodology seemed to be the most suitable for implementing the conceptual change teaching strategies in this study. The teachers commented on the usefulness of the collaborative aspect of the planning stage,

*“we actually did that little bit of planning like professional development which was enough to get us started... it was really good to have that time to put together what we'd learnt at the conference and put all our ideas together” (T02INT 11/08/04).*

This concurs with Feldman & Minstrell who state that “teachers get the most out of doing action research when it is done collaboratively with other teachers” (2000, p. 452). Feldman & Minstrell also recommend collaborating with teachers from other schools so that they less constrained by their own school culture.

The teachers also thought that the process helped them to start implementing change,

*“We had been to that conference, where a lot of ideas were discussed and then not had time to just quite see how we would change what we were doing. It sort of gave us an incentive”*  
(T01INT, 11/08/04).

The flexible and dynamic nature of the process seemed to parallel the “dynamic and recursive” process of conceptual change (Krajcik, 1991, p. 129), allowing teachers to plan, reflect and replan as teachers’ or student ideas changed.

Although the action process was new to the teachers to begin with, it became more intertwined with teaching practice as the study went on. Although planning and reflection stages did take more of the teachers’ time, disruptions in class time were minimal which made this research methodology very suitable for this study.

### **7.3 Did students’ mental models change for *chemical equilibrium* and *acids and bases*?**

In this section, the changes in the mental models students held for *chemical equilibrium* and *acids and bases* will be examined. Possible reasons for these changes will also be discussed.

#### **7.3.1 *Chemical equilibrium***

Before the teaching of *chemical equilibrium*, students in this study had little or no knowledge of equilibrium in a chemistry context, presumably because of lack of exposure to the topic before year 12. For this reason, the author did not ask questions about specific concepts within *chemical equilibrium* in pre-teaching interviews. As seen in section 6.1, students’ mental models of equilibrium paralleled those in recent literature (Gussarky & Gorodetsky, 1990; Johnstone, 2000; Maskill, 1989). Students perceived equilibrium to be:

- a) static. Many students did not know what the word *dynamic* meant.
- b) two-sided. Most students related the word *equilibrium* to their experience of physics (section 6.1.1).

Because these were the major ideas about equilibrium that arose from pre-teaching interviews, the author and teachers focussed on helping students to change those ideas and start to see equilibrium in a chemistry context.

Interviews after the teaching of *chemical equilibrium*, demonstrated a significant conceptual change in the mental models of the students. Most students in this study were able to communicate their mental models of equilibrium in a chemistry context and indicated that *chemical equilibrium* was a dynamic process and involved simultaneous presence of forward and reverse reactions, as seen in students' ideas about double arrows in section 6.2.3. This is in contrast with the significant number of students in post-teaching interviews in the literature (Gussarky & Gorodetsky, 1990) who failed to show an understanding of the dynamic nature of a system at equilibrium.

Students in this study also indicated conceptual changes in their mental model of equilibrium as being two-sided. Post-teaching interviews (section 6.2.2) revealed that several students were able to differentiate between equilibrium in a physics or chemistry context and most students, even when presented with trick questions, similar to those of Johnstone, MacDonald and Webb (1977) indicated that a symbolic equilibrium equation represented a system containing both reactants and products. An example is the explanation of reactants and products being

*“all in there together”* and that *“whatever you do affects the whole system”* (ST15INT, 27/08/04).

Again this differs from the literature. A review of common alternative conceptions of *chemical equilibrium* (Garnett et al., 1995) indicates that many students believe each side of an equation to represent separate entities and that the concentration of one reactant or product can be changed without affecting the concentrations of the other species.

Additional conceptual changes in the mental models of students in this study were shown by comments they made about the concentrations of reactants and products at equilibrium. Almost all students indicated that the concentrations of reactants

and products at equilibrium would be different from each other. This is quite different to several studies where students believe that the equal rates of forward and reverse reactions at equilibrium also mean equal concentrations of reactants and products (Hackling & Garnett, 1985; Hameed, et al., 1993; Maskill, 1989). Several students in this study further demonstrated their understanding of the relative concentrations of reactants and products at equilibrium by describing their ideas of the equilibrium constant ( $K_c$ ). In their answers, both Student 06 and Student 11 (see section 6.2.6) showed that they believed the concentrations of reactants and products to be different at equilibrium.

The conceptual understandings students had about the purpose of equilibrium expressions were less convincing. Although some students seemed to understand  $K_c$  as a ratio of products to reactants, most students were not clear about why they had been shown how to write equilibrium expressions. To these students, the expressions seemed barely *intelligible*. This is evidenced in the statement of Student 12 when she says;

*“K is the rate. I don’t really know. I just know how to do them (equilibrium expressions)” (ST12INT, 27/08/04).*

Camacho & Good describe this as “lack of equilibrium literacy” (1989, p. 256). From their interview responses, it would appear that many students had a superficial understanding of equilibrium expressions. This may be because, at year 12, students learn the format of the expression but do not use it to calculate  $K_c$  values until they reach year 13. It is possible that equilibrium expressions would have more meaning at year 12 level if students began to calculate values then, rather than waiting until year 13. The constant can then be used to predict whether the concentration of reactants or products is higher for a reaction at equilibrium.

*Chemical equilibrium* is a complex topic and this study has only touched on trying to remedy some of the misconceptions students have. While modelling the sub-microscopic aspect of reactions may help students to construct understanding at

year 12 level, the complexities of the topic at more advanced levels may be simply too difficult to model in this way.

### 7.3.2 *Acids and bases*

Like *chemical equilibrium*, pre teaching interviews revealed that students' mental models of *acids and bases* were very similar to those in the literature. Although they had already completed a unit on acid-base titrations, students had a surprisingly superficial understanding of *acids and bases*. Students indicated that:

- a) acids and bases are defined by their pH (section 6.3.1). Similar findings were reported by Garnett et al (1995) and Zoller (1990),
- b) neutralisation occurred when an acid and base formed a physical mixture (section 6.3.2) as reported in Nakleh & Krajcik (1994) and all but one student had not entertained the idea of proton transfer,
- c) concentration and strength meant the same thing (section 6.3.4).

Again the teachers and author focussed on these three ideas in their planning for this unit. Although post teaching interviews for acids and bases were not conducted until one month after teaching of the topic had ended, most students were very sure of their responses and their mental models had changed markedly. During interviews, most students defined acids and bases according to their behaviour as proton donors and acceptors (Brønsted-Lowry definition). This definition continued in student ideas on neutralisation. Student 07 is a representative example of most students who changed their mental model of neutralisation as a physical reaction to that of a chemical reaction. Most seemed to be able to imagine what was happening at a sub-microscopic level during neutralisation (table 6.5). Student 07 was also able to offer ideas about the amphiprotic nature of water without being prompted. Although the response of Student 09 (table 6.5) did not clearly show her understanding of neutralisation as a chemical reaction, she did describe an enlightened view of the reaction between strong acids and weak bases, acknowledging that the resulting pH of the solution was not 7. Zoller (1990) on the other hand found that many students thought the resulting salt formed in a neutralisation reaction was always neutral, ie. pH 7.

