

1990

# The development and evaluation of a computer-assisted strategy designed to change student misconceptions about chemical equilibrium

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## Recommended Citation

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The Development and Evaluation of  
a Computer-Assisted Instructional Strategy  
Designed to Change Student Misconceptions about  
Chemical Equilibrium

By

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Submitted

in partial fulfilment of the requirements  
for the degree of

Master of Education

Department of Science Education  
Edith Cowan University

Date of submission: December 14, 1990

## ABSTRACT

The main aims of this thesis are twofold. First, to identify and describe misconceptions about chemical equilibrium held by Year-12 chemistry students in the Maldives. Second, to investigate the effects of using a computer-assisted instructional strategy in changing those misconceptions.

A misconception identification test and an interview schedule developed by Garnett & Hackling (1984) were used to diagnose student misconceptions about chemical equilibrium. The remediation aspect of the study used a computer-assisted instruction (CAI) package. The package was designed in accordance with a model of conceptual change proposed by Posner, Strike, Hewson & Gertzog (1982). The CAI package consists of eleven modules. The conceptual change strategies, as implemented in the package, mainly used simulations to create cognitive conflict to assist accommodation.

The results of the study indicate that misconceptions about chemical equilibrium are common

among Year 12 chemistry students in the Maldives. In addition, these misconceptions were found to be similar to those reported by Hackling and Garnett (1985) which identified misconceptions among Western Australian students.

Results also indicate that the remediation aspect of the study, which used the CAI package, produced significant and lasting conceptual changes in students holding the misconceptions.

## **DECLARATION**

I certify that this thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any institution of higher education and that, to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where due reference is made in the text.

*Hassan Hameed*

## ACKNOWLEDGEMENTS

I acknowledge, with profound gratitude, the unflagging support, advice and encouragement rendered to me by the supervisors, Dr Mark Hackling and Dr Pat Garnett. Their attention to detail and the depth and range of criticisms were most illuminating.

I would like to thank Dr Dennis Goodrum and Dr Norm Hyde for their encouragement and interest in the study. Dr John Happs provided assistance at the conceptualization stage of the study.

This thesis was drafted on special facilities provided by the University. Dr Sybe Jongeling ensured that these facilities and the supplies of consumables were well-maintained. I am indebted to him for this and many other forms of assistance.

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## CHAPTER 1

### Introduction to the Study

#### Introduction

Science educators and cognitive psychologists have shown a growing interest in the intuitive ideas of students about natural phenomena prior to, or following exposure to, instruction. A large number of studies have shown that many of these ideas are in marked contrast with the scientific conceptions they are expected to learn (Osborne & Gilbert, 1979; Osborne & Wittrock, 1985). The alternative views are often referred to as misconceptions.

Empirical studies also indicate that misconceptions are quite resistant to change and hinder the acquisition of scientifically correct conceptions (Posner, Strike, Hewson & Gertzog, 1982). Students can successfully complete science courses while still clinging to misconceptions since they are often not revealed by traditional evaluation methods. Further, many students are known to view scientific knowledge as distinct and inapplicable to the realm of everyday experience (Novak, 1988).

Numerous studies have sought to catalogue students' misconceptions in a variety of science

topics. For example, chemical equilibrium has been identified as a topic about which some students have misconceptions (Driscoll, 1960; Gussarsky & Gorodetsky, 1990; Hackling & Garnett, 1985). It is generally accepted that the unlearning of misconceptions might be the most crucial step in the subsumption of new knowledge. Various theories and models have been developed to foster conceptual change (Posner et al., 1982). However, very few studies have sought to test these in experimental settings.

#### Background to the Study

The literature on misconceptions can be usefully divided into three types: descriptive studies, explanatory studies and studies to foster conceptual change (Hashweh, 1988). Descriptive studies document misconceptions in various subject areas. Explanatory studies try to explain the reasons for conceptual stability and change, and studies to foster conceptual change use the theoretical basis of explanatory studies to engender conceptual change in students. This study was based on the descriptive study of chemical equilibrium misconceptions by Hackling and Garnett (1985) and the model of conceptual change proposed by Posner et al. (1982).

This model was used as a theoretical basis for the design and development of a computer-assisted instructional package to change student misconceptions

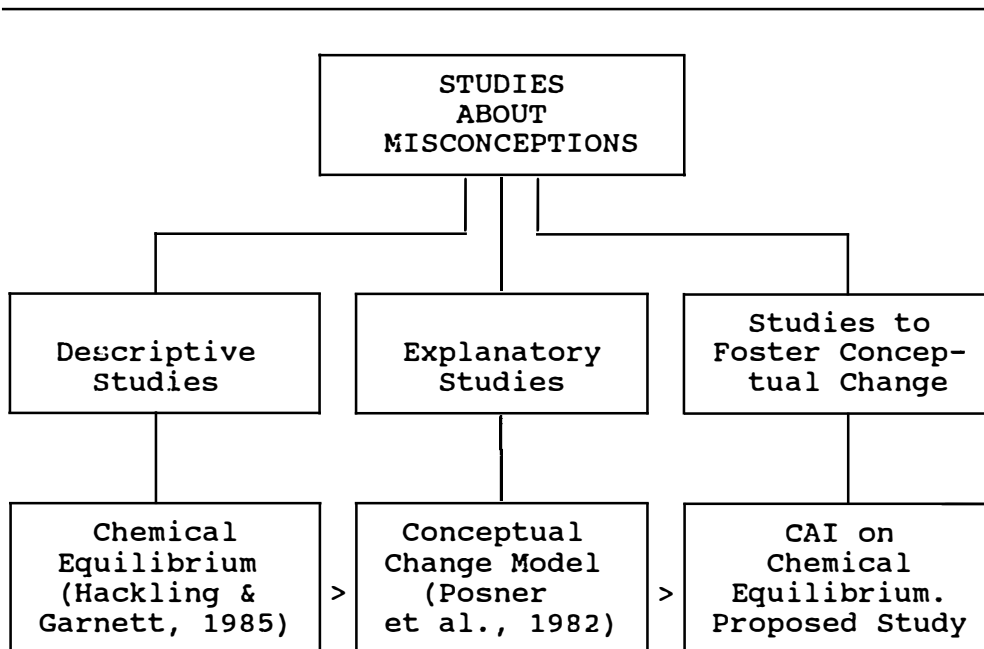


FIGURE 1

Proposed Study in Relation to Previous Research.

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about chemical equilibrium. Some support for the effectiveness of the model in exchanging misconceptions for scientifically acceptable conceptions has been demonstrated in studies which attempted to foster conceptual change (Fetherstonhaugh, 1988; Zietsman & Hewson, 1986).

Figure 1 shows the place of this study within the existing literature.

### The Research Problem

Students' misconceptions about science topics have been a major concern of educators because of the

difficulties they pose in learning. In the area of chemistry, misconceptions about chemical equilibrium can be expected to hamper acquisition of further chemistry concepts.

Several conceptual change strategies have been proposed. However, the educational benefits of these strategies have not filtered through to the classroom. This could be because practical instructional strategies based on conceptual change theories have not been adequately researched and their curriculum implications not fully explored. This study is designed to evaluate a practical strategy for conceptual change.

#### Rationale and Significance of the Study

The crucial role misconceptions play in concept learning is now well-established. Many studies continue to document misconceptions in various science topics. However, very few explanatory studies have been conducted to investigate the nature of conceptual change and stability. Even fewer studies have utilized the results of these investigations in the development of teaching programmes. The proposed research makes a contribution to the literature in this area.

Chemical equilibrium is recognized as one of the most difficult topics of chemistry at school level (Finley, Stewart & Yarroch, 1982). Non-traditional instructional strategies for remediating misconceptions

about this topic, especially the use of the computer, have yet to be pursued. This study may suggest useful ways of providing remedial instruction in this topic.

Further, as this study evaluates a teaching strategy, it may lead to suggestions for improving classroom instruction in chemistry and curriculum materials.

### Purpose and Research Questions

The proposed research is undertaken with two main purposes in view. First, to develop a computer-assisted teaching strategy based on a model of conceptual change to challenge the previously identified misconceptions of chemical equilibrium. Second, to determine the effectiveness of the developed strategy in changing Year-12 students' misconceptions about chemical equilibrium.

More specifically, the study will address the following research questions:

- (1) What misconceptions about chemical equilibrium are held by Year 12 chemistry students from the Maldives?
- (2) To what extent are misconceptions of chemical equilibrium changed by working through the computer-assisted instruction (CAI) programme based on a conceptual change strategy?

In addition, the study will also address the following subsidiary research question:

- (3) How does the incidence of chemical equilibrium misconceptions in Maldives' students compare with Western Australian students?

#### The Scope and Limitations of the Study

This study was designed to achieve the following objectives.

- (a) Identify the level and type of misconceptions about chemical equilibrium in the sample.
- (b) Draw comparisons between the misconceptions held by students in the Maldives and those in Western Australia. For this comparison, the results in Hackling and Garnett (1985) will be used. Comparisons will also be attempted with a broader collection of misconceptions about the topic gathered from previous research (e.g. Gorodetsky & Gussarsky, 1986).
- (c) Design and develop a computer-assisted instructional package based on a model of conceptual change to overcome misconceptions.
- (d) Evaluate the effectiveness of the computer-assisted instructional strategy in changing the misconceptions.

The theoretical basis for the development of the computer-assisted instruction has been the model

proposed by Posner et al. (1982). However, their model has been modified for computer-assisted instruction. This modification is slight and affects neither the structure nor the sequence of the steps they deemed necessary for conceptual change. Chapter 3 outlines the modifications made.

The instructional strategy takes the form of a computer package written in Basic for the BBC Master Series computers as these were the ones available to the target population. The small size of the memory and the slow speed of these computers severely restricted the use of sophisticated heuristics and graphics that can be used in the package. However, the package incorporates and makes prolific use of those features that make a package user-friendly, easy to use and attractive, despite the memory and speed constraints. No previous experience with computers is necessary to use the package.

The package is menu-driven and consists of eleven modules. The modules address specific misconceptions and closely follow the instructional plan for conceptual change as proposed by Posner et al. (1982) and modified by the author.

The non-portability of the package especially to IBM microcomputers is a limiting factor. However, it was not an objective of this developmental study to

prepare a package suitable for widespread classroom use.

The students who underwent the intervention programme were given two tests. The initial posttest was given three days after the intervention. The delayed posttest was administered thirty days after the initial posttest. However, the very long-term effect of the intervention is outside the scope of this study.

A limitation is imposed on the external validity of the study by the use of the study sample from the Maldives. The sample of students who underwent the intervention in the Maldives may have characteristics different from those in other countries. Thus, generalizations must be made with care.

## CHAPTER 2

### Literature Review

#### Introduction

Since the late 1970s, there has been a growing interest among researchers about students' intuitive ideas of natural phenomena. Further, these intuitive ideas, variously called misconceptions, preconceptions and alternative conceptions, are found to be resistant to instruction and impede acquisition of scientific conceptions (Cosgrove & Osborne, 1985; Rice & Feher, 1987).

A large number of studies have attempted to catalogue these misconceptions in various subject areas. Investigators have examined the nature of misconceptions, their acquisition, persistence, and change (Gilbert & Watts, 1983; Osborne & Wittrock, 1985; Posner et al., 1982).

However, despite the plethora of research efforts, the lack of coherence in the studies led Gilbert and Watts (1983) to comment that "there is no agreement on the aims of enquiry, the methods to be used, criteria for appraising data, the use to be made of the outcomes" (p. 61). These researchers described the state of research to be in a "pre-paradigmatic" phase.

Hashweh (1988) concurred with Gilbert and Watts and argued that many studies are still characterized by a misfit between the purpose of the study and the methodology used, by diagnosis and conceptualization problems and by validation problems. To illustrate, he stated that many descriptive studies which lack an explanatory model of conceptual change advocate certain instructional strategies for conceptual change. He contended that for change to be theoretically based one should be able to explain why a certain intervention should induce change. According to him a differentiation should be made between three kinds of studies of student misconceptions: descriptive studies, explanatory studies, and studies that attempt to foster change. Explanatory studies which form the bulk of the misconceptions literature attempt to identify and describe misconceptions in various science topics. Explanatory studies aim to explain conceptual stability and change. The last kind, of which there are very few studies, attempts to test the explanations offered by explanatory studies and promote conceptual change. The author's research falls within this last category.

This review first presents the definitions of key terms used, and discusses the origin and persistence of misconceptions. Descriptive studies of misconceptions about chemical equilibrium are then reviewed. It then outlines the constructivist

perspective in science learning. This perspective holds that prior experiences of the student are important in learning. This is followed by a discussion of various strategies for bringing about conceptual change and their implications for instruction. Previous studies on conceptual change are summarized including those using computer-assisted instruction. Finally, a discussion of the methodological aspects of the study completes this review.

### Definition of Terms

One of the reasons for the lack of an established paradigm of research is the confusion regarding the basic ideas: concepts and misconceptions. It is, therefore, essential at the beginning to define the meanings attached to these key terms.