The most marked conceptual changes in this topic were seen in students' models of concentrated and dilute solutions and strong and weak solutions. While all students had some idea of concentrated and dilute solutions having differing proportions of solute and water to start with (table 6.6), all represented dilute and concentrated acids, indicating the relative number of particles in the post-teaching interviews (table 6.6). While no students could define or represent an appropriate model of strong or weak acids in pre-teaching interviews (section 6.3.4), by the end of the topic, all students correctly represented or described strong and weak acids as having a differing rate of dissociation. Ten of these students (nine of them from the class of Teacher 1) could apply this concept correctly to an activity they had carried out in the laboratory where they reacted ethanoic and hydrochloric acid of the same concentration with the same mass of magnesium ribbon (section 6.4.1). These students indicated that the acids would perform as well as each other, but the ethanoic would take longer because of its slower rate of dissociation. Five students (four of them from the class of Teacher 2) indicated that the ethanoic acid could not perform as well as the hydrochloric acid and would not react completely with the magnesium, even though most of them had seen the magnesium completely dissolve in both acids in the laboratory. This misconception is common in the literature (Garnett et al., 1995) and may indicate a lack of understanding of chemical equilibrium. Students would need to understand that in the equation below



more ethanoic acid ( $\text{CH}_3\text{COOH}$ ) dissociates as hydronium ions ( $\text{H}_3\text{O}^+$ ) are removed by reaction with magnesium, until eventually all the acid has reacted.

It is interesting to note that in post-teaching acids and bases interviews, all students opted to represent their models by using acids as examples, not bases. This echoes the findings in the literature which suggested that compared with bases, acids are more likely to “stick out” in students' minds because the word “acid” is more likely to be in our everyday vocabulary (Ross & Munby, 1991).

The author also attempted to use student-constructed concept maps before and after the teaching of each topic to learn about student ideas. However, these maps provided no valid data because students did not have enough time to learn the skills concept mapping requires.

#### **7.4 What helped the students' mental models change for both topics?**

Because conceptual changes in students' mental models have occurred, it is useful here to examine the effectiveness of each of the four strategies employed by the teachers.

##### **7.4.1 Strategy 1**

The rationale behind interviewing students before the teaching of each topic was useful not only for establishing a "base-line", but also so the teachers could plan appropriately for their lessons. Because assimilation of a new concept, "occurs against the background of a learner's current concepts" (Posner et al., 1982, p. 212), teachers needed to know what mental models students relied on in order to plan activities that could potentially help them to accommodate new ideas and change their mental models.

The inability of most students to model the behaviour of particles in a beaker of boiling water in pre-teaching interviews suggested that knowledge of the sub-microscopic level was very limited to begin with. Students who did elect to model water molecules with dots or drawings mostly indicated incorrect distance between particles in a gas and a liquid (figure 6.3, 6.4, 6.5), and/or that the molecules changed size when phase change occurred (figure 6.1). The author and teachers in this study, armed with this information, planned activities to try and address this erroneous view of the sub-microscopic level if it was to be a "plausible, intelligible and fruitful" (Posner et al., 1982, p. 214) way for students to make sense of *chemical equilibrium* or *acids and bases*. This sentiment is echoed in a study published by Chittleborough et al. (2005). Subsequent to the completion of the practical parts of this study, Chittleborough et al. (2005) found that poor understanding of the sub-microscopic level actually hindered understanding of chemistry concepts.

Teachers found that knowledge of students' mental models of concepts in *chemical equilibrium* and *acids and bases* was very helpful in planning, because it helped them to focus on areas students had problems with. Pre-teaching ideas about *chemical equilibrium* meant the teachers concentrated on ways to dispel ideas of equilibrium as static and two-sided, rather than just launch into teaching the topic as they usually would (section 6.2.1).

For *acids and bases*, teachers knew that students' models of dilute and concentrated solutions were basically correct and that they needed to work on building students' knowledge of how to represent this at a sub-microscopic level. Teachers also knew that students had virtually no knowledge of strong and weak acids and bases, so planned to spend more class time on those concepts than they usually would. Students' ideas about neutralisation being a physical reaction surprised both the teachers and they decided that modelling the chemical reaction at a sub-microscopic level (strategy 3) would help students to see that new substances were formed when an acid and base reacted. Student conceptions influenced teacher planning significantly for both chemical equilibrium and acids and bases. It is likely that strategy 1 contributed to the changes in the students' mental models because the teachers took the life experiences of the students into account.

#### **7.4.2 Strategy 2**

It is difficult to tell if strategy 2 was effective in helping students change their mental models of chemical equilibrium, because in this cycle, teachers were still coming to grips with its implementation. Both teachers were learning to use the three levels of chemistry in a sequential fashion. While the teachers did plan their lessons so that the macroscopic, sub-microscopic and symbolic realms were covered in sequence and sometimes carried this out in lessons, teachers rarely, explicitly identified the move between levels to the students (section 5.2.2). Interestingly though, Gussarky and Gorodetsky suggest that a static view of chemical equilibrium indicates a deficiency in understanding of "the microscopic behaviour of a system" (1990, p. 202). Because students in this study *had* changed their mental models from static to dynamic, it seems that the mere presence of the

sub-microscopic level in teacher explanations may have helped the students change their mental models for chemical equilibrium.

By the time the teaching of *acids and bases* began, the teachers were more comfortable with employing this strategy, making the move between levels in their explanations explicit to the students about 50% of the time. Although the teachers differed in the way they implemented strategy 2 in this cycle (section 5.2.2), post-teaching interviews with students from the classes of both teachers revealed significant changes in students' models of concepts within the acids and bases topic (tables 6.4, 6.5, 6.6 and 6.7). Teachers did manage to make an excellent start in implementing strategy 2 over the teaching of chemical equilibrium and acids and bases, considering that they had seldom represented the sub-microscopic level in their previous lessons. Ideally, several more cycles would be needed for teachers to become really familiar with and fully implement this strategy.

Whether the implementation of the strategies in this study was complete or not, the mental models of the students did change for the better. Although a recent study (Bunce & Gabel, 2002) has found that girls in particular, benefit from the three realms of chemistry presented in a macroscopic, sub-microscopic, symbolic sequence, it would appear that the *inclusion* of explanations at the sub-microscopic level, even if not in the suggested sequence, was very helpful for students' learning in this study. Put in the context of Stinner's model of concept acquisition in science (1992) (see figure 2.5), one could speculate that the inclusion of explanations dealing with the sub-microscopic helped students to make the link between the evidential and logical planes. However, more evidence is needed to support this idea and it is beyond the scope of this study.

Like Bunce & Gabel (2002) though, it is the author's view that the macroscopic → sub-microscopic → symbolic sequence in the teaching of chemistry is the ideal, and the moves between these levels made explicit to students. If we are helping students to construct knowledge, it makes sense to start with familiar real life examples or reactions students can observe with the naked eye, and then make symbolic equations meaningful by modelling the particles the symbols represent.

### 7.4.3 Strategy 3

There is significant evidence to suggest that teachers modelling the behaviour of particles at the sub-microscopic level helped students to change their mental models in chemical equilibrium and acids and bases. Student responses about the dots in the post-teaching interviews were overwhelmingly positive (section 6.5.2). The students perceived the dots to be helpful in constructing understanding because they helped to make the invisible, visible. This attitude is reflected in the high degree of on-task behaviour during dot use in tables 6.10 and 6.11. When teachers modelled a reaction with the particle dots on the board, students seemed to be listening closely and were very keen to copy down the dot formations once the teacher had finished her explanation. It is worth noting that the few students who were off task during dot use such as Student 13 (table 6.10) displayed off task behaviour during a significant portion of the lesson, regardless of the activity.