### Concepts

Traditionally, concepts were believed to be "universal statements" acquired from inductive generalizations of a large number of diverse events observed with an unprejudiced mind and using unprejudiced sense organs (Osborne & Wittrock, 1985). In the 1940s this view of concept was attacked on the grounds of conclusive experimental evidence that showed observations to be theory-laden and marred by the observer's personal experiences. New views of concepts

take note of the fact that they may be subjective and contaminated by personal experience (Gilbert & Watts, 1983).

Gilbert and Watts (1983) distinguished three distinct views of "concept" which they termed classical, actional and relational. The classical view holds that all concepts share common features and these features alone are sufficient and necessary to define the concept. The "actional" view of a concept supports the notion that conceptualizing is a kind of "doing". Learning is seen to be active, constructive and intentional. The learner actively constructs meaning by organizing and restructuring pre-existing information. The "relational" view is a composite notion containing features of both previous views. Specific instances are judged according to the degree of fit to a particular concept and the concept judged in terms of its relationship to other concepts. This notion stresses the importance of the relational organization of a concept within a network and the characterization of each concept by well-defined features.

A careful consideration of the three views reveal that the distinctions between them are only superficial. Most researchers seem to subscribe to a view of concept that has characteristics of all three. For example, Novak (1988) defined concept as "a perceived regularity in events or objects designated by

a label" (p.82). White (1988) defined concept as "the collection of memory elements that are associated with a label and the pattern of their links" (p. 46). He stated that,

Since the concept is the set of related elements and these can be added to virtually without limit through new propositions and new episodes, it is really a zero-infinity rather than a zero-one situation. It is the elements that are possessed or not possessed; the concept is possessed to a greater or lesser degree. (p. 47)

A similar definition of concept is given by Pines and Leith (1981). They defined a concept as "a locus of meaning - sort of summary of all the propositional relationships in which that concept participates" (p. 15). They argued that human beings create concepts by slicing the world into objects and events that bear similarity. Concepts that are similar are then further categorized creating hierarchical conceptual structures.

The following definition of concept by Hashweh is, perhaps, broad and general enough to appeal to a wider audience and contains the essence of all previous definitions:

... concept is an abstraction, a representation of some portion of the world that is composed of elements, each of which may itself be another schema, and relations between these elements. (Hashweh, 1988, p. 231)

In this view the notion of a misconception is attributed to a flaw in the schema. For example, the

concept of "density" is delineated in terms of critical properties or attributes that define it. A missing or irrelevant attribute would represent a misconception.

Preconceptions,  
Misconceptions and Alternative Conceptions

Confusion about terminology is not restricted to the term concepts alone. A generally acceptable term to describe existing concepts that differ from the accepted scientific knowledge has been a matter of contention for many years. "What the student knows prior to instruction" has been described as preconceptions by Pines and Leith (1981, p. 18). Preconceptions is a neutral term, similar to existing conceptions, and prior schemata, which do not connote wrong knowledge. Those preconceptions that are different from the consensus scientific conceptions have been variously called erroneous concepts, misunderstandings, erroneous ideas, mistakes and more generally misconceptions (Abimbola, 1988). However, several researchers (Pines & Leith, 1981; White, 1988) contended that student misconceptions are well-established, empirically verified and meaningful to the learners, hence misconceptions is an inappropriate term. Student misconceptions are not attributed to cognitive deficiency, carelessness or poor teaching but rather they are viewed as natural and inevitable in the learning process. Further, in many cases the concepts are complex and contain multiple links to

other concepts within the cognitive structure. Therefore, Pines and Leith (1981) suggested the term alternative frameworks to describe those preconceptions that are discordant with the consensus scientific conceptions.

Rowell, Dawson and Lyndon (1990) referred to misconceptions as errors in constructive generalizations. "By misconceptions, then, we shall mean both explanatory (i.e., theoretical) knowledge judged by 'experts' in the field to be limited, but on the right track and that judged to be wrong" (p. 167).

However, Abimbola (1988), after considering the epistemological roots of various terms that have been used to describe student misconceptions, concluded that "alternative frameworks" was an inappropriate term to describe preconceptions different from scientific conceptions. According to him,

... alternative frameworks are just the undergirders that anchor ideas... 'frameworks' refer more to the organization of ideas rather than the ideas themselves. 'Frameworks' then are not what are revealed to us in research about students' existing conceptions; they are what we infer... (Abimbola, 1988, p. 181)

He suggested "alternative conceptions" which he argued is more appropriate, applicable and inclusive. Despite the fact that the suggestion makes good sense, researchers have continued to use the term "misconceptions". In keeping with the tradition, in

this review misconceptions will be used throughout and should be taken as synonymous with "alternative conceptions".

### Origin and Persistence of Misconceptions

#### Origin of misconceptions

Several studies have shown that student misconceptions about scientific topics are extraordinarily similar (Eaton, Anderson & Smith, 1984; Stead & Osborne, 1980;). In a comparative study, Fetherstonhaugh, Happs and Treagust (1987) found that student misconceptions about light are almost identical across age groups and national boundaries. In another study, Shipstone et al. (1988) gave the same test about basic electrical concepts to 15 - 17 year-old students in England, France, Netherlands, Sweden and West Germany, and found that the between-country differences of misconceptions were quite small.

The uniformity of the misconceptions suggests that well-defined causes must be responsible for their formation. Gilbert, Osborne and Fensham (1982) suggested four underlying reasons for the origin of misconceptions. First, many young children do not interpret natural phenomena in impersonal objective ways. Their anthropocentric views are coloured by common beliefs. Second, for a number of children, what is not observable does not exist. Third, children tend

to endow objects with human qualities. Many children do not take statements such as "the electric current chooses the path of least resistance" as merely metaphoric. Finally, children think of abstract ideas such as momentum and velocity as physical entities. These views lead to a perspective which is quite different from the scientists' and a corresponding variation in the interpretation of reality.

Similarly, Rowell et al. (1990) argued that the construction of misconceptions starts with the recognition of a knowledge gap of some kind. Depending on what is already known and on experience, the learner evaluates gap-filling possibilities from which a selection is made and often subsequently modified. The resulting misconception or knowledge is the best the individual can synthesize and would form the basis for generating future constructions.

Many events of every day life do not betray the underlying scientific principles for their manifestation. For example, many students have the misconception that to keep a body in motion a force must always act on the body. Hewson (1981) argued that this Aristotelian view of motion is the natural experience of most students who have ridden bicycles. They know that to keep on riding faster one needs to keep on pedalling harder. The moment pedalling is stopped, the bicycle will decelerate. Observation of almost all moving object on Earth would verify their

misconception. Thus, by the time they go to school, most students are firm believers in Aristotelian mechanics.

Misconceptions are also derived from everyday use of language. Eaton et al. (1984) found that a common misconception among students is that colour is a property of an object not light. They argued that common statements such as "the book is red" rather than "the book is reflecting red light" imply colour to be a characteristic of the object and may lead to the formation of the misconception. Veiga, Pereira and Maskill (1989) also found that misconceptions were embedded in the linguistic metaphors and analogies used by teachers in discussions with students. They argued that misconceptions stand little chance of being eradicated since the knowledge they must use in order to communicate contains an implicit and serious barrier to understanding.

Misconceptions can arise from the incorrect transfer of existing knowledge to explain new phenomena. Learners could try to accommodate to new information by incorrectly synthesizing existing fragmented and inconsistent pieces of knowledge. Mohapatra (1988) found experimental evidence for induced incorrect generalization to be a generative cause of misconceptions. For example, Eylon and Linn (1988) suggested that since mass is generally important in determining motion students expect mass to be

important in determining the rate of oscillation of pendulums. Other possible sources of misconceptions would include teachers and textbooks. Teachers could reinforce or create certain misconceptions by failing to discuss the concepts correctly. In one study, Eaton et al. (1984) found that the textbook students used did not explicitly mention that opaque objects are seen because of the light rays they reflect. This omission subtly reinforced the common misconception that bodies are seen because light "brightens" them.

In summary, misconceptions can be formed from physical experiences, social experiences and invalid transfer of knowledge to new situations.

### The Persistence of Misconceptions

Psychologists and educators differentiate between two types of knowledge, procedural and declarative. Hashweh (1986) suggested that misconceptions are similar to procedural knowledge, a feature which accounts for their persistence. Almost all researchers agree that misconceptions arise from the learner's interaction with the world. Through experience and repetition a stage will be reached when their use becomes unconscious and automatic. Once this stage is reached, the knowledge may be termed as procedurally encoded. Procedural knowledge, like certain habits, is difficult to change and is automatically invoked when certain conditions are satisfied.

Hashweh (1986) identified several classroom factors which abet the persistence of misconceptions. First, many teachers are unaware of student misconceptions. Second, evaluation methods do not reveal misconceptions. Finally, misconceptions are not addressed by the teachers even when revealed by students' answers.

Other factors which contribute to the persistence of misconceptions include cultural beliefs and the tenacity of common-sense epistemology. Explicit cultural beliefs are often in conflict with scientific explanations of many phenomena. For example, religious views regarding the creation of humans conflicts with the scientific explanation of evolution. Many cultures still nurture common-sense epistemology because it is adequate for explaining many every day experiences.

Because misconceptions are persistent and have been used again and again to interpret real world events, careful sequencing and explanation of new information are often not sufficient to lead to the acquisition of correct conceptions. Existing misconceptions must be directly addressed with innovative instructional strategies.

#### Misconceptions about Chemical Equilibrium

The topic of chemical equilibrium has long been recognized as presenting conceptual difficulties to

students. Finley et al., (1982) found that many teachers consider chemical equilibrium to be the most difficult topic in school chemistry. This is evidenced by the number of studies undertaken to comprehend learning difficulties and misconceptions about the topic (Driscoll, 1960; Gorodetsky & Gussarsky, 1986; Hackling & Garnett, 1985; Johnstone, MacDonald & Webb, 1977; Wheeler & Kass, 1978).

As far back as 1960, learning difficulties about chemical equilibrium have been reported in the literature. Driscoll (1960) noted that, in particular, Le Chatelier's Principle is misunderstood by many students and consistently led to incorrect predictions. He suggested several causes for the mistaken conceptions. These are briefly discussed below.

(1) Statements of Le Chatelier's Principle in many textbooks are meaningless, ambiguous and incorrect. Driscoll contended that a suitable statement should differentiate between intensive properties (temperature, pressure, concentration) and extensive properties (enthalpy, volume and mole number).

(2) Students do not fully appreciate the factors affecting the position of equilibrium. For example, consider a flask containing a gaseous equilibrium mixture of  $A + B = C$ . Many students wrongly assume that if an inert gas such as neon is now introduced into the system at constant volume the forward reaction

would proceed to a greater extent. Driscoll argued that many textbooks, by failing to mention that Le Chatelier's Principle is applicable only to systems where the chemical equilibrium is upset, tend to encourage students to apply the Principle to inappropriate systems.

(3) Confusion regarding the extent and rate of reactions. Many students are not aware that Le Chatelier's Principle cannot be used to predict anything about the rate of the reaction.

(4) Application of the Principle to systems not in thermodynamic equilibrium. The point needs to be stressed that Le Chatelier's Principle is applicable to changes in an equilibrium condition of a system already in equilibrium.

(5) In systems where several equilibria are involved, students tend to ignore the effect of a particular change on all equilibria. Many textbooks do not contain examples of the application of the Principle when several equilibria are involved.

Driscoll hinted that an unambiguous and correct statement of Le Chatelier's Principle could be helpful to students when making more difficult predictions. It is important to note that Driscoll did not report on how the above observations were made.

Johnstone et al. (1977) investigated the nature and origin of conceptual difficulties experienced by

students. Misconceptions were diagnosed using a multiple choice test. The investigation revealed misconceptions previously not reported in the literature. In particular, it was found that 80% of the students in the sample tended to visualize equilibrium systems as consisting of two independent and separate compartments rather than one whole. Almost all the students were found to have the misconception that that increased pressure due to heating a system at constant volume alters the composition of a mixture in a manner which results in a reduction in pressure. The students were also found to have a variety of misconceptions relating to the action and effect of catalysts on reaction rates and concentrations.

Based on the work of Driscoll (1960), Wheeler and Kass (1978) conjectured the prevalence of certain misconceptions in the topic of chemical equilibrium. Using a misconception identification test, their findings were, (a) the inability to distinguish between the concepts of mass and concentration, and between extent and rate, (b) uncertainty as to when the equilibrium constant is in fact a constant, (c) misuse of Le Chatelier's Principle, (d) inability to appreciate that certain substances display a fixed or constant concentration in certain chemical reactions, and (e) inability to consider all possible factors

affecting the equilibrium condition of a chemical system.

One of the most comprehensive descriptive studies of chemical equilibrium was carried out by Hackling and Garnett (1985). They found that students generally had a poor understanding of the quantitative aspects of chemical equilibrium. The most significant misconceptions revealed by the study were:

1. the rate of the forward reaction increases with time from the mixing of the reactants until equilibrium is established;
2. a simple arithmetic relationship exists between the concentrations of reactants and products at equilibrium; and
3. when a system is at equilibrium and a change is made in the conditions, the rate of the favoured reaction increases but the rate of the other reaction decreases.

A total of fourteen misconceptions were identified. A complete list of the misconceptions is shown in Table 1.

Gorodetsky and Gussarsky (1986) used different evaluative methods to identify problematic aspects of understanding chemical equilibrium. Their studies confirmed the existence of misconceptions in eight areas of the topic. Most of these misconceptions had previously been reported by Driscoll (1960) and Johnstone et al. (1977).

TABLE 1

Most Common Misconceptions of Chemical Equilibrium  
(Hackling and Garnett, 1985)

---

Approach to Equilibrium

1. Forward reaction rate increases as the reaction gets going.
2. Reverse reaction rate is the same as the forward rate.

Characteristics of Chemical Equilibrium

1. There is a simple arithmetical relationship between the concentrations of reactants and products.

Changing Equilibrium Conditions

Effect on concentrations

1. After the  $[\text{NO}]^a$  is instantaneously increased the  $[\text{NO}]$  remains the same.

Initial effects on rates of reactions

1. When the  $[\text{NO}]$  is increased the rate of the reverse reaction is decreased.
2. When the temperature is increased the rate of forward reaction is decreased.
3. When the volume is decreased the rate of the reverse reaction is decreased.

Rates of reactions when equilibrium is re-established

1. When equilibrium is re-established the rates of the forward and reverse reactions will be equal to those at the initial equilibrium.

Effect on equilibrium constant

1. When NO is added and equilibrium is re-established the equilibrium constant is greater than under the initial conditions.
2. When the volume is decreased and equilibrium is re-established the equilibrium constant is greater than under the initial conditions.
3. When the temperature is increased and equilibrium is re-established the equilibrium constant is the same as under the initial conditions.

Effect of a catalyst

1. A catalyst can affect the rates of the forward and reverse reactions differently.
- 

Note. The study was based on the reaction between nitric oxide (NO) and chlorine ( $\text{Cl}_2$ ) forming nitrosyl chloride ( $\text{NOCl}$ ).

<sup>a</sup>  $[\text{NO}]$  refers to the concentration of nitric oxide.

Maskill and Cachapuz (1989) used word association tests (WATs) with 15-year old students studying chemical equilibrium to externalize the developing ideas of students while they were learning the topic. The study revealed that certain interfering misconceptions could block learning. They include notions of chemical equilibrium as static, equilibrium when everything is equal, and the idea of reversibility as a physical reversing of movement. A commonly-held misconception about chemical equilibrium is that the speed of a reaction is the factor which governs the position of equilibrium (Cachapuz & Maskill, 1989).

Camacho and Good (1989) conducted a study about chemical equilibrium to describe the problem-solving behaviours of experts and novices using think-aloud protocols. This study confirmed the prevalence of some misconceptions previously identified by earlier studies. The study also revealed that many students do not understand the fact that, in terms of energy content, all reactions are either endothermic or exothermic. The nature of equilibrium constant and the factors affecting it are also generally misunderstood.

A number of suggestions have been made to deal with the misconceptions. Wheeler and Kass (1978) proposed emphasizing the limitations of Le Chatelier's Principle in teaching. Other researchers have suggested using analogies and graphical representations

(Thiele, 1990). Some have argued for the complete abandonment of the Le Chatelier's Principle (Johnstone et al., 1977). It is believed that static equilibrium so emphasized in physics may be responsible for some of the misconceptions in chemical equilibrium. Teachers need to be aware of misinterpretations of the concepts and tacit assumptions made by students. Because of its inherent abstract nature, chemical equilibrium will remain a difficult topic for students unless better ways of teaching are sought.

#### The Constructivist Perspective in Science Learning

Magoon (in Driver, 1986) described constructivism as "a perspective about human beings as purposive, active, adaptive, knowing, self-aware, social organisms which encompasses this range of concerns" (p. 1). The constructivist perspective has its roots in the interpretive tradition in the social sciences which stressed the importance of personal experience in understanding actions.

Traditionally, some researchers have assumed that students come to school with a "blank minds" or tabula rasa and that they can be filled easily with teachers' science. Others assumed that whatever conceptions children bring to school are of no consequence to their learning. These views had dominated the Western education system for the greater part of this century.

One of the first to suggest the importance of personal experience in constructing new knowledge was Piaget. Although his name has been associated with the developmental perspective, many researchers maintained that he was a constructivist (Osborne & Wittrock, 1983).

As far back as 1969, the importance of personal experience has been alluded to by Kelly (in Pope & Gilbert, 1983). Kelly proposed that people develop models of the world which represent it as they see it. These models are composed of interrelated hypotheses called personal constructs. These personal constructs are used by each person to describe present experience, predict future and assess past experiences. Kelly emphasized the uniqueness of each person's construct system which continually changes in order to make meaning of personal experiences. Kelly believed that successful communication depends not so much on the commonality of construct systems but on the extent one person can construe the construct system of the other. The implication of this idea for school learning is obvious, the teacher needs to develop an understanding of the existing frameworks of the students.

According to Novak (1988) the first comprehensive effort to present a theory of learning that dealt with the role of meaning was David Ausubel's (1963) 'The Psychology of Meaningful Verbal Learning'. In the

epigraph to his 1968 book, 'Educational Psychology: A Cognitive View', he stated,

If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.

Osborne and Wittrock (1983, 1985) identified three major findings identified after an extensive review of literature on science teaching and learning.

(1) Children have firmly held views about many science topics that are discordant with the consensus scientific views. These views are prevalent even before the formal learning of science.

(2) Older children who have considerable exposure to science teaching continue to have views that are significantly different from scientists' views. Thus children's views are tenacious and resistant to teaching.

(3) Traditional science teaching is ineffective in bringing about conceptual change. Osborne and Wittrock (1985) cited many instances where the proportion of children who held misconceptions increased from a lower age group to a higher age group.

Driver (1986) identified a number of underlying assumptions in the constructive perspective. According

to her, the knowledge learners possess and their internal representations of the world have implications for their behaviours and interactions. She argued that students' alternative conceptions about natural phenomena are examples of mental representations. Driver (1986) delineated the process by which knowledge is constructed as a "process whereby schemes are brought into play (either tacitly or explicitly), their fit with new stimuli is assessed and, as a result the schemes may be modified" (p. 5). She noted that to know something does not involve correspondence between our conceptual schemes and what they represent in the real world, but the construction of coherent and useful schemes. According to this view science as knowledge is rigorously tested constructions through which we try to interpret and understand our experiences.

Osborne and Wittrock (1983) proposed a new model of learning consistent with the research findings. They called this model the Generative Learning Model. According to them, the model is central to the constructive perspective. This model stresses the all-important role of the learner in processing information.

The essence of the Generative Learning Model (GLM) is that people tend to generate perceptions and meanings that are consistent with what they already know. According to Osborne and Wittrock (1983) the sensory information received from the environment

interacts with the stored memories and processing strategies to actively construct meanings. The authors maintained that generation is a fundamental cognitive process in comprehension and differentiated it from semantic processing and "fitting information into slots or schemata". In their words:

The generative learning model is concerned with the influence of existing ideas on what sensory input is selected and given attention, the links that are generated between the stimuli and aspects of memory store, the construction of meanings from sensory input and information retrieved from long-term memory, and finally the evaluation and possible subsumption of constructed meanings. (Osborne & Wittrock, 1985, p. 64)

Although the model can be used to successfully explain many observed phenomena such as the persistence of misconceptions, the authors (Osborne & Wittrock, 1985) accepted that the model of human learning is an oversimplification like any other model.

### Conceptual Change

Because misconceptions are highly resistant to change, they are likely to persist into adulthood unless successful intervention strategies occur. In one study Novak (1988) followed a group of children from grade one through grade twelve and found that certain misconceptions persisted over ten years of schooling.

Such studies of persistence of misconceptions have drawn the attention of researchers to the process of

how one set of concepts change to another set, incompatible with the first. There are several possible ways in which new knowledge can interact with the old (Hewson, 1981; Pope & Gilbert, 1983). The most important two ways are briefly outlined below.

- (1) The new knowledge is "compatible" with the old.

In this case, learning would proceed without difficulty. The new knowledge is intelligible, fruitful and plausible to the learner. It is readily integrated into the existing conceptions which become reinforced as a result. This type of learning has been called assimilation by Posner et al. (1982) and conceptual capture by Hewson (in Hewson & Thorley (1989)).

- (2) The new conception is "incompatible" with the existing relevant conceptions.

In this case the new conception is not plausible to the learner. The acceptance and integration of the new conception is then impeded by existing relevant conceptions. These old conceptions are often wrong and have to be restructured or revised. They form the basis of misconceptions which block learning. For learning to take place, the misconceptions have to be repudiated. It is only then that the new knowledge can be meaningfully integrated into the cognitive framework. This second type of

conceptual change which involves a re-organization of the conceptual framework, has been labelled accommodation by Posner et al. (1982) and conceptual exchange by Hewson (in Hewson & Thorley (1989)).

The goal of much research in recent years has been to uncover the factors which can facilitate the last type of conceptual change. However, in spite of vigorous research activities, a widely acceptable explanation for conceptual stability and change has been rather elusive.

Posner et al. (1982) proposed a model of conceptual change. This model comprises two major components, the conditions that need to be satisfied in order for a person to experience conceptual change and the person's conceptual ecology that provides the context in which the conceptual change occurs and has meaning. Both phases are believed to occur against the background of learner's current concepts called conceptual ecology. The selection of a new concept for subsumption depends on the features of the conceptual ecology, such as anomalies (i.e. the characteristic weaknesses of existing concepts to explain new phenomena) and the learner's epistemological commitments (beliefs about the nature of knowledge). Anomalies provide the sort of cognitive conflict or dissonance that prepares the students' conceptual ecology for accommodation.

According to Posner et al. (1982) four important conditions must be fulfilled before accommodation could occur.

(1) There must be dissatisfaction with existing conception as a result of an accumulated store of unsolved puzzles and anomalies.

(2) A new conception must be intelligible to the student.

(3) A new conception must appear initially plausible, that is, it must be able to solve problems and be consistent with existing knowledge.

(4) A new conception should lead to new insights and discoveries, that is, it should be fruitful.

Accommodation which is a radical reorganization of a student's conceptual system cannot occur abruptly. The authors acceded to the view that accommodation is a slow process because concepts and misconceptions have been slowly constructed through experience.

Hasweh (1986) disagreed with those researchers who suggested that conceptual change is mainly facilitated through conceptual conflict, discussion and dialectical processes. He proposed a model of conceptual change which stressed the conflict between misconception and scientific conception (which he called preconception and postconception, respectively) within the cognitive

structure itself. Most researchers have emphasized the conflict between the misconception and a new phenomenon and ignored the internal conflict between the new and old conceptions. In many cases misconceptions are special cases of scientific conceptions. This fact, though seldom recognized, is crucial in fostering conceptual change. Misconceptions are derived from scientific conceptions if generalities are ignored as when they arise from limited experience of the learner. As an example, Hashweh quoted the relativistic equations of motion which can be reduced to Newtonian equations at low speeds. According to him, it is the provision of synthesizing information that shows the relationship between the two sets of equations which is important in inducing conceptual change. Hashweh echoed the concern of other researchers to provide students with opportunities to reinterpret past experiences after the scientific conception is accepted, for example, in discussion and debate.

Hewson and Hewson (1988) suggested that conceptual conflict leads to change only if the plausibility of the existing conceptions is decreased and the plausibility of the new conception is increased. Even then students may revert to the old conception. Happs (1985) noted that some conceptual change is transitory and regression to misconceptions is common over an extended time. Students tend to compartmentalize their knowledge and form multiple conceptions for the

same phenomenon. Obviously, conceptual conflict is not sufficient to achieve change.

Eylon and Linn (1988) reviewed literature on conceptual change and concluded that while conceptual conflict creates opportunity for conceptual change, it may not always lead to change. They suggested that conceptual change can be induced if teaching encourages coherent understanding while counteracting misconceptions.

### Conceptual Change Instruction

There is remarkable similarity among the pedagogical implications suggested for conceptual change by different researchers (Driver, 1986; Hewson & Hewson, 1988; Nussbaum & Novak, 1982; Osborne & Wittrock, 1985; Van Hise, 1988). The following list, based on Van Hise (1988) is representative.

1. Provide opportunities to make student ideas explicit and give students opportunities to test those ideas.
2. Confront students with situations where their misconceptions cannot be used as explanation, and let them become aware of the conflict.
3. Help students accommodate the new conception by providing opportunities to test them and experience their fruitfulness.

A number of methods have been suggested to enable students to become aware of their misconceptions. Gunstone and White (1981) advocated those methods used in conceptual research because of the way they require the students to examine their beliefs in detail. Debates, discussions and the technique of "concept-mapping" have also been suggested. Hewson (1981) suggested differentiation of the misconceptions which are ill-defined or confused into a more clearly defined conception.

In constructivism, the key players are the learners themselves, hence the instructor should engender in the students that the "locus of control" is within themselves and they themselves are responsible for the success or failure of the learning outcomes. In addition, to help focus attention and assist interpretation, Osborne and Wittrock (1983) suggested carefully-worded headings, focus questions and objectives. If learning is to be generative, appropriate retrieval cues should be provided. Students can also be encouraged to evaluate the constructed meaning against their experiences and real-life situations. Such linkages would facilitate subsumption. Multimode presentation of the concepts and the use of analogies have been suggested by Eylon and Linn (1988). Several of these strategies have been tested by different researchers.