Although teachers were still learning to integrate the dots into their explanations during the teaching of chemical equilibrium, it is feasible that the use of the dots as illustrated in figure 5.2 helped students to see an alternative to a two-sided, see saw view of equilibrium because reactants and products are pictured together. Teachers also tried to encourage students to dismiss the need for balance by using the formation of dots in figure 5.2 as a way of demonstrating an inequality in the concentrations of reactants and products at equilibrium. This might have contributed to students' building a mental model of equilibrium different to the one they began with. Moving the dots to mimic the breaking and forming of bonds, while keeping the same symbolic equation, may have helped students to change their mental model of chemical equilibrium from a static to dynamic one. In her reflections about the dots, Student 11 alluded to the way the dots helped her "*see the action*" (section 6.5.2). Similarly, Student 09 thought the dots helped her to "*imagine how they (atoms) combine together*".

Although several more cycles would be needed for teachers to be really proficient with the use of the dots, the students' mental models of acids and bases changed significantly. Even if students represented particles with symbols only, there seemed to be more of an awareness of the presence of, (Student 03, table 6.6), interaction between, (Student 11, table 6.7) and relative numbers of particles

(Student 07, table 6.6) in a solution. Often, both teachers moved the dots around to show interaction of particles during a chemical reaction and while one student found this distracting, many indicated that it helped them to imagine what was happening at a sub-microscopic level.

While students demonstrated a conceptual change in their mental models of concepts within both *chemical equilibrium* and *acids and bases*, students' ability to represent the sub-microscopic level still needs development. For *chemical equilibrium* none of the students in post-teaching interviews, elected to use the dots or even draw particles to illustrate their mental models in this topic. All either responded verbally or pointed to a symbolic equation to answer the interview questions. For *acids and bases*, again, no students elected to use the dots, but did draw particles or respond verbally to the questions. Lack of particle representation in the post-teaching *chemical equilibrium* interviews could be attributed to the abstract nature and complexity of the topic, incorrect mental models of the sub-microscopic level (although this is contrary to students' verbal responses), and/or that students were not used to using the dots. It also may have been helpful for students to introduce this strategy in an easier, more straightforward topic. Improved ability to model the sub-microscopic level by drawing particles in the post-teaching acids and bases interviews may indicate that this topic is less abstract, and/or a growing familiarity with the sub-microscopic level of chemistry. Increased teacher confidence in modelling may have also contributed to students' increased representation of particles. The most likely explanation for students' lack of modelling with dots may be found in the recent work of Chittleborough et al. (2005) who investigated the modelling ability of non-major university chemistry students. Results of this study suggest that "continuous use of models and representations have been shown to be advantageous to helping students to gain an appreciation of the sub-microscopic level of matter" (p. 38). Although students in the author's study were regularly *shown* models of the sub-microscopic level by their teacher, students were rarely offered or took the opportunity *to model with* the dots themselves. In class, students tended to draw pictures of the dots the teacher had arranged on the whiteboard and this behaviour was mimicked in the post-teaching interviews for *acids and bases*. Chittleborough et al. (2005) suggest that the skill of modelling

needs to be taught to students explicitly at first, instead of being taught indirectly when it is used to explain a concept. Future studies could examine whether learning how to model and the increased use of models by students improved their understanding of the sub-microscopic level in year 12 chemistry.

To begin with, role plays were generally not well received by students and this can be attributed to a number of factors. Teachers had not used role plays before so students and teachers were unfamiliar with this strategy, most chemistry classes were after lunch when students were more likely to be sleepy and not want to move from their seats and in cycle 1, the role plays were probably too long. All students were off task for a significant part of the role play in the class of Teacher 1 (table 6.8) and although most students were on task in the class of Teacher 2 (table 6.9), students took part in the activity with some reluctance. Although the writer and teachers thought that role plays would be an ideal way of demonstrating the dynamic nature of *chemical equilibrium*, it is interesting to note that in post-teaching interviews, some students who were positive about the role plays indicated that they helped the students to *remember* rather than *understand* the activity (section 6.5.1). While it is difficult to know whether students' use of these words was intentional, it was clear that some of the students who used the word *remember*, did seem to change their *understanding*. An example is Student 15 who indicated in pre-teaching interviews that:

*"Equilibrium means balanced sort of, it's like two things balancing and they have the same amounts of energy or weight"* (ST15, 17/06/04),

but had changed her ideas by post-teaching interviews took place:

*"(Physics) "is kind of the opposite really. Physics is like a see saw, but chemistry, it looks like it's (the reaction) stopped, but it hasn't really"* (ST15INT, 27/08/04).

Because role plays offered another way of modelling the target (the sub-microscopic level) as recommended by many authors (Gilbert & Ireton, 2003; Harrison & Treagust, 2000a, 2000b; Justi & Gilbert, 1999; van Driel & Verloop,

1999), it is possible that role plays helped to illustrate another aspect of the sub-microscopic level that dots could not. Although students of Teacher 2 became less reluctant to take part in the role plays in this cycle, there is not sufficient evidence to establish whether the use of this strategy aided student learning in acids and bases, since Teacher 1 did not use them in this cycle.

It must be noted that there are many different ways of representing the sub-microscopic level of chemistry. In this study, dots and role plays were used because they were readily available and manageable. Modelling the sub-microscopic level using computer animations of molecules, 3 dimensional molymod models, small magnets or even balloons can all be useful in helping students to construct mental models for concepts at this level.

#### 7.4.4 Strategy 4

Although several authors recommend analysis of the strengths and weaknesses of expressed models (Chittleborough et al., 2005; Gilbert & Ireton, 2003; Tredidgo & Ratcliffe, 2000) and this was the essence of strategy 4, teachers barely touched on this aspect of modelling during the teaching of chemical equilibrium (section 5.2.2). The most likely explanation for this is that the teachers may have been overloaded with implementing strategy 2 and 3 as well as coping with being involved in a research project and having an observer in their classroom. In the second cycle, when teachers were more comfortable with the action research process and had become more familiar with the strategies they were implementing, they did encourage discussion of the limitations of the dots and the role plays with their students and this was revealed in post-teaching interviews with students. For example, Student 09, when talking about modelling with dots commented that

*“even though they’re not really like atoms, ‘cause they’re flat, they do help a lot” (ST09INT, 27/08/04),*

and Student 07 recognised that in a chemical reaction there are really

*“millions and millions of molecules, not just five or six” (ST07, 27/08/04).*

## 7.5 Summary

The outcomes of this action research study can be summarised as follows. Conceptual change was apparent for both teachers and students during the study. Teachers began to employ four new strategies to improve teaching and learning in their year 12 chemistry classes. More time is needed for the teachers to employ these strategies fully, as conceptual change is a gradual process. The teachers became more reflective as the study progressed and let their reflections influence future planning and teaching. The action research process was practical and useful in providing a structure within which to trial the new strategies. Conceptual change in students' mental models of concepts within *chemical equilibrium* and *acids and bases* was apparent after teaching even though teachers had not fully employed the four strategies. Modelling the sub-microscopic level of chemistry was particularly helpful for students to construct understanding in these topics.

## **CHAPTER EIGHT – CONCLUSIONS AND RECOMMENDATIONS**

### **8.1 Introduction**

Chapter eight summarises the outcomes of this study in terms of the action research process and the changes that occurred in students' mental models. The implications for teaching and assessment arising from the findings of this study are also stated. The limitations of the study are examined and suggestions made for future research projects in this area.

### **8.2 Major findings of the study**

#### **8.2.1 Was the action research process useful and practical?**

The action research process was well suited to the implementation of the new teaching strategies in this study. Cycles of planning, action, observation and reflection gave the teachers a strong but flexible structure in which they felt safe to trial and modify new strategies in their classrooms. The reflection phase of action research was particularly useful in that it formalised the post-teaching ideas teachers had about how their lessons had gone. These ideas were shared, clarified and then used to inform planning for the proceeding lessons and/or topic. Time spent in group planning was also very valuable for a number of reasons. Teachers had the opportunity to brainstorm, consider other's ideas and be encouraged by others to try things they hadn't tried before.