Rowell and Dawson (1983) reported a study which investigated the role of counter examples in engendering conceptual change. The results showed that empirical counter examples might not provide the information needed by many students to correct their misconceptions. The researchers argued that what is intended by a teacher as a stark clash between reality and students' beliefs may simply be interpreted as an anomaly. In some students, counter examples may produce confusion. Some students when presented with the counter example, accept it only at a verbal level. Thus, counter examples or cognitive conflict alone is not sufficient to cause conceptual change.

Rowell, Dawson and Lyndon (1990) argued that for a high rate of progress in overcoming a misconception, students should first construct another potentially relevant, potentially contradictory, better explanation. The new explanation must be based on aspects of knowledge familiar to students. Only when a rival theory is on an "equal" mental footing with the old theory would the students be able to argue the pros and cons of which theory to retain. The cooperative debate following the teaching of a better theory is useful only if the students can unambiguously identify and discriminate between both theories and their respective expectations. Rowell et al. (1990) concluded from experimental evidence that the re-activation of old theory, its labelling, its systematic

discrimination and the generalization of the new theory are all important in engendering conceptual change. These conclusions are consistent with the conditions for conceptual change proposed by Posner et al. (1982).

In order to achieve optimal conceptual change, it is not enough to create cognitive conflict, or structure lessons in a meaningful fashion. Fetherstonhaugh (1988) developed a four-module teaching unit on light that attempted to fulfil all four conditions for conceptual change according to Posner et al. (1982). The module was implemented with Year 8-10 students who were known to have misconceptions about the topic. Interviews and a posttest following the teaching intervention provided some evidence in support of the postulates of Posner et al. (1982). Students were able to give more correct answers on the diagnostic test after instruction. It is not known whether the intervention produced permanent conceptual changes as no follow-up study was reported.

### The Use of Computers in Conceptual Change

Several researchers have advocated the use of computers in conceptual change instruction (Reif, 1987; Zietsman & Hewson, 1986).

Reif (1987) asserted that the unique capabilities of computers can be exploited to implement instructional strategies impossible with other teaching

methods. For example, the graphics capabilities of computers can be used to present meaningful symbolic representations including dynamic representations of time dependent processes. Normally unobservable events such as the motion of molecules in solutions could be visually represented in animated colourful displays. In addition, computers can provide a supportive environment where students can construct and explore new concepts while providing proper guidance and help at the right time by merely pressing a button. Further, computers could easily store and redisplay past work on cognitive tasks thus enabling the student to diagnose and correct their own errors and misconceptions. Nachamias, Stavy and Avrams (1990) reported the development of a microcomputer-based diagnostic system (MBDS) designed for identifying students' conceptions in the domain of heat and temperature.

Zeitsman and Hewson (1986) reported an investigation into the effects of instruction using microcomputer simulations and conceptual change strategies. The computer program was designed in accordance with a model of conceptual change to diagnose and remediate a misconception regarding the confusion between velocity and position.

The diagnostic part of the program consisted of six different simulated races. The students were asked to respond by pressing a key when they thought the two

objects were travelling at the same velocity. The responses were categorized and used to determine whether the students held the misconception or not. The remedial part of the program consisted of two further races. One was aimed at creating dissatisfaction with the misconception, and the other showed that the correct conception is a plausible and fruitful alternative to the misconception. In all the instances, immediate feedback was provided following the student responses. Results indicated that the remedial part of the program was very effective in engendering conceptual change.

Murray, Schultz, Brown and Clement (1988) exploited many more capabilities of the computer in developing an analogy-based tutor for remediating misconceptions about Newton's Third Law. Their results showed that most of the students improved their understanding of Newton's Third Law following the intervention.

In the area of chemistry, computers have been used to simulate chemical equilibrium by Simpson (1986) and Cullen (1989). In both instances the motivation for simulation has been the difficulty of designing meaningful qualitative laboratory experiments. The effectiveness of these computer simulations in enhancing student understanding has not been demonstrated by the developers nor are they based on a model of conceptual change. The simulations are rather

simplistic and the reactions they simulate cannot be changed. They are not tailored to overcome any previously identified misconceptions about chemical equilibrium. Searches of literature have not revealed any computer package based on a model of conceptual change, which deals with known student misconceptions of chemical equilibrium.

### Methodological Aspects of the Study

This section briefly reviews literature pertinent to the methodology of the study. The features and use of interviews and multiple choice tests for the identification of misconceptions are outlined.

#### Interviews

Perhaps the earliest procedure used to probe children's understanding was the interview. The classical studies of Piaget have shown that this method is fruitful for this purpose. Osborne and Gilbert (1979) refined the interview method further to identify misconceptions. The technique, which was named "interview-about-instances" required the student to respond to drawings on cards. Cards represented instances and non-instances to be discussed in the interview. Each student was individually interviewed.

Osborne and Gilbert (1980) argued that the success of the method depended largely on the choice of appropriate instances and non-instances to be

represented on the cards. Consideration of the theoretical structure of the concept and its different attributes are both useful in making a suitable set of instances and non-instances. Experienced teachers could also provide useful input. The method can also be used with events and non-events.

Several studies have demonstrated the effectiveness of the interview method (Rice & Feher, 1987; Stead & Osborne, 1980; Watts, 1985). The strengths and weaknesses of the method have been identified by Stead and Osborne (1980). An important advantage of the method is that reasons behind a student's answer can be obtained through asking supplementary and explanatory questions. The method allows the student to clarify the question and resolve ambiguities in the wording. In addition the students can express their ideas in their own words. Further, interviews are less dependent on reading skills.

The main disadvantages of the method are the needs for skill and time. Interviews place great responsibilities on the interviewer who has to be familiar with interview techniques and the subject matter of the interview. Interviews are time-consuming and may restrict the sample size in investigations and the range of concepts explored. The small samples will result in lower reliability and external validity of the findings.

### Multiple Choice Tests

An alternative method, which overcomes the shortcomings mentioned above is the use of multiple choice tests. They have been successfully used by a number of researchers for identification of misconceptions (Fetherstonhaugh, 1988; Haslam & Treagust, 1987; Peterson, Treagust & Garnett, 1986; Stead & Osborne, 1980; Treagust, 1988). In the construction of multiple choice items, distractors are chosen to represent known misconceptions established by other means. Tamir (1971) described how distractors could be based on students' responses gleaned from answers to interview questions. Perhaps, the most comprehensive explanation of the development process of multiple choice tests for the purpose of identifying misconceptions is given by Treagust (1988). The method involves ten stages grouped into three broad areas. A lucid description of the development process is outlined in Treagust (1988). This rigorous method of test design has been used successfully by a number of researchers (Haslam & Treagust, 1987; Peterson et al., 1986; Treagust, 1988).

Stead and Osborne (1980) outlined several advantages and disadvantages of using multiple choice tests. Ease of administration to a large number of students and the ability to make comparisons between students are two of the chief virtues. Their main weaknesses are the restriction of student choices,

dependence on reading skills and the limited ability to probe why a certain choice was made. In this regard, two tier multichoice items proposed by Treagust (1988) are a great improvement.

Interviews and multiple choice tests are not the only procedures for identification of misconceptions. The use of word association tests and computer programs for this purpose have been mentioned previously in this review. However, the methodology adopted in the proposed study is a combination of multiple choice tests and interviews. The purpose of this approach is to achieve triangulation. Triangulation has been defined by Denzin (in Jick, 1979) as "the combination of methodologies in the study of the same phenomenon" (p. 602). Jick argued that triangulation allowed the researcher to be more confident of the data particularly if the data collected by different methods converge.

In summary, research conducted mostly in the past two decades has shown that students' misconceptions play a major role in science concept learning. Misconceptions arise from personal experience and are resistant to change. Research has confirmed the prevalence of significant misconceptions among students about chemical equilibrium. Models of conceptual change have sought to explain the nature of conceptual

stability and change. Several strategies for conceptual change have been suggested.

Computers can play a significant role in bringing about conceptual change by providing meaningful simulations, judicious guidance and immediate feedback.

Numerous studies have demonstrated the effectiveness of interviews and multiple choice tests in diagnosing student misconceptions in science. A combination of the two methods provides an effective strategy which would overcome the weaknesses of any individual method.

## CHAPTER 3

### Development of the CAI Package

#### Introduction

The development of the package from planning through coding to testing was the single most time-consuming activity of this study, taking over three months to complete. Twenty programs of a total size of 88.6 kilobytes were written. This chapter outlines the theoretical basis for the development of the CAI package. It then outlines how the conceptual change strategy was translated into an operational model to form a usable framework for the development of the CAI package. Finally, the chapter briefly describes the package and discusses some issues considered in its design.

#### Theoretical Basis for the Design of the Package

The design of the package is based on a constructivist interpretation of learning. This interpretation assumes that humans are knowing, active, adaptive beings. They create their own knowledge and use previous learning in interpreting new experiences and constructing new knowledge (Osborne & Wittrock, 1983).

Student misconceptions have to be taken seriously because from the students' point of view they are sensible and meaningful. They are used to interpret and integrate new knowledge into the cognitive framework. Hence even if correct knowledge is imparted by teachers and textbooks, students may represent this information in their schemata in incorrect unscientific ways. Therefore, the constructivist perspective leads to a model of learning as conceptual change (Osborne & Wittrock, 1985). The pre-existing ideas of students must be sought and, if incorrect, altered. Teaching should involve not only providing new information but changing students' conceptions.

The design of the CAI package is concerned with this type of conceptual change called accommodation by Posner et al. (1982) and conceptual exchange by Hewson and Thorley (1989). Hewson and Hewson (1988) outlined the key points in the instructional strategies for conceptual exchange.

- (1) Diagnosis of student misconceptions about the topic under discussion by using probing questions or tests based on misconception research.
- (2) Provision of opportunities for students to clarify their own thoughts through individual work or group discussion.

(3) Provision of opportunities to create conflict between misconceptions identified in (1) and the corresponding scientific conceptions. The contrasting of correct and incorrect conceptions help to create dissatisfaction with the misconceptions and increase students' readiness for conceptual change.

(4) Provision of immediate opportunities for the scientific view to be used in explaining a phenomenon so that students feel that the new concept is a plausible one.

(5) Provision of immediate opportunities for students to apply the scientific conception to novel settings. This helps students to see that their new conception is fruitful in explaining related phenomena.

This sequence of steps form a conceptual change model referred to below as CCM. The five steps were used in the order listed here as the underlying theoretical basis for the development of the computer-assisted instructional strategy.

The Adaptation of the Conceptual Change  
Model for the Design of the CAI Package

One criticism of the CCM has been the difficulty of translating it into effective instructional

sequences for classroom transactions (Hewson & Thorley, 1989). It is even harder to represent the model in computer-assisted instruction. The computer can respond in only finite ways to student input. With little intuition inherent in it, meaningful dialogues are impossible with students, especially if their responses display creative insights. Therefore, an operational model for the design of the package was derived from the CCM. This adaptation is consistent with the CCM and differs from it mainly in the nature of the strategy for each step. Figure 2 represents the adapted model.

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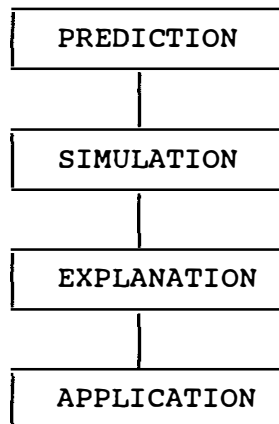


FIGURE 2

An Operational Model for the Design of the CAI Package

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Diagnosis of the students' misconceptions can be effected by tests already developed by researchers in this field. Some researchers have written computer programs to diagnose misconceptions about heat and temperature (Nachamias et al., 1990). However, it was

decided to use pencil and paper tests for the diagnosis. This step is, therefore, not included in the CAI package. However, the whole package addresses misconceptions identified in a previous study (Hackling & Garnett, 1985). The first phase of the operational model corresponds to the second step of the CCM, the second phase to step three of the CCM, and so on.

As implemented in the package, the prediction phase requires the students to state their views on what might happen to a system after certain changes are made to it. The question directly relates to the misconceptions identified by Hackling and Garnett (1985). In doing so, they clarify their own thoughts and commit their views. Since the students would be interacting individually with the computer, the environment is not threatening to the students.

In most cases, feedback is not given immediately following the student input. This feature is a significant way in which the strategy differs from conventional CAI packages. The feedback is withheld for several reasons. First, according to the constructivist perspective, neither the computer programs nor the teachers can change student beliefs. Students must construct their own knowledge. Delayed feedback facilitates such constructions and helps to shift emphasis from getting the correct answer to reflecting on the question and relevant knowledge.

Murray et al. (1988) noted that delaying feedback has been successful in many computer-based tutoring systems.

The simulation phase of the operational model corresponds to the third step of the CCM. In this phase the student is shown, usually in dynamic graphics, the correct answer to the prediction question. In other words, what really happens to the equilibrium system is simulated on the screen following the change. The student responses are displayed about this point in the instructional sequence. The juxtaposition of what was predicted by the student and what really happens creates the cognitive conflict necessary for conceptual change. It also increases students' dissatisfaction with the misconception and prepares the students to accept the alternative (scientific) view.

In the explanatory phase of the operational model, which corresponds to step four of the CCM, the plausibility of the scientific conception is explained. This is achieved by explaining the conception in relation to the initial prediction question posed. The explanation emphasizes the consistency of the scientific conception with other science theories and past experience. Where appropriate diagrams are incorporated. In some cases, the optimum point for providing feedback on the initial prediction question

is at this phase. If delayed further, the feedback may not be useful in consolidating learning. Students may also become frustrated in continuing a dialogue without feedback.

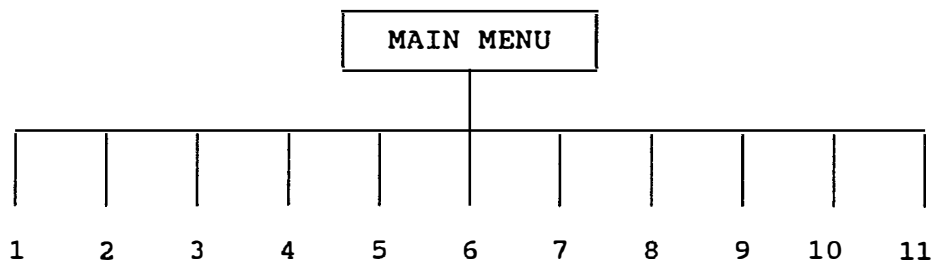
The final phase of the operational model involves providing opportunities to apply the new conception to different settings. If the new conception can resolve previous anomalies and is successful in interpreting new situations, then the students are more likely to exchange the misconceptions for the correct ideas. Additional application opportunities to test the fruitfulness of the new conception are provided by a worksheet.

A worksheet was prepared for the educational intervention. This fulfilled two purposes. No matter how interactive a CAI package is, students can quickly move through the whole programme without much care. The worksheet provided some motivation for the students to concentrate on the task at hand. More importantly, it highlighted some important aspects of the conceptual changes taking place. Some questions in the worksheet allowed the students to apply the principles they were learning to a new situation providing an additional application opportunity for students. The worksheet did not address misconceptions in any direct way, and was purposefully structured so as not to prepare the

students for the posttest. The worksheet is included in Appendix 1.

### The Design of the Package

The package consists of 11 learning modules selected from a menu. At an organizational level the package may be represented as in Figure 3.



The modules are:

1. Completion reactions
2. Reversible reactions
3. Equilibrium constant
4. Equilibrium concentrations
5. Equilibrium rates
6. Effect of catalysts on rates
7. Le Chatelier's Principle (LCP)
8. LCP and concentrations
9. LCP and volume
10. LCP and temperature
11. Changing equilibrium constant

FIGURE 3

### Organization of the CAI Package

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Each module consists of several frames. The modules are listed in the sequence that they should be worked through. Two modules, 1 and 7, are not part of the conceptual change strategy in that they are not

based on misconceptions. They provide perspective and prerequisite background to the following modules. Other modules are written to address misconceptions as identified by Hackling and Garnett (1985). At the end of each module, the user has the option of going to the menu or through the same module again.

In the planning of the package the identified misconceptions were first sequenced in the order that they should be presented to the students and then grouped into modules while retaining the sequence order. The objectives for each module were then written. Unlike conventional CAI, the objectives are not displayed to the students.

The structure of all the modules is similar, a brief description of one module, Module 6: Effect of Catalysts on Rate, is provided below to illustrate how the CCM has been implemented in the CAI strategy.

Module 6 consists of six frames. The first frame is designed to give an introductory explanation of catalysts. The second frame asks the **prediction** question. According to Hackling and Garnett (1985), students perceive (wrongly) that "a catalyst can affect the rates of the forward and reverse reactions differently" (p. 210). The question asked is directly related to this misconception. Following the student's response, frame 3, a **simulation** graph showing how the

forward and reverse rates increase after introducing a catalyst to the system is displayed. Frame 4 gives an **explanation** of the effect of the catalyst based on activation energy diagrams. Most students would be familiar with the diagram and the explanation would be plausible and consistent with their prior scientific knowledge. Both, frames 5 and 6, allow the student to **apply** the new conception to new situations. The worksheet provides an additional opportunity to reinforce the scientific conception.

#### Design Considerations and Issues

The research was to be carried out in a school where most of the computers available were BBC (British Broadcasting Corporation) Master Series microcomputers. Easy access to Master Series computers was unavailable at the design stage, hence the package was developed on an earlier model (Model B) with 32 kilobytes of memory and a clock speed of 2 MHz. BASIC was the only programming language available. Master Series computers have four times as much memory, twice the disk space and additional features. The author had to do without these.

All CAI packages have some common elements such as orientation information for students, directions and options. According to Heines (1984) two of the most common questions students ask themselves as they work

through any package are "How much have I done?" and "How much more do I have to do?". Students can lose all awareness of their current place when working through a large package. For this reason, orientation information in the form of a running head is provided. The organization of the package in terms of a menu also helps to orient them. The header displays module number, name and frame number. These are displayed in black on a yellow background in a subdued manner so that a student's attention is not detracted from the main subject matter of the frame.

Student directions and options are generally placed at the bottom of the screen. In this way students always know where to look for direction even if the screen is changing constantly. Unanticipated student input is beeped and hence draws the attention of the students immediately.

Great emphasis was placed on maximising student interaction with the package. Many CAI packages have deservedly been called electronic page-turners (Watson, 1987). Wherever possible and meaningful, students have to provide some input. Much attention was paid to the communication style. Generally only one concept appears on a single screen. Lines are double spaced and a controlled vocabulary was used. In the layout of the frames, large areas of a single colour have been avoided. In the display mode used in the programs,

four colours could be used. Text and graphics appear on a black background. The foreground colours used were yellow, cyan and green - colours which make pleasing pairings with each other and black (Watson, 1987).

In the design of the package, consideration was given to the fact that typical Year 12 students would not have many keyboard skills. The frames are designed to reduce the number of keystrokes required. In many cases where questions are posed, students are shown a list of possible answers and asked to select from them by typing a single letter. If the answer to a question is "Yes" or "No" students have to type only Y or N in either lower or upper case before the whole word is displayed. For moving between frames students have to press "<" or ">"; these characters appear on keys containing "," and ".". Though not transparent to the student, they need not shift between the characters to obtain the action of "<" or ">". The input is validated; invalid responses are beeped. The main menu can easily be accessed by pressing the "ESCAPE" button from anywhere in the program.

The development of the package was supervised and critically appraised at every stage by a subject matter expert and a science educator. The package underwent several revisions before arriving at a usable product. In addition, the chemistry teacher at the target school

further worked through the package before it was used in the research.

It was not the intention of the design to use the package as a regular curriculum material in the present form. The objective of the design was to find out whether a computer-assisted instructional strategy is effective, in the form it was designed, in producing conceptual change in students concerning chemical equilibrium. To be useful as curriculum software, the package needs additional effort. In particular, supporting material containing educational aims, teacher notes and student materials need to be produced.

In summary, the conceptual change model as outlined by Posner et al. (1982) was adapted to form an instructional sequence for a computer-assisted instructional strategy. Guided by this model several modules dealing with misconceptions about chemical equilibrium were programmed on a BBC microcomputer. In the development of the modules, consideration was given to the communication and interaction style used and the attributes of the target population. The package was critically appraised by a content expert and science educator. Sample screen dumps of Module 6 are included in appendix 5.

## CHAPTER 4

### Methods

#### Introduction

This chapter first describes the two instruments used for gathering data, a misconception identification test and an interview schedule. The subjects of the study form the next part of the chapter. Following the description of the subjects, the procedure is outlined. The procedure followed in this study is a mix of qualitative and quantitative approaches. The data analysis section forms the final section of this chapter.

#### Instruments

The CAI package used as the basis for the intervention strategy and its accompanying worksheet were discussed in the previous chapter. This section focuses on the features of the test instrument and the interview schedule.

Both the misconception identification test and the interview schedule used in this study were developed and used successfully for the identification of misconceptions on two separate occasions (Garnett & Hackling, 1984; Hackling & Garnett, 1985). Their

usability for this purpose had, therefore, been established.

The test consists of 47 multiple choice and true/false items. All the items dealt with one equilibrium system:  $2\text{NO} + \text{Cl}_2 \rightleftharpoons 2\text{NOCl}$ . This system was chosen because it is not included in the regular curriculum and was therefore novel to the students. Hackling (personal communication, November 20, 1990) explained how the test items were developed. Once the equilibrium system to be used in the study was decided, the propositions deemed necessary for understanding chemical equilibrium and the application of Le Chatelier's Principle to the system were listed. The propositions were then cross-validated by tertiary lecturers and experienced chemistry teachers. The proposition list is included in Appendix 2 (Hackling & Garnett, 1985). Interviews were then carried out to find out the misconceptions prevalent among their study sample. In interviews students had to provide their own ideas about particular concepts. Thus the interview allowed the researchers to delve deeply into the students' ideas about the nature of chemical equilibrium. A typical question was:

"I'd like you to consider what happens if a catalyst is added to the system.

Can you describe what happens to the rates of the reactions when the catalyst is added?

\* forward?

\* reverse?"

Some questions required students to respond by drawing graphs. Student response sheets with drawn and labelled axes were provided by the interviewer for students to draw graphs or write expressions. The interview schedule is included in Appendix 3.

The interview data were later coded and categorized to arrive at the list of misconceptions (shown as Table 1 in Chapter 2). The misconception identification test was developed from the interview data. The distractors for each multiple choice test item represent misconceptions identified by the interviews and not merely arbitrary wrong responses. The test instrument is included in Appendix 4.

There is almost a one-to-one correspondence between the chemical equilibrium propositions and the test items. This correspondence for all the test items and propositions is shown in Table 2.

TABLE 2

Relationship between Propositions and Test Items

Proposition number	Test item number	Proposition number	Test item number
1	1	15 (b)	28
2 (a)	2	(c)	29
(b)	2	16 (a)	-
3	1, 2, 6-11	(b)	30
4	3	17	31
5	4-5	18	32
6 (a)	10	19	-
(b)	12-15	20 (a)	33
7	-	(b)	34
8	21	(c)	35
9 (a)	16	21 (a)	36
(b)	17	(b)	37
(c)	18	(c)	38
10 (a)	19	22 (a)	-
(b)	20	(b)	39
11 (a)	-	23	40
(b)	22	24 (a)	41
12	23	(b)	42
13	-	(c)	43
14 (a)	24	25 (a)	44
(b)	25	(b)	45
(c)	26	(c)	46
15 (a)	27	26	47

Figure 4 shows sample items from the list of propositions and test to illustrate how the correspondence table (Table 2) was derived.

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Proposition:

After equilibrium has been achieved a catalyst is added to the system,

The rate of the

24. (a) forward reaction is increased  
(b) reverse reaction is increased  
(c) forward and reverse reactions are equal.

Test items for the corresponding propositions:

After equilibrium has been achieved a catalyst is added to the system but other conditions remain unchanged.

When the catalyst is added to the system:

41. The rate of the forward reaction will be
- (a) unchanged
  - (b) increased
  - (c) decreased
  - (d) either unchanged or increased depending on whether the catalyst favours the forward or reverse reaction.
42. The rate of the reverse reaction will be
- (a) unchanged
  - (b) increased
  - (c) decreased
  - (d) either unchanged or increased depending on whether the catalyst favours the forward or reverse reaction.
43. The rate of the forward reaction will be
- (a) equal to the rate of the reverse reaction
  - (b) greater than the rate of the reverse reaction
  - (c) less than the rate of the reverse reaction
  - (d) either greater or less than the rate of the reverse reaction depending on whether the catalyst favours the forward or reverse reaction.

FIGURE 4

Correspondence Between Propositions and Test Items  
Dealing with the Addition of a Catalyst to a System in  
Equilibrium.

(The propositions and test items are from appendices 2  
and 4 respectively.)

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The correspondence between the propositions and test items ensures the content validity of the test. A measure of the reliability of the test (Coefficient Alpha) was calculated and reported in Chapter 4.

### Subjects

The subjects in this study consisted of 30 students aged 16 - 18 years in Grade 12 (Year 12 equivalent in Western Australia). Thirteen of the students were girls and the rest were boys.

The students were from the only Grade 12 Chemistry class of the Science Education Centre (SEC), Male', Maldives, that is they represent the entire population of Year 12 chemistry students. Hence, sampling errors will be negligible. There were 36 regular students in the class. The research study started with all 36 students but six students were lost during the course of the study due to experimental mortality.

The students were preparing to sit the General Certificate of Education Examinations (GCE) at the Advanced Level conducted by the University of London School Examinations Board (ULSEB). These examinations will take place in January 1991. The study was conducted in August 1990. About four months before the study, the topic of chemical equilibrium was taught to the students. The ULSEB Chemistry syllabus was compared with that of Western Australia and were found to be essentially the same in terms of their coverage

of chemical equilibrium. The chemistry teacher confirmed that all the concepts covered in the research instrument had been taught to the students.