Upon reflection, the author concludes that there are four main issues to be considered when teachers become involved in action research:

1. It takes time to get into the rhythm of the action research process. Although this study took place over 3 school terms, and 2 cycles were completed, many more cycles are needed for the teachers to become fully confident with the process and its implementation.
2. Teachers need time away from their classes to think and plan, ideally in groups with other teachers so that brainstorming and sharing of ideas can take place. Much of the planning for the two topics in this study took place late in the afternoon and had to fit around sports practices and the teachers' other school commitments.

3. Teachers need to be passionate about or at least interested in the objective of the study. Even though this study was initiated by an outside researcher, the teachers were keen to implement the new strategies partly because they had already heard about them at a conference and thought they were a good idea.
4. Teachers need to implement new ideas gradually and as time and inclination allow. Too many ideas at once may overwhelm the teacher, disrupting their classes and lead to the eventual downfall of the whole process.

### **8.2.2 Did the teachers change their teaching strategies?**

As a result of the action research process, the four teaching strategies developed in this study were:

- |            |  |
|------------|--|
| Strategy 1 | Using the information from pre-teaching student interviews (and sometimes literature) to inform planning for each topic.   |
| Strategy 2 | Use the three levels of chemistry concepts sequentially, exploring the macroscopic level, then sub-microscopic level, and lastly the symbolic level of a concept, and making this process explicit to students during lessons. |
| Strategy 3 | Modelling the behaviour of particles at the sub-microscopic level using magnetic cardboard dots or student role plays during lessons.  |
| Strategy 4 | Drawing students' attention to the limitations of these concrete models, or any others used during lessons.  |

The teachers employed the four new strategies to varying degrees. While both teachers used strategy 1 during this study, neither uses it currently. The teachers used the students' ideas to inform their planning during the study but do not have the luxury of time to interview students before the teaching of other topics. While reading current science education literature may help to get an idea of students' mental models for a particular topic, it is possible that other, less time-consuming

methods of eliciting student ideas such as concept maps and concept cartoons might be useful to these teachers in the future.

For one teacher in particular, the implementation of strategy 2 improved as the study progressed and probably took the most effort to put into practice for both teachers. Teachers found they needed to be very purposeful about planning and teaching in this sequence, because it was a completely new concept, very different to what they had done in the past. The teachers themselves were changing their mental models of the way they taught chemistry concepts.

Strategy 3 seemed to be the most manageable to implement and was used by the teachers even if the sequence in strategy two was not followed. Both teachers currently use the cardboard dots and one of the teachers finds the role plays very useful for modelling particles or processes not easily seen with the naked eye.

While central to any use or discussion of models, strategy 4 was not employed to any great extent until the second cycle. This could be evidence of the teachers becoming overwhelmed by implementing four strategies simultaneously. It is the author's opinion that the teachers need more time to come to terms with the limitations of models *per se* before they feel comfortable to employ this strategy.

### **8.2.3 Did the students mental models for chemical equilibrium and acids and bases change? Why?**

While pre-teaching student ideas about *chemical equilibrium* and *acids and bases* were similar to current science education literature, overall, there was a marked change in students' models in post-teaching interviews. For *chemical equilibrium*, most students moved from a static, two-sided view of equilibrium, to a dynamic system of reactants and products with two reactions happening at the same time and at the same rate. Students recognised that changes made to the conditions in an equilibrium system affected all species and that the concentrations of reactants and products at equilibrium were very unlikely to be the same. Although some students understood the equilibrium constant to be a ratio of products to reactants, most students' understanding of equilibrium expressions and their purpose was limited. This is possibly because such a small

portion of the topic is spent on equilibrium expressions. Students' mental models of *acids and bases* changed substantially from one which described acids and bases in terms of their pH to one which recognised the relative numbers, presence and interaction of particles. This was demonstrated in students' drawings of strong, weak, concentrated and dilute acids.

Interestingly, although the cardboard dots were used extensively in both cycles, none of the students elected to use the cardboard dots to model particles in post-teaching interviews. The most likely reason for this is that students did not have enough opportunity to use them during lessons. Students need to practise modelling in order to become proficient at it. Instead, students watched their teacher model particle interaction with the dots and then drew the models in their notes. This was reflected in their pictures of particles in post-teaching acids and bases interviews.

It is difficult to accurately pinpoint the reasons for the changes in students' mental models in this study, because teachers were still learning to use the strategies and although both teachers made a sterling effort, none of the strategies was fully implemented by the end of the second cycle. However, evidence from student interviews indicates that the teachers' explanations at the sub-microscopic level, whether in sequence or not, and use of the cardboard dots most likely helped the students to change their mental models for *chemical equilibrium*, and *acids and bases*. The author also acknowledges that conceptual change is gradual and slow, with students sometimes retreating to old conceptions. Ideally the students in this study should be re-interviewed annually to establish whether their mental models for these topics have further developed, or regressed.

### **8.3 What are implications for teaching and assessment?**

In reviewing the outcomes of this study and recent literature, the author recommends taking the following points into consideration when planning and teaching year 12 chemistry topics:

1. Before teaching starts, find out what students know about concepts within the topic so as to plan effectively. Although interviewing

students may not be possible, teaching students to use concept maps and using these to elicit student ideas could be helpful.

2. Help students to build knowledge by starting with a concept that is familiar to them. If there is nothing familiar, start with an activity that is directly observable, *ie.* an activity which demonstrates the macroscopic level of chemistry.
3. If possible, try to follow the macroscopic, sub-microscopic, symbolic sequence. For example, instead of asking students to write symbolic equations for reactions they have seen during practical work, help them to first model the sub-microscopic level with role-plays, computer animations, cardboard dots, *molymod* models, drawings, or even balloons. The last step is to symbolise these models with a chemical equation and link the three levels together.
4. Make the three levels of chemistry explicit to students and let them know when changing from one level to another during explanations.
5. Teach students about the nature of expressed models and their limitations, providing opportunities for them to practice modelling the sub-microscopic level with a variety of aids.
6. Encourage group discussion and metacognition. Students need opportunities to become aware of their changing ideas and compare and contrast them with the ideas of others.

The implications for assessment also need consideration. From one perspective, traditional chemistry assessments where students are asked to complete questions about the macroscopic and symbolic levels should be less of a problem for students if the strategies from this study are employed in chemistry classrooms. On the other hand, teachers need to question whether this type of assessment really assesses student understanding. It is possible that assessments, part of which require students to demonstrate their ability to model the sub-microscopic level, would better demonstrate their mental models of chemistry concepts.

#### **8.4 Limitations of the study**

In hindsight, this study was quite ambitious. Not only did the author and teachers decide on the strategies they would use to improve the teaching of *chemical*

*equilibrium*, and *acids and bases*, they also began to implement and make judgements about the efficacy of them. In addition to these tasks, teachers also had to make sense of a completely unfamiliar research methodology. Similarly, although the author had studied action research methodology in theory, it is quite challenging to then implement this approach for the first time. Ideally, the teachers and author needed to have significantly more time to become familiar with the action research process.

Teachers also needed more time to introduce the new strategies. In introducing these strategies, the teachers were trying something completely unfamiliar. Depending on the individual teacher and the nature of the topics, it may be better to gradually introduce one or two strategies at a time over four or five topics. In the same vein, although the teachers used all the strategies at least some of the time, it was difficult to assess the effectiveness of the new strategies when they were not fully implemented by the end of the study.