English is the language used in instruction in the Science Education Centre and therefore students would have little difficulty comprehending the tests and the intervention package. At the end of Grade 10, the students sat the GCE Ordinary Level examinations which is conducted in English. In Grade 12 the students were studying two other main subjects in addition to Chemistry. These two other subjects would be from a group consisting of pure mathematics, mathematics with statistics, biology and physics.

#### Procedure

The procedure followed in this study is shown diagrammatically in Figure 5.

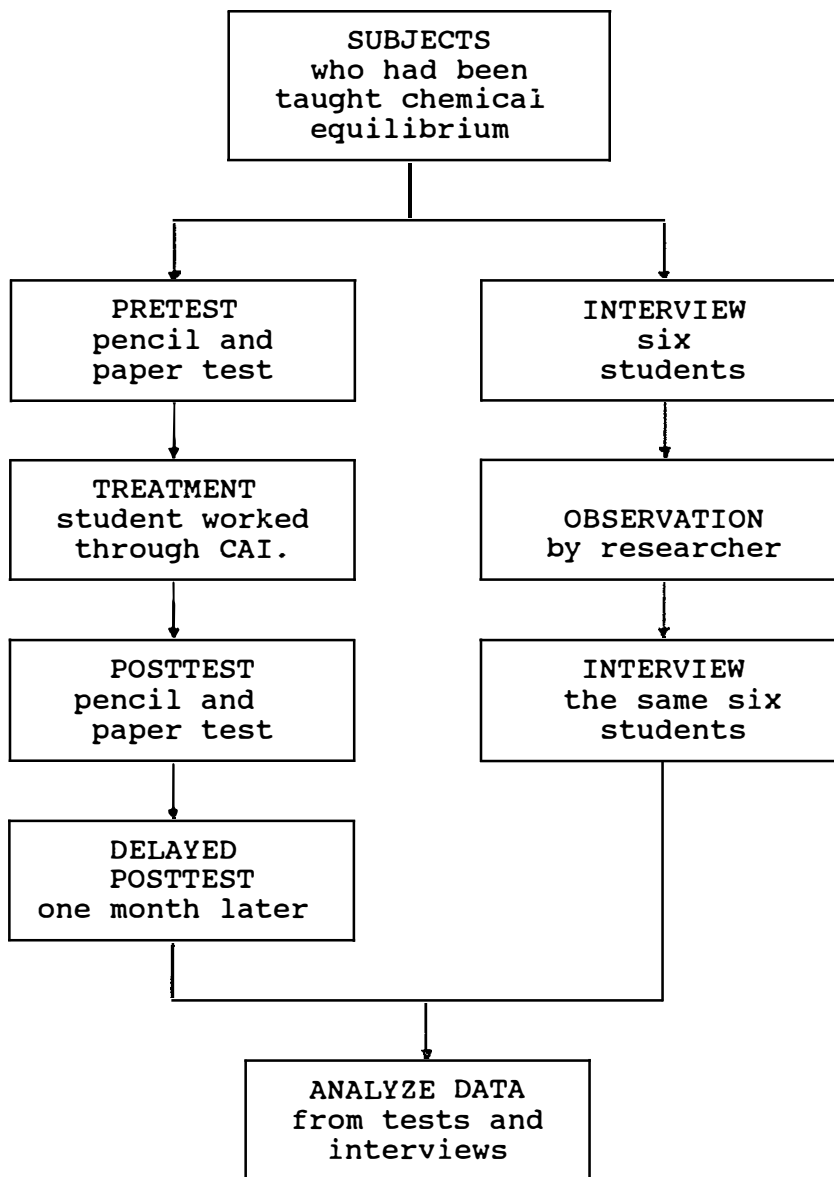


FIGURE 5

## Research Procedure

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The sequence of phases depicted in Figure 5 was followed closely in the actual study. As can be seen from the Figure, this study does not involve a control

group. One of the main reasons for including a control group in experimental designs is to improve the internal validity. After a careful consideration of the threats to internal validity, it was decided that its inclusion would not significantly increase the validity of the findings in the present study.

Gay (1981) discussed several factors which may contribute to internal invalidity including history, maturation, instrumentation, testing, statistical regression and mortality. Some of these factors, for example, statistical regression, become threats when sampling is involved.

History refers to the occurrence of any event which is not part of the experimental treatment but which may affect the scores on the posttest, for example, private reading. Students are unlikely to undertake new learning experiences during the experimental period. Students were told that the study did not form any part of their regular assessment. They were not told about the posttest until the time of its administration. To further reduce the threat posed by history, the pretest, treatment and immediate posttest were spaced close together (12 days) in time.

Effects due to maturation are also reduced by having the pretest, treatment and posttest taken close together; although evidence from previous research supports the assertion that maturation will affect the

study little. Numerous studies (Novak, 1988; Osborne & Wittrock, 1985) have shown that misconceptions are persistent and that traditional instruction rarely creates conceptual change.

The threat to internal validity by testing refers to the improved scores on the posttest resulting from the students having taken the pretest. To minimise this threat, the question papers and answer scripts were collected after both pretest and posttest. No feedback on the pretest was given.

The instrumentation factor refers to the unreliability of the test instruments. Since the same instrument was used in all three test situations of the experiment, any problems due to the use of different instruments at each test phase is eliminated. To minimize the practice effect from repeated exposure to the test, results of the tests were not divulged. Measures of reliability were calculated for the test instruments at all three test phases and were found to be high (coefficient alpha > 0.82). As mentioned previously, six students were "lost" during the treatment. To reduce this effect of mortality, their scores were taken out of the pretest analyses.

The study follows a mix of naturalistic and positivist research paradigms. This triangulation of data improves reliability and validity. To supplement and complement data from the pencil and paper tests,

structured interviews were conducted immediately before the pretest and posttest. Six students identified by the teacher as having average ability participated in the interviews. The interviews were recorded on audio tape with the permission of the students.

Thus, it was felt that sufficient caution has been taken to ensure internal validity without a control group. The inclusion of a control group would pose other threats to internal validity due to sampling. Since the entire population of the Grade 12 chemistry students at the Science Education Centre was 36, the incorporation of a control group would significantly reduce the total number available for treatment.

For the pretest, the test papers with answer sheets were distributed to the students in an examination setting. No time limit was given for the students to complete the tests. Most of the students finished the test in about 45 minutes. Both the question papers and the answer sheets were collected from the students when they had finished the test. All queries that arose during the tests were answered by the researcher. Three students clarified the meaning of the phrase "adjusted value" used in questions 16, 33, 34, and 35 of the test paper. No feedback on the performance on the pretest was given to the students.

Thirteen computers were available for use by students. Therefore, for the intervention, students

were divided into three groups. Each group went through the CAI package in two lessons each of one and a half hours duration. The researcher was present during the lessons as a participant observer. No queries were raised by the students. The students were given the worksheet described earlier.

BBC master series computers were used for the intervention. Medium resolution colour monitors were utilized as video display units instead of the modified televisions commonly used with BBC microcomputers in Western Australia. Colour monitors render the graphics and text a stability and resolution vastly superior to that provided by modified televisions.

Interviews with the six students who had been previously interviewed were held after they had finished the treatment phase of the study. As with the previous interviews, these interviews were also recorded on audio tape.

Three days after the last group of students worked through the CAI package, the posttest was held. Students would not have known that the pretest and the posttest were the same before taking the posttest. The posttest was held in the same environment as the pretest. The answer sheets and the test paper were collected after the test.

The delayed posttest was administered one month after the initial posttest. Its purpose was to

determine the degree of stability of changes effected using the conceptual change strategies. Previous studies have shown that misconceptions are tenacious and changes produced as a result of normal instruction are small and temporary (Eylon & Linn, 1988). Happs (1985) stated that regression to reliance on intuitive knowledge is common over a period of time. The delayed posttest is a feature that had been incorporated in very few conceptual change research designs.

The pretest, the posttest and the delayed posttest were all the same test developed by Garnett and Hackling (1984). Answers to the test were discussed with the students by the regular chemistry teacher following the delayed posttest.

#### Data Analysis

The intention of conducting interviews was to supplement the data from the tests which formed the backbone of the data in this study. Data from the tests are amenable to normal statistical analyses. Interview data are used to check the validity of the findings from quantitative data. The interview analysis consisted of coding the significant responses and creating categories of misconceptions.

In order to analyse the pretest for misconceptions, a statistical package called LERTAP was

used. LERTAP is a public domain software for test analysis. It is particularly suitable for multiple choice tests. The student responses for each item were entered into LERTAP. From these data, LERTAP was used to carry out an item analysis for the whole test. Item analyses include frequencies of each distractor for any item, correlation between distractors, item means, test averages, standard deviations and the reliability (coefficient alpha) of the test. LERTAP provides other useful statistics including individual profiles.

From distractor frequencies for any item, it is possible to work out the common misconceptions held by students. This is because each distractor represents a possible distinct misconception. The interviews were used to obtain corroborating evidence for the existence of particular misconceptions. If more than a quarter (25%) of the students had chosen a particular distractor, it was taken as representing a prevalent misconception. The 25% is an arbitrary figure but it helps to focus the study on significant misconceptions. From the LERTAP output, those distractors chosen with frequencies greater than 25% were listed as representing prevalent misconceptions among the subjects.

To find out whether the intervention had been effective, the posttest data were subjected to the same item analysis as the pretest. An initial indication of the success or failure of the intervention was gleaned

by comparing the mean scores for the pretest and posttest. Another indication of the effect of intervention was obtained by comparing the individual scores of the thirty students from the pretest and posttest. Tables of these results are included in the next chapter.

A more reliable comparison was obtained by carrying out a t-test on paired data from the two tests. LERTAP does not have a facility for carrying out such comparisons. Therefore, another statistical package, MINITAB, was used for this purpose.

The differences between the individual student scores for the pretest and posttest, while providing an indication of the degree of change, do not allow one to ascertain the effect of the intervention on individual misconceptions. This is because students with a particular misconception might have changed to another misconception following the intervention. The total score on the test could have been higher owing to the students responding correctly to other questions. To find the number of instances of students changing from a misconception in the pretest to the correct conception in the posttest, students who had a particular misconception in the pretest were noted. The posttest responses of these students were scanned to count the number of cases in which the student had selected the correct answer to the question on the posttest. The count obtained in this way constitutes a

measure of the success of the conceptual change strategy.

In the delayed posttest, the researcher's aim was to work out whether the students' changed conceptions were sustained. This information can be obtained from individual scores for the delayed posttest. The delayed posttest responses were analysed using LERTAP for individual scores and test reliability (coefficient alpha). The scores obtained were compared with those from the pretest and posttest. The results of these analyses are presented in the next chapter.

## CHAPTER 5

### Results

#### Introduction

This chapter presents the results of the analyses of data carried out to identify misconceptions and ascertain the effect of the intervention. First, the results of the tests to identify misconceptions prevalent in the test population are shown. This is followed by tables of posttest results after the intervention. The data in these tables indicate the success or failure of the intervention in remediating the misconceptions. Finally, tables and graphs summarizing the effects of time on the permanence of conceptual changes are presented.

#### Diagnosis of Misconceptions

In order to discuss the test analyses, it is easier to group the test items into categories. The categories used were based on Hackling and Garnett (1985). However, one category has been removed and one added. Table 3 shows how the items of the test were grouped into different categories. Other categorizations are possible. The reliability coefficient ( $\alpha$ ) calculated for the pretest was 0.82.

TABLE 3  
Categorization of the Test Items

Categories	Items
1. Approach to equilibrium	1 - 5
2. Characteristics of chemical equilibrium	6 - 15
3. Effect on concentrations	16-18, 24-26, 32-34
4. Initial effects on rates	19-21, 27-29, 36-38
5. Rates when equilibrium is re-established	22, 30, 39
6. Effect on K	23, 31, 40, 47
7. Catalysts - rates	41-43
8. Catalysts - concentrations	44-46

The distractors in the multiple choice test represent specific misconceptions not merely wrong responses. Where the item analysis indicated that more than 25% of the sample selected a particular distractor, this was taken as evidence of a prevalent misconception in the sample. Table 4 shows those distractors which were selected by more than 25% of the students in the pretest. Some misconceptions were very frequent, for example, those represented by the distractors 10 a and 20 c. It is important to note that several distractors may refer to one basic misconception. Therefore, although 27 items have been chosen with frequencies greater than 25%, there are less than 27 basic misconceptions.

TABLE 4

Distractors Selected by Greater than  
Twenty-Five Percent of the Students

Item	Distractor	Frequency (%)
1	c	46.7
2	b	26.7
5	b	56.7
8	a	33.3
9	a	53.3
10	a	70.0
13	b	46.7
14	a	50.0
20	c	73.3
22	a	63.3
26	c	26.7
27	b	66.7
29	b	36.7
30	a	46.7
32	a	40.0
33	a	26.7
34	a	30.0
36	c	30.0
37	c	50.0
38	c	30.0
39	a	66.7
41	d	50.0
42	d	50.0
43	d	53.3
44	d	36.7
45	d	33.3
46	d	36.7

The misconceptions represented by the distractors are listed below. The particular distractor(s) corresponding to the misconception and the frequency of the misconception in the sample of students are shown within brackets.