The choice of *chemical equilibrium* and *acids and bases* as topics for this study was made out of necessity rather than preference. The author had to accommodate the topics the teachers were to teach during the time of the study. Although *acids and bases* is a relatively straight-forward topic, *chemical equilibrium* is highly abstract in comparison. In hindsight, it would have been less challenging for teachers and students to employ new strategies for an “easier” topic, before using them in the teaching of *chemical equilibrium*.

The major limiting factor in this study was its short duration. Ideally, more time would have been spent educating teachers about the action research process and trialling the four strategies before teaching began. More time for metacognition for both teachers and students would also have been advantageous in this study. Although both teachers and students appeared to undergo some form of conceptual change, they needed more time to develop an awareness of *how* and *why* their ideas had changed. A study of longer duration would also have allowed time for students to become familiar with new assessment techniques such as concept mapping. Although the author attempted to use student-constructed concept maps before and after the teaching of each topic, to learn about student

ideas, these maps provided no valid data because students had not had enough time to learn the skills for effective concept mapping.

### **8.5 Recommendations for further research**

Possibilities for future research are endless, but some suggestions are mentioned here. An extension of this study which explores student ideas about *chemical equilibrium* and *acids and bases* longer term would show whether conceptual change has really occurred or whether students have regressed to old ideas. It would also be very interesting to find whether increased student modelling of the sub-microscopic level had an effect on their understanding of this level. Students could begin modelling as early as primary school.

More work needs to be done investigating student ideas about the quantitative aspects of *chemical equilibrium* and *acids and bases*. For *chemical equilibrium* it would be interesting to concentrate on student ideas of rates of reaction approaching, and at equilibrium, and ways to model these phenomena at the sub-microscopic level. For *acids and bases*, investigating the use of the strategies employed in this study to help students understand titration curves and buffers would be very useful.

### **8.6 Concluding remarks**

Teaching and learning chemistry is not easy. However it is hoped that teachers can examine their teaching practice in light of the findings in this study. Instead of expecting students to somehow imbibe the chemistry knowledge they need to pass assessments, we need to become familiar with students' pre-teaching ideas and let these influence our planning. We then need to help students construct knowledge, helping them recognise and make the links between the macroscopic, sub-microscopic and symbolic realms of chemistry concepts. Implicit in this approach is helping students learn about modelling and the limitations of expressed models and providing students with opportunities to model the sub-microscopic aspect of chemistry phenomena. While this approach may not suit all chemistry topics, it has the potential to substantially reduce many of the difficulties chemistry students have.

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## **Research on developing strategies for the teaching of Year 12 Chemistry**

### INFORMATION SHEET FOR PRINCIPAL AND BOARD OF TRUSTEES

My name is Lauren Downs and I am a secondary school science teacher enrolled in the Master of Education programme at Massey University, Palmerston North. I am about to embark on some research for my thesis which has a focus on developing effective teaching strategies for secondary school chemistry.

#### **My objectives are to:**

1. find what perceptions some Year 12 chemistry students hold for two Year 12 chemistry topics
2. develop effective teaching strategies for these topics
3. gauge the success of these teaching strategies
4. produce refined, practical teaching strategies for use by chemistry teachers

The research would involve ten students from each Year 12 chemistry class. Students would be asked to answer open-ended questions about two chemistry topics – before, during and after they have been taught these by their classroom teacher. Student responses would be recorded on audio tape. Students would also be observed by me during their chemistry lessons. It is likely this would all take place in term 3 of this year.

The data collected will help me to identify which teaching strategies used by the teacher will help students to understand chemistry concepts.

#### **My requirements for the research are:**

1. one or two Year 12 chemistry teachers who will work with me to plan lessons for the two concepts. This would take place at the end of term 2.
2. ten students from each of the chemistry teachers' classes who would be willing to be interviewed in pairs for a total of six twenty minute sessions (during class or study time). These students would also be observed in their class. This would involve me observing from the back of the classroom with minimal interruption to the lessons, writing notes and recording some parts of the lesson or student comments on audio tape.

### **Recruitment of teacher and students for study**

After consent has been obtained from the principal and board of your school, the teacher and students would be recruited by me for the study. This would be done by meeting with the Year 12 Chemistry teacher(s) in your school and presenting them with an information sheet detailing the objectives and requirements of the study. This information would then be left with the teacher(s) to consider. If a teacher wishes to be involved in the study, they can contact me using the details provided on the information sheet.

Once the teacher has consented to being involved in the study, students will be recruited. The students would be visited by me during class time (at the teacher's discretion) and an information sheet supplied to each student detailing the objectives and requirements of the study. Students will have the opportunity to ask me any questions they have about any aspect of the study.

Ten students will be randomly selected from the class to take part in the study using the following process. All students will be given a small piece of paper and the students wishing to take part will write their name on the paper and fold it in two. Students not wishing to take part in the study will leave the paper blank and fold it in two and in this way will remain anonymous. All papers will then be collected and placed in a hat. The first ten names drawn out will be the participants providing they agree to sign a consent form. The remaining papers in the hat will be destroyed. In a case where the student is fifteen years or younger, written consent will also be required from the parent(s)/caregiver(s).

### **Confidentiality and anonymity**

Every effort will be made to protect confidentiality and anonymity for participants and the research will be conducted according to Massey University Ethics Committee guidelines. Data collected during the study will remain confidential unless otherwise agreed upon in advance. It will be coded in the final report so that the students, teacher and school remain anonymous. Data collected will be made available to the teacher with the exception of data containing student identifying information. A copy of the final report will be sent to the principal, board and the teacher.

If you agree to take part in this research project, the teacher or students involved have the right to withdraw at any time and refuse to provide answers to any of the questions they are asked. I am happy to provide copies of the information sheet and participant consent form for teachers and students if you would like to see them.

This project has been reviewed, judged to be low risk and approved by peer review under delegated authority from the Massey University Human Ethics Committee. If you have any concerns about the conduct of this research, please contact Professor Sylvia Rumball, assistant to the Vice-Chancellor (Ethics and Equity), telephone 06 350 5249, email: [humanethics@massey.ac.nz](mailto:humanethics@massey.ac.nz).

Appendix 1: Information sheet for Board of Trustees and Principal

I look forward to your reply. Should you need further clarification of any aspects of the project, please do not hesitate to contact me using the details below. Please feel free to contact my Massey University College of Education supervisor also if you wish. His contact details are also listed below.

Thank you for your time

Sincerely

Lauren Downs

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## Research on developing strategies for the teaching of Year 12 Chemistry

### INFORMATION SHEET FOR TEACHERS

My name is Lauren Downs and I am a secondary school science teacher enrolled in the Master of Education programme at Massey University, Palmerston North. I am about to embark on some research for my thesis which has a focus on developing effective teaching strategies for secondary school chemistry.

#### My objectives are to:

1. find what perceptions some Year 12 chemistry students hold for two Year 12 chemistry topics
2. develop effective teaching strategies for these topics
3. gauge the success of these teaching strategies
4. produce refined, practical teaching strategies for use by chemistry teachers

The research would involve ten students from each Year 12 chemistry class. Students would be asked to answer open-ended questions about two chemistry topics – before, during and after they have been taught these by their classroom teacher. Student responses would be recorded on audio tape. Students would also be observed by me during their chemistry lessons. It is likely this would all take place in term 3 of this year.

The data collected will help me to identify which teaching strategies used by the teacher will help students to understand chemistry concepts.

#### My requirements for the research are:

1. two Year 12 chemistry teachers who will work with me to plan lessons for the two concepts.
2. ten students from the chemistry teacher's class who would be willing to be interviewed in pairs for six twenty minute sessions of class time and observed in the classroom. This would involve me observing from the back of the classroom with minimal interruption to the lessons, writing notes and recording some parts of the lesson or student comments on audio tape.

#### Recruitment of teacher and students for study

Now that consent has been obtained from the principal and board of your school, two teachers and ten students from each of their classes can now be recruited by me for the study. This information sheet will be left with you to consider. If you wish to be involved

## Appendix 2: Information sheet for teachers

in the study, or have any questions about the study, please feel free to contact me using the details provided on this sheet.

Once you have consented to being involved in the study, students will be recruited. The students would be visited by me during class time (at the teacher's discretion) and an information sheet supplied to each student detailing the objectives and requirements of the study. Students will have the opportunity to ask me any questions they have about any aspect of the study.

Ten students will be randomly selected from each class to take part in the study using the following process. All students will be given a small piece of paper and the students wishing to take part will write their name on the paper and fold it in two. Students not wishing to take part in the study will leave the paper blank and fold it in two and in this way will remain anonymous. All papers will then be collected and placed in a hat. The first ten names drawn out will be the participants providing they agree to sign a consent form. The remaining papers in the hat will be destroyed. In a case where the student is fifteen years or younger, written consent will also be required from the parent(s)/caregiver(s).

### **Confidentiality and anonymity**

Every effort will be made to protect confidentiality and anonymity for participants and the research conducted according to Massey University Ethics Committee guidelines. Data collected during the study will remain confidential unless otherwise agreed upon in advance. It will be coded in the final report so that the students, teacher and school remain anonymous. Data collected will be made available to the teacher with the exception of data containing student identifying information. A copy of the final report will be sent to the principal, board and the teachers.

If you agree to take part in this research project, you and the students involved have the right to withdraw at any time and refuse to provide answers to any of the questions they are asked.

This project has been reviewed, judged to be low risk and approved by peer review under delegated authority from the Massey University Human Ethics Committee. If you have any concerns about the conduct of this research, please contact Professor Sylvia Rumball, assistant to the Vice-Chancellor (Ethics and Equity), Telephone 06 350 5249, email: [humanethics@massey.ac.nz](mailto:humanethics@massey.ac.nz).

I look forward to your reply. Should you need further clarification of any aspects of the project, please do not hesitate to contact me using the details below. Please feel free to contact my Massey University College of Education supervisor also if you wish. His contact details are also listed below.

Thank you for your time

Sincerely

Mrs Lauren Downs

## Appendix 2: Information sheet for teachers

41 Cashmere Rd  
Mathematics Education  
Cashmere  
Christchurch  
ph 332 6228  
email: [downslc@xtra.co.nz](mailto:downslc@xtra.co.nz)

**Supervisor:**  
Mr. Bill Macintyre  
Dept. Technology, Science &

Massey University College of Education  
Private Bag 11 222  
Palmerston North  
ph (06) 356 9099  
email: [W.R.Macintyre@massey.ac.nz](mailto:W.R.Macintyre@massey.ac.nz)



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F 64 6 351 3472

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**Research on developing strategies for the teaching of chemistry.**

**PRINCIPAL/BOARD CONSENT FORM**

I/we have read the information sheet and understand the details of this study. Any queries I have about the research have been answered to my satisfaction, and I understand I may ask further questions at any time.

I/we understand that students have the right to withdraw from the study at any time.

I/we understand that the teacher involved has the right to withdraw from the study at any time.

I/we understand that Lauren Downs will do all she can to protect the confidentiality and anonymity of the students, teacher and school.

The board and principal agree to participate in this study under the conditions set out in the information sheet.

I/we agree to allow \_\_\_\_\_ to participate  
in \_\_\_\_\_

Name of school

this study which will be carried out according to the conditions in the information sheet.

Signed:

Name:

Date:



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**Research on developing strategies for the teaching of chemistry.**

**TEACHER PARTICIPANT CONSENT FORM**

I have read the information sheet and understand the details of this study. Any queries I have about the research have been answered to my satisfaction, and I understand I may ask further questions at any time.

I understand I have the right to withdraw from the study at any time.

I will give my first name on the understanding that this will not be used without permission.

I understand that Lauren Downs will do all she can to protect my confidentiality and anonymity and that of the students and school.

I agree to participate in this study under the conditions set out in the information sheet.

I \_\_\_\_\_ agree to participate in  
Name of teacher

this study which will be carried out according to the conditions in the information sheet.

Signed:

Name:

Address:

Phone:

Date:



**Massey University**

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## **Research on developing strategies for the teaching of Year 12 Chemistry**

### INFORMATION SHEET FOR STUDENTS

My name is Lauren Downs and I am a secondary school science teacher enrolled in the Master of Education programme at Massey University, Palmerston North. I am about to embark on some research for my thesis which has a focus on developing effective teaching strategies for secondary school chemistry.

#### **My objectives are to:**

1. find what perceptions some Year 12 chemistry students hold for two Year 12 chemistry topics
2. develop effective teaching strategies for these topics
3. gauge the success of these teaching strategies
4. produce refined, practical teaching strategies for use by chemistry teachers

The research would involve ten students from each year 12 chemistry class. Students would be asked to answer open-ended questions about two chemistry topics – before, during and after they have been taught these by their classroom teacher. Student responses would be recorded on audio tape. Students would also be observed by me during their chemistry lessons. It is likely this would all take place in term 3 of this year.

The data collected will help me to identify which teaching strategies used by the teacher will help students to understand chemistry concepts.

#### **My requirements for the research are:**

1. two Year 12 chemistry teachers who will work with me to plan lessons for the two concepts.
2. ten students from each of the chemistry teacher's classes who would be willing to be interviewed in pairs for six twenty minute sessions of class time and observed in the classroom. This would involve me observing from the back of the classroom with minimal interruption to the lessons, writing notes and recording some parts of the lesson or student comments on audio tape.

#### **Recruitment of teacher and students for study**

Consent has been obtained from the principal and board of your school, and your chemistry teacher. Now is the time for students to be recruited by me for the study. This information sheet will be left with you to consider. If you have any questions about the study, please feel free to contact me using the details provided on this sheet.

## Appendix 5: Information sheet for students

Ten students will be randomly selected from the class to take part in the study using the following process. All students will be given a small piece of paper and the students wishing to take part will write their name on the paper and fold it in two. Students not wishing to take part in the study will leave the paper blank and fold it in two and in this way will remain anonymous. All papers will then be collected and placed in a hat. The first ten names drawn out will be the participants providing they agree to sign a consent form. The remaining papers in the hat will be destroyed. In a case where a student is fifteen years or younger, written consent will also be required from your parent(s)/caregiver(s).

### **Confidentiality and anonymity**

Every effort will be made to protect confidentiality and anonymity for participants and the research conducted according to Massey University Ethics Committee guidelines. Data collected during the study will remain confidential unless otherwise agreed upon in advance. It will be coded in the final report so that the students, teacher and school remain anonymous. Data collected will be made available to the teacher with the exception of data containing student identifying information. A copy of the final report will be sent to the principal, board and your teacher.

If you agree to take part in this research project, you have the right to withdraw at any time and refuse to provide answers to any of the questions you are asked.

This project has been reviewed, judged to be low risk and approved by peer review under delegated authority from the Massey University Human Ethics Committee. If you have any concerns about the conduct of this research, please contact Sylvia Rumball, assistant to the Vice-Chancellor (Ethics and Equity), telephone 06 350 5249, email: [humanethics@massey.ac.nz](mailto:humanethics@massey.ac.nz).