#### APPROACH TO EQUILIBRIUM

(1) [1c, 47%]

As equilibrium approaches, the concentrations of the reactants decrease and the concentration of

the products increase becoming equal at equilibrium.

(2) [2b, 27%]

Both forward and reverse reaction rates increase at the same rate as equilibrium approaches. Both rates are equal at equilibrium.

(3) [5b, 57%]

If the reaction quotient ( $Q$ ) is greater than the equilibrium constant ( $K$ ) then the system is not in equilibrium and more products would be formed.

#### CHARACTERISTICS OF EQUILIBRIUM

(4) [8a, 33%]

At equilibrium the concentrations of reactants equal the concentration of the product.

(5) [9a, 53%]

At equilibrium the concentration of NO equals the concentration of NOCl.

(6) [10a, 70%]

At equilibrium the concentrations of reactants and the product vary constantly as the reaction oscillates between reactants and product.

(7) [13b, 47%]

At equilibrium the rates of the forward and reverse reactions are not constant but equal.

(8) [14a, 50%]

At equilibrium the rates of the forward and reverse reactions are changing but equal.

## CHANGING EQUILIBRIUM CONDITIONS

## Effect on concentration

(9) [26c, 27%]

When equilibrium is re-established following an increase in temperature, the concentration of  $\text{NOCl}$  will be greater than at the initial equilibrium.

(10) [32a, 40%]

When the volume of a system at equilibrium is instantaneously reduced, the concentrations of all species of the system are unchanged.

(11) [33a, 27%]

When equilibrium is re-established following a volume decrease, the concentration of  $\text{NO}$  will be greater than the adjusted value.

(12) [34a, 30%]

When equilibrium is re-established following a volume decrease, the concentration of  $\text{Cl}_2$  will be greater than the adjusted value.

## Initial effects on rates of reactions

(13) [20c, 73%]

When the system at equilibrium is disturbed by increasing the concentration of  $\text{NO}$ , the reverse reaction rate will instantaneously decrease.

(14) [27b, 67%]

When the system at equilibrium is disturbed by increasing the temperature, the rate of the forward reaction will instantaneously decrease.

(15) [29b, 37%]

When the system at equilibrium is disturbed by increasing the temperature, the rate of the forward reaction will be greater than the rate of the reverse reaction.

(16) [36c, 30%; 37c, 50%; 38c, 30%]

When the system at equilibrium is disturbed by decreasing the volume, the rates of both forward and reverse reactions will decrease; but, the forward rate will be less than the reverse rate.

Rates of reactions when equilibrium is re-established

(17) [22a, 63%]

When equilibrium is re-established following an increase in the concentration of NO, the rates of forward and reverse reactions will be equal to those at the initial equilibrium.

(18) [30a, 63%]

When equilibrium is re-established following an increase in temperature, the rates of forward and reverse reactions will be equal to those at the initial equilibrium.

(19) [39a, 67%]

When equilibrium is re-established following a decrease in volume, the rates of forward and reverse reactions will be equal to those at the initial equilibrium.

Effect on equilibrium constant

No distractor was selected with a frequency greater than 25%.

## EFFECT OF CATALYSTS

## Effect on rates

(20) [41d, 50%; 42d, 50%; 43d, 53%]

When a catalyst is added to the system at equilibrium, the rates of the forward and reverse reactions are either unchanged or increased depending on whether the catalyst favours the forward or reverse reaction.

## Effect on concentrations

(21) [44d, 37%; 45d, 33%; 46d, 37%]

When a catalyst is added to the system at equilibrium, the concentrations of NO, Cl<sub>2</sub> and NOCl (i.e. all the species in the reaction) will change (increase or decrease) depending on the effect of the catalyst.

Altogether 21 basic misconceptions are listed above. The categories can be broadened and the total number reduced by subsuming some misconceptions into others.

The evidence from the interviews supports the existence of these misconceptions. As previously mentioned, the students were given response sheets for use in answering some interview questions. These response sheets were collected and used for analysis with the interview data.

The response sheets clearly indicate the type of misconceptions students have about the nature of

equilibrium and equilibrium concentrations. The two graphs in Figure 6 are typical responses to the interview question, "Can you draw a graph showing the rates of reactions from the start of the reaction until equilibrium is achieved?" The graphs 1 and 2 correspond to misconceptions 1 and 2 outlined above.

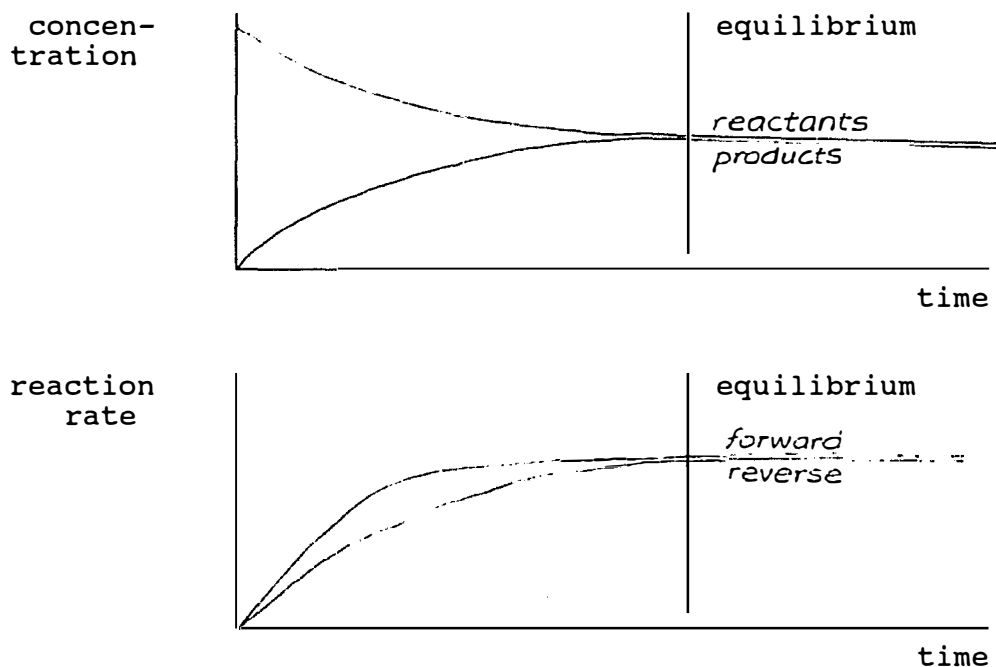


FIGURE 6

Typical Student Graphs as  
the System Approaches Equilibrium

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To illustrate the agreement between the results of the interviews and tests and, therefore, the convergent validity of the instruments, the students' responses on these instruments regarding misconceptions are compared. These data are presented in Table 5.

TABLE 5  
 Agreement Between Students' Responses  
 on the Pretest and Interviews

Item	Dis- tractor	Subjects interviewed						Proportion agreement
		1	2	3	4	5	6	
1	c	d	a	a	a	a	a	0.83
2	b	a	a	a	a	d	a	0.83
5	b	a	a	d	d	d	d	0.33
8	a	a	a	a	d	d	a	0.67
9	a	a	a	a	d	a	a	0.83
10	a	a	a	a	a	a	a	1.00
13	b	d	a	a	a	a	a	0.83
14	a	a	a	a	a	d	a	0.83
20	c	a	a	a	a	a	d	0.83
22	a	a	a	d	a	d	a	0.50
26	c	a	d	a	a	a	d	0.67
27	b	a	a	d	a	a	a	0.83
29	b	a	d	a	d	a	a	0.67
30	a	a	d	a	d	a	a	0.50
32	a	a	a	d	a	d	a	0.67
33	a	a	a	a	d	a	a	0.83
34	a	d	a	a	a	d	a	0.67
36	c	d	a	a	d	a	a	0.67
37	c	a	d	a	a	a	a	0.83
38	c	d	a	a	d	a	d	0.50
39	a	a	a	a	d	a	a	0.83
41	d	a	d	d	a	a	a	0.67
42	d	a	d	a	a	d	a	0.67
43	d	a	d	d	d	d	a	0.50
44	d	a	d	a	a	d	a	0.67
45	d	a	a	a	d	a	a	0.83
46	d	a	a	a	a	d	a	0.83
Proportion agreement		0.81	0.74	0.74	0.63	0.55	0.81	<u>0.72</u>

Note. a Agreement between subjects' responses on the two instruments.

d Disagreement between subjects' responses on the two instruments.

If a student's responses to the interview question and the test item were similar, the responses were coded with an 'a' to signify agreement. If the responses to the two instruments regarding the same misconception are different, then the responses were coded with a 'd'

to signify disagreement. The agreement between responses on the two instruments, for all misconceptions, was 0.72 of cases.

Since all the students who participated in the test were not interviewed, total congruency between the results of the test data and interview data cannot be established. However, within the limits imposed by the number of interviews, the interview data are comparable with the test data as shown in tables 4 and 5. The purpose of the interviews was to obtain qualitative data about the nature of misconceptions. To illustrate the nature of misconceptions, the responses of a typical student (S2) to the questions regarding catalysts is reproduced below.

I: What do you think will happen to the rates of the reaction when a catalyst is added to the system?

S2: Rate of forward reaction will increase.

I: What about the rate of the reverse reaction?

S2: Constant.

I: What you are saying is that a catalyst increases the rate of forward reaction and not the reverse reaction, OK?

S2: That is assuming that the catalyst favours the forward reaction.

I: You mean a catalyst favours either the forward reaction or reverse reaction?

S2: It usually favours [the] forward reaction.

I: And not the reverse reaction? So, if we want to ... increase the rate of reverse reaction we have to put a different type of catalyst?

S2: Yes.

The direction-specific nature of catalysts was found to be a misconception of about half (51%) of the students interviewed (distractors 41d, 42d, 43d of Table 4). The students linked the effect of catalysts on concentrations with the misconstrued directional specificity of the catalyst. They noted that if the catalyst favoured the forward reaction then the concentration of products would be increased and vice versa.

#### Effect of the Intervention

In order to determine the effectiveness of the intervention, the posttest results were compared with the pretest results. Three kinds of comparisons were made, (1) the total score of each student on the pretest was compared with the score from the posttest, (2) the frequencies of misconceptions in the pretest and posttest were compared, and (3) the number of students who changed from the misconception to the correct conception were compared. Table 6 shows the results of the first comparison.

TABLE 6  
Comparison of Students'  
Pretest and Posttest Scores

Student number	Pretest score(%)	Posttest score(%)	Increase (%)
1	57.5	76.6	19.1
2	78.7	91.5	12.8
3	70.2	83.0	12.8
4	51.1	40.4	-10.6
5	74.5	72.3	-2.1
6	63.8	78.8	14.9
7	74.5	70.2	-4.3
8	40.4	66.0	25.5
9	48.9	78.7	29.8
10	44.7	48.9	4.3
11	66.0	87.2	21.3
12	83.0	91.5	8.5
13	44.7	61.7	17.0
14	40.4	74.5	34.0
15	29.8	59.6	29.8
16	34.0	57.4	23.4
17	38.3	55.3	17.0
18	44.7	61.7	17.0
19	68.1	83.0	14.9
20	72.3	95.7	23.4
21	46.8	72.3	25.5
22	59.6	74.5	14.9
23	46.8	66.0	19.1
24	42.6	53.2	10.6
25	57.4	72.3	14.9
26	68.1	78.7	10.6
27	51.1	57.4	6.4
28	85.1	97.9	12.8
29	66.0	95.7	29.8
30	55.3	76.6	21.3

In most cases, there was an increase in the score from the pretest to the posttest. In a few cases the posttest score is lower than the pretest score.

A one-tailed t test for paired data indicates that the students' mean posttest score (72.6) was significantly greater than the mean pretest score (56.8),  $t(29) = 8.39$ ,  $p < 0.001$ . The mean scores and standard deviations are shown in Table 7.

TABLE 6  
Comparison of Students'  
Pretest and Posttest Scores

Student number	Pretest score(%)	Posttest score(%)	Increase (%)
1	57.5	76.6	19.1
2	78.7	91.5	12.8
3	70.2	83.0	12.8
4	51.1	40.4	-10.6
5	74.5	72.3	-2.1
6	63.8	78.8	14.9
7	74.5	70.2	-4.3
8	40.4	66.0	25.5
9	48.9	78.7	29.8
10	44.7	48.9	4.3
11	66.0	87.2	21.3
12	83.0	91.5	8.5
13	44.7	61.7	17.0
14	40.4	74.5	34.0
15	29.8	59.6	29.8
16	34.0	57.4	23.4
17	38.3	55.3	17.0
18	44.7	61.7	17.0
19	68.1	83.0	14.9
20	72.3	95.7	23.4
21	46.8	72.3	25.5
22	59.6	74.5	14.9
23	46.8	66.0	19.1
24	42.6	53.2	10.6
25	57.4	72.3	14.9
26	68.1	78.7	10.6
27	51.1	57.4	6.4
28	85.1	97.9	12.8
29	66.0	95.7	29.8
30	55.3	76.6	21.3

In most cases, there was an increase in the score from the pretest to the posttest. In a few cases the posttest score is lower than the pretest score.