Should you need further clarification of any aspects of the project, please do not hesitate to contact me using the details below. Please feel free to contact my Massey University College of Education supervisor also if you wish. His contact details are also listed below.

Thank you for your time

Sincerely

Mrs Lauren Downs

41 Cashmere Rd  
Mathematics Education  
Cashmere  
Christchurch  
ph 332 6228  
email: [downslc@xtra.co.nz](mailto:downslc@xtra.co.nz)

### **Supervisor:**

Mr. Bill Macintyre  
Dept. Technology, Science &

Massey University College of Education  
Private Bag 11 222  
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**Research on developing strategies for the teaching of chemistry.**

**STUDENT PARTICIPANT CONSENT FORM**

I have read the information sheet and understand the details of this study. Any queries I have about the research have been answered to my satisfaction, and I understand I may ask further questions at any time.

I understand I have the right to withdraw from the study at any time.

I will give my first name on the understanding that this will not be used without permission.

I agree to interviews being audiotaped

I understand that I have the right to check a transcript of my responses to the interview questions administered by Lauren Downs.

I understand that I can decline to answer an interview question at any time

I wish/do not wish to have audiotapes returned to me at the end of the study or if I withdraw from the study at any time

I understand that Lauren Downs (the researcher) will do all she can to protect my confidentiality and anonymity.

I agree to participate in this study under the conditions set out in the information sheet.

I \_\_\_\_\_ agree to participate in  
Name of student

this study which will be carried out according to the conditions on the information sheet and above.

Signed:

Name:

Date:

Appendix 7: Example of open observation

Observation notebook ①

6/08/04  
1st equilibrium lesson  
Teacher

Start off

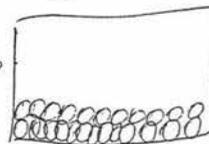
What comes to mind when equilibrium is mentioned?  
equal  
equation - reactants & products

teacher - not necessarily everything is equal

- teacher explains macro, sub-micro, takes what need for "picture in mind" of what's going on at micro level -
- students fired, a bit chatty, some scribbling in diary
- move desk away and students role play particles in a solid.

students describe particles in solid touching, compact, vibrating, claustrophobic

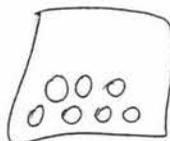
teacher draws →



particles are uniform and touching

⑦

heat up solid → particles vibrate



teacher represents what students have done

what is in b/w?

(S) air, space, excess H and O

(+) Synnyses

(2)

You can compress air in syringe but cannot compress liquid

(S) "You can compress air because there are spaces b/w particles"

coq. correct.

Students then correct their model and roll past each other. They just move a bit more

(T) heat up liquid further. What happens?

(S) move faster, jostling

(T) turn into gas

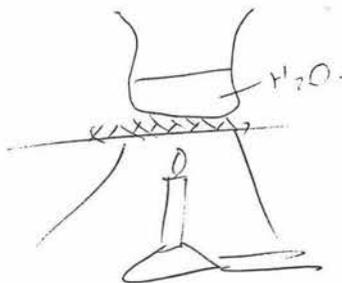
(S) bump into each other, collide with walls

(T) what is in the space b/w molecules.

We know there is nothing because gas can be compressed.

I teacher sets up demo.

③.



Students agreed - oh we've never seen water evaporate Bt.

Q What happens as water is heated?

S Bubbles at bottom - closest to heat.

T What is in bubbles?

S air, oxygen.

T Is this system at equilibrium

S no because no lid some  $H_2O$  molecules can escape

T put lid on - what will happen?

S condensation

T if burner is taken away

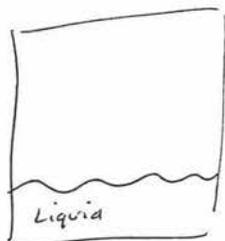
Unfortunately no replay of this demo.

Teacher also makes mistake & calls bubbles "air"

(1) Notes on board. - students chatting as they write - not concentrated (4)

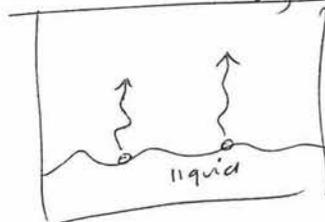
## Chemical equilibria

Equilibrium in a change of state.



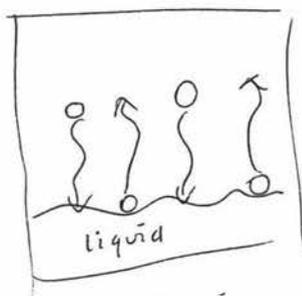
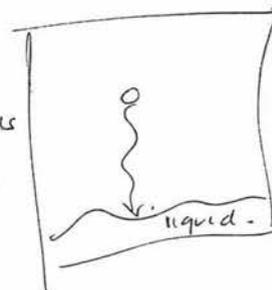
closed system

In a liquid in a closed system some molecules will have enough energy to escape into the gas. In the gas above the liquid, some molecules will lose energy & fall into the liquid.



the liquid

This system can reach equilibrium when the rate at which molecules form a gas equals the rate at which molecules fall into the liquid.



equilibrium

class quiets down and seems to concentrate more now. (S)

(T) Another example of physical equilibrium holds up sodium chloride dissolved in  $H_2O$ . When no ~~more~~ more dissolved it's called . . . -

(S) saturated.

solid at bottom and liquid

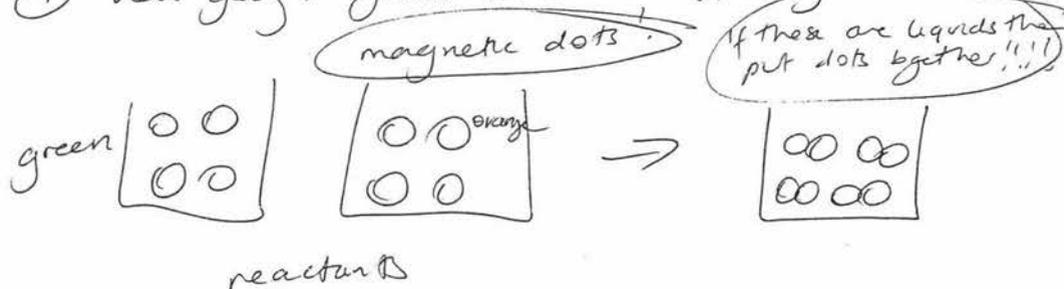
When a system is at eqm you can't see anything happening. level of liquid stays the same (going back to  $H_2O$  example).

(T) What processes are happening in sat sol<sup>n</sup>.

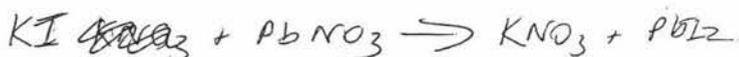
(T) Some are dissolving

(S) Some are solidifying (recrystallizing).

(T) now going to focus on what's happening in chem rxn

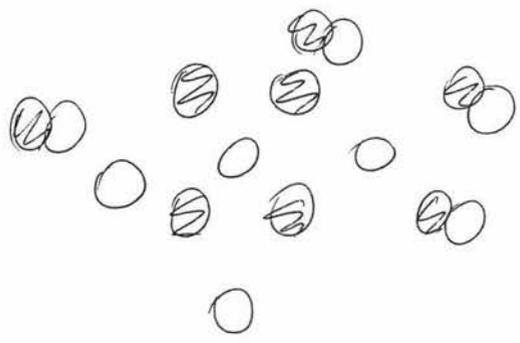
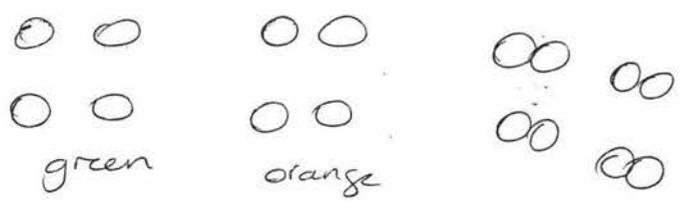


First do complete react



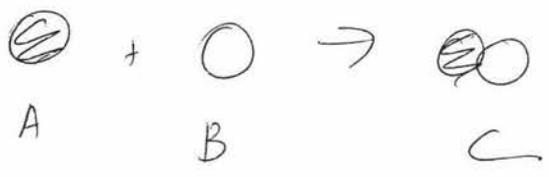
④ In an equilibrium system there's reactants still there & products.