A one-tailed t test for paired data indicates that the students' mean posttest score (72.6) was significantly greater than the mean pretest score (56.8),  $t(29) = 8.39$ ,  $p < 0.001$ . The mean scores and standard deviations are shown in Table 7.

TABLE 7  
Students Mean Pretest and  
Posttest Scores and Standard Deviations

	Mean	Standard deviation
Pretest	56.8	15.1
Posttest	72.6	14.7
t	8.39*	

\*  $p < 0.001$ , one-tailed t test for paired data

TABLE 8  
Percentage of Misconceptions  
in the Pretest and Posttest

Item	Distractor	Pretest(%)	Posttest(%)	Decrease(%)
1	c	46.7	20.0	26.7
2	b	26.7	26.7	0.0
5	b	56.7	43.3	13.4
8	a	33.3	13.3	20.0
9	a	53.3	23.3	30.0
10	a	70.0	70.0	0.0
13	b	46.7	20.0	26.7
14	a	50.0	16.7	33.3
20	c	73.3	33.3	40.0
22	a	63.3	10.0	53.3
26	c	26.7	13.3	13.4
27	b	66.7	30.0	36.7
29	b	36.7	20.0	16.7
30	a	46.7	13.0	33.4
32	a	40.0	16.7	23.3
33	a	26.7	26.7	0.0
34	a	30.0	26.7	3.3
36	c	30.0	16.7	13.3
37	c	50.0	46.7	3.3
38	c	30.0	10.0	20.0
39	a	66.7	20.0	46.7
41	d	50.0	13.3	36.7
42	d	50.0	30.0	20.0
43	d	53.3	23.3	30.0
44	d	36.7	23.3	13.4
45	d	33.3	23.3	10.0
46	d	36.7	30.0	6.7

Table 8 shows the frequencies of the misconceptions on the pretest and posttest. The

frequencies are shown as percentage of students selecting a particular misconception. The incidence of misconceptions has been reduced by the intervention in most cases. For some misconceptions the change is very great. However, this table may be a little misleading. It is possible that the result of the intervention is to change the misconception in an unexpected way. For example, a student who is known to have a misconception may change to another misconception and not to the correct conception.

TABLE 9

Percentage of Students who Changed from a  
Misconception to the Correct Conception

Item	Dis- tractor	Incidence at pretest	Number changed	Percent changed
1	c	14	6	42.9
2	b	8	2	25.0
5	b	17	8	47.1
8	a	10	6	60.0
9	a	16	9	56.3
10	a	21	4	19.0
13	b	14	10	71.4
14	a	15	13	86.6
20	c	22	6	27.3
22	a	19	18	94.7
26	c	8	3	37.5
27	b	20	12	60.0
29	b	11	6	54.5
30	a	14	11	78.6
32	a	12	8	66.7
33	a	8	4	50.0
34	a	9	4	44.4
36	c	9	3	37.5
37	c	15	5	33.3
38	c	9	6	66.7
39	a	20	10	50.0
41	d	15	10	66.7
42	d	15	5	33.3
43	d	16	9	56.3
44	d	11	5	45.5
45	d	10	4	40.0
46	d	11	2	18.2

In order to measure the real effectiveness of the intervention, what is important is the actual number of instances in which a student displaying a particular misconception changed to the scientifically correct conception. To identify these instances, the posttest results were scanned for the students who previously held the misconception but had changed to the correct conception. The results of this analysis are shown in Table 9. In all the cases, the intervention has been successful in changing the misconceptions to correct conceptions, albeit to different degrees. The intervention is very effective in changing some misconceptions, for example 22a, but less successful for others, for example 10a. This differential efficacy of the intervention is discussed in the next chapter.

The reliability coefficient ( $\alpha$ ) of the posttest was 0.84. Corroborating evidence for the effectiveness of the intervention was obtained from the interview data. For example, four out of the six students interviewed drew correct graphs for the change in concentrations as the system approached equilibrium. The other two students drew graphs which showed equal concentrations of reactants and products at equilibrium. In the initial interviews none of the six students drew correct graphs. To illustrate the nature of change, the responses of one student (S6) to

questions regarding catalysts in the pre-interview and post-interview are written below:

I: What do you think will happen to the rates of the reaction when a catalyst is added to the system?

Pre-interview:

S6: The rate is going to be faster. But, is this going to help the forward reaction or the backward reaction?

I: What do you think?

S6: I thought that there are catalysts to increase the backward reactions also in some cases.

I: You mean sometimes the catalyst increases the backward reaction and sometimes it increases....

S6: Yes.

Post-interview:

S6: Rate of forward and reverse [reactions] will increase.

I: Will they increase equally or differently?

S6: Equally.

I: What will happen to the concentrations of all the substances involved?

Pre-interview:

S6: If it's going to help the forward reaction then the concentration of  $\text{NOCl}$  will increase.

Post-interview:

S6: Concentrations will not change.

Both the interviews and the tests indicate that the intervention has resulted in a number of conceptual changes in the students.

The researcher was present during the intervention phase of the research. Students were requested to seek help from the researcher if they had any queries. All students worked through the package seemingly absorbed in it. It was observed that many students went through different modules more than once. No questions were raised by the students.

Permanence of Remediation

In order to see whether the conceptual changes that had occurred in the sample were long-lasting, the posttest was administered again, exactly 30 days after the initial posttest. The results of this test are shown in Figure 7. For comparison, the pretest and the initial posttest results are also included.



Figure 7 shows that the conceptual changes have been, for the most part, long-lasting. A one-tailed t test for paired data indicates that the students' mean delayed posttest score (69.6) was significantly greater than the mean pretest score (56.8),  $t(29) = 5.97$ ,  $p < 0.001$ . The mean scores are shown in Table 10.

TABLE 10  
Students Mean Pretest, Posttest and Delayed Posttest Scores and Standard Deviations

	Mean (%)	Standard deviation
Pretest	56.8	15.08
Delayed posttest	69.6	17.0
t	5.97*	

\*  $p < 0.001$ , one-tailed t test for paired data

The mean scores for the pretest, posttest and the delayed posttest are shown graphically in Figure 8.

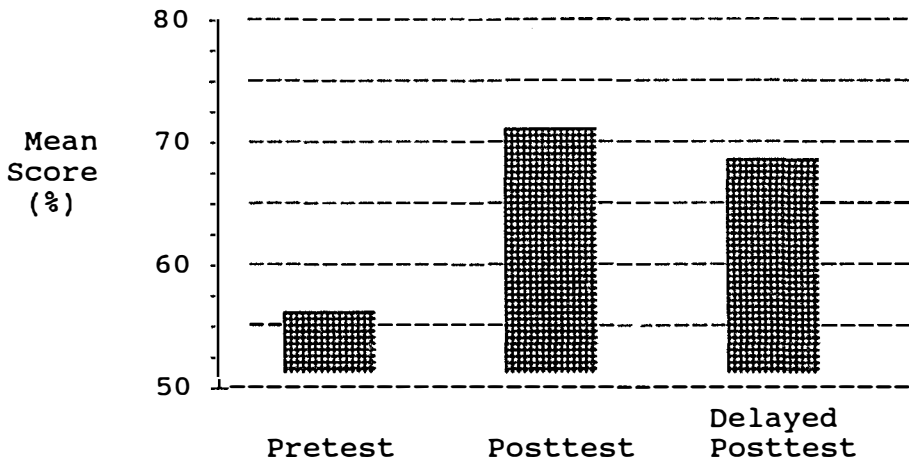


FIGURE 8

Long Term Effect of Intervention

The mean score has fallen by only 3% in 30 days from the posttest to the delayed posttest.

The results of this study indicate that misconceptions about chemical equilibrium are prevalent among Grade 12 chemistry students in the Maldives. In addition, the results also show that the intervention using the CAI package produced significant and lasting conceptual changes in students holding the misconceptions.

## CHAPTER 6

### Discussion

#### Introduction

This chapter discusses the misconceptions identified in Maldivian students, their incidence and origin, and compares them with misconceptions previously reported for a sample of Western Australian students. The differential efficacy of the intervention on misconceptions is also discussed. In so doing, an attempt is made to identify features of the package that could have contributed to the success or failure of different modules in engendering conceptual change.

#### The Type and Incidence of Misconceptions Held by Maldivian Students

A key objective of this thesis was to find out the misconceptions held by Grade 12 chemistry students from the Maldives. The misconceptions and the percentage of students having those misconceptions have been stated in the previous chapter. This section discusses the more significant of these misconceptions in greater detail.

Approximately half of the students seem to have misconceptions about how the concentrations of products

and reactants vary as the system approaches equilibrium. Most of these students tend to think that equilibrium denotes equal concentrations of products and reactants. This finding is consistent with other misconceptions about the characteristics of chemical equilibrium. If students can understand the features of an equilibrium system, it is likely that misconceptions in other areas of the topic can be significantly reduced. Students tend to take equal concentrations of products and reactants as the most significant feature of a system in equilibrium instead of the constancy of concentrations.

The scores on pretest item 5 were difficult to interpret. In the test item, the equilibrium constant ( $K$ ) at a certain temperature was given. The students were required to predict the direction of the reaction from the concentrations of all the species. The students would have to calculate the reaction quotient ( $Q$ ) and compare it with  $K$  to predict the direction. The calculations and the involved reasoning required to arrive at the correct response may, in part, explain why 43% of the students got this item wrong. The involved nature of the item makes it inappropriate to deduce a single misconception from the scores for the item.

Most students successfully used Le Chatelier's Principle to predict changes of concentrations following changes to reaction conditions. However,

many students failed to correctly predict the reaction rates following these changes. The data indicate that some students have used the Principle to predict rates. These students seem to be unaware of the limitations and the scope of applicability of Le Chatelier's Principle. More than 60% of the students cannot correctly compare the equilibrium rates before and after a change.

Misconceptions about the role of catalysts were common. Both interview and test data indicate that students did not understand the nature, effect and role of catalysts. The most significant misconception was the notion that a catalyst affects the rates of forward and reverse reactions differently. Other less common misconceptions are: (1) catalysts have no effect on the reverse reaction rate; (2) catalysts decrease the reverse reaction rate; (3) catalysts increase the concentrations of products; and (4) concentrations of all the species are changed depending on whether the catalyst increases the forward or reverse reaction rate.

#### Comparison of Misconceptions with Those from Previous Studies

The subsidiary research question of this thesis addressed comparisons of the incidence of misconceptions between Maldivian students and Western Australian students. Such a comparison would provide

TABLE 11

Percentage of Students Having Certain Misconception  
in Western Australia (WA) and the Maldives

Misconception	Percentage of students	
	Maldives	WA <sup>a</sup>
<b>APPROACH TO EQUILIBRIUM</b>		
1. Forward rate increases as the reaction gets going.	23	27
2. Reverse reaction rate is the same as the forward rate.	17	27
<b>CHARACTERISTICS OF EQUILIBRIUM</b>		
3. There is a simple arithmetical relationship between the concentrations of reactants and products.	50	43
<b>CHANGING EQUILIBRIUM CONDITIONS</b>		
Effect on concentration		
4. After the [NO] is instantaneously increased the [NO] remains the same.	17	10
Initial effects on rates of reactions		
5. When the [NO] is increased the rate of the reverse reaction is decreased.	43	73
6. When the temperature is increased the rate of the forward reaction is decreased.	57	67
7. When the volume is decreased the rate of the reverse reaction is decreased.	63	50
Rates of reactions when equilibrium is re-established		
8. When equilibrium is re-established the rates of the forward and reverse reactions will be equal to those at the initial equilibrium.	31	59
Effect on equilibrium constant		
9. When (a) volume is decreased or (b) [NO] is increased, the equilibrium constant K is greater than under the initial conditions.	(a) 30 (b) 20	20 23
10. Equilibrium constant is not affected by an increase in temperature.	27	17
Effect of a catalyst		
11. A catalyst can affect the rates of the forward and reverse reactions differently.	27	50

Note. <sup>a</sup> Percentages as reported by Hackling and Garnett (1985).

evidence of the similarities or differences of misconceptions across countries and cultures.

The comparison data is presented in Table 11. In reading the results several points have to be considered. The misconceptions reported by Hackling and Garnett (1985) were identified using interviews. In this study both an interview and a test were used for identifying misconceptions. The written test was not used on Grade 12 students in WA. Therefore a lot more misconceptions were found in the Maldives because the test is more extensive than the interview. Hence, only common misconceptions could be compared. Some items of the test correspond to the same basic misconception. Therefore for comparison, the mean frequencies of those items have been used. For example, Hackling and Garnett (1985) gave three percentages for misconception number eight in Table 11 because it corresponded to three separate propositions. In Table 11 which summarizes the comparisons, the mean values of the reported percentages for this particular misconception have been used.

As Table 11 shows, the incidences of misconceptions in both countries are comparable. The mean percentages for the 11 misconceptions differ by only five percent. The largest differences occur in misconceptions related to the use of Le Chatelier's Principle and the effect of catalysts. In particular, for misconceptions five, eight and eleven