⑥



break up at same rate as they get together

(This could give students idea that at eqm conc. are equal of r & p)



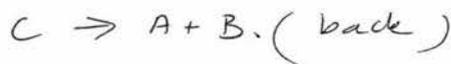
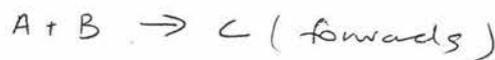
introduce  $\rightleftharpoons$

Chemical equilibria

In a chemical equilibrium the rxn doesn't go to completion. At eqm there will be a mixture of reactants and products.  $A + B \rightleftharpoons C$

Chemical equilibrium is a dynamic equilibrium (7)

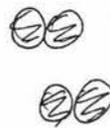
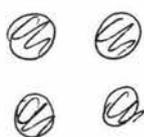
This means that reactions continue to occur



At equilibrium the rate of the forwards reaction equals the rate of the backwards rxn

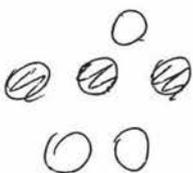
ratio

$$\frac{2 \text{ prod}}{4 \text{ react.}} = 0.5$$



4 reactants  
2 products

$$\frac{1 \text{ prod}}{6 \text{ react.}} = 0.167$$



diff no. of molecules

(7)

How much A, B & C will there be at eqm? If we change amount of reactants, ~~the~~ depends on rxn. You can measure by K (eqm constant)

$$K = \frac{[\text{prod}]}{[\text{reactant}]} = \text{ratio}$$

The eqm constant is characteristic of a particular chemical rxn.

Appendix 8: Example of structured observation

Student		Student	
1. A	6. F	1. A	6. F
2. A	7. A	2. A	7. A
3. A	8.	3. A	8.
4. A	9.	4. A	9.
5. D	10	5. D	10

Student		Student	
1 A	6 F	1 A	6 F
2 A	7 A	2 A	7 A
3 A	8	3 A	8
4 A	9	4 A	9
5 D	10	5 D	10

Student		Student	
1. A	6. F	1. A	6. F
2. A	7. A	2. A	7. A
3. A	8.	3. A	8.
4. A	9.	4. A	9.
5. D	10	5. D	10

Student		Student	
1 A	6 F	1 A	6 F
2 A	7 A	2 A	7 A
3 D	8	3 D	8
4 A	9	4 A	9
5 D	10	5 D	10

Student	
1. D	6. F
2. A	7. D
3. D	8.
4. A	9.
5. D	10

Student		Student	
1 A	6 F	1 A	6 F
2 A	7 A	2 A	7 A
3 A	8	3 A	8
4 A	9	4 A	9
5 D	10	5 D	10

Student		Student	
1 A	6 F	1 A	6 F
2 A	7 A	2 A	7 A
3 A	8	3 A	8
4 A	9	4 A	9
5 D	10	5 D	10

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teacher's desk

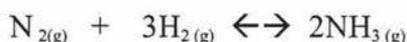
Teacher 1.  
Equilibrium lastless  
A - on task, discuss with T  
B - on task, doing A  
C - talking about topic  
D - chatting

Chemical Equilibrium pre-teaching interview questions

1. If I say the term, chemical equilibrium – what does it mean, what does it make you think of?
2. Show students demonstration with water boiling in a sealed container on a hot plate.  
Please explain what is happening to the water in this container.
3. Imagine you could see the water “up close”. What would you see?  
Can you use these cardboard dots to show me what you think is happening? If not, could you draw what you imagine is happening?
4. what would it look like up close

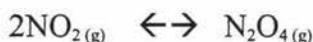
Chemical Equilibrium Post-teaching Interview Questions

1. What is chemical equilibrium?
2. Has your understanding of chemical equilibrium changed since the first interview? How?
3. What does the double arrow show?
4. a) Did you notice that your teacher used some new teaching strategies in your lessons?  
b) What were they?  
c) What did you think of them – were they helpful to you or not?  
d) What would you change about the lessons?
5. What is Kc? What does it mean?
6. What can you tell me about the concentration of reactants and products at equilibrium?
7. Here is a reaction which shows the production of ammonia (NH<sub>3</sub>) in the Haber process.



Which side of the reaction should I apply pressure to in order to increase the production of ammonia in the Haber process?

8. a) Brown nitrogen dioxide gas (NO<sub>2</sub>) and colourless dinitrogen tetroxide gas (N<sub>2</sub>O<sub>4</sub>) are in equilibrium in the reaction below.  
If the temperature of the system increases, what will be favoured, reactants or products?



- b) In class, your teachers and some of the students modelled this reaction with cardboard dots on the board. Do you think you could try this now?
- c) Can you model any equilibrium reactions you know with the dots or drawings?

Acids and Bases pre-teaching interview questions

1. What do you know about acids and bases? (look, taste etc)?
2. What is an acid ? What do acids have in common?
3. What is a base ? What do bases have in common ?
4. What is pH?
5. If we could look at an acid or a base “up close”, what would it look like?  
Can you use the cardboard dots or drawings to demonstrate this?
6. What are concentrated and dilute solutions? Can you use cardboard dots or drawings to model what they would look like “up close”?
7. What are strong and weak acids and bases? Can you use cardboard dots or drawings to model what they would look like “up close”?
8. What happens during neutralisation?

Acids and Bases post-teaching interview questions

1. What do you know about acids and bases? (look, taste etc)?
2. What is an acid ? What do acids have in common?
3. What is a base ? What do bases have in common ?
4. What is pH?
5. You did an activity in class where you put a piece of magnesium into some ethanoic acid and also some hydrochloric acid. What can you tell me about that?
6. If we could look at an acid or a base “up close”, what would it look like? Can you use the cardboard dots or drawings to demonstrate this?
7. What are concentrated and dilute solutions? Can you use cardboard dots or drawings to model what they would look like “up close”?
8. What are strong and weak acids and bases? Can you use cardboard dots or drawings to model what they would look like “up close”?
9. What happens during neutralisation?
  - a) Did you notice that your teacher used some new teaching strategies in your lessons?
  - b) What were they?
  - c) What did you think of them – were they helpful to you or not?
  - d) What would you change about the lessons?
10. How do you think your understanding of acids and bases has changed?



Teacher reflection questions

1. How did you feel the lessons went overall ?
2. Did you feel that you did anything very different to what you'd normally do?
3. Anything you found a bit uncomfortable?
4. Anything you especially liked about the lesson?
5. Did the students respond differently to how they normally would?
6. Was there a turning point in the lesson?
7. Anything you'd do differently next time?
8. Was the lesson successful in helping students to change their prior conceptions?
9. Do you think students improved their assessment answers ?
10. How did you see this whole exercise (PD?)
11. Did you find the action research process helpful?
12. Do you find yourself using the 3 levels in other topics ?
13. What will you do with these topics next year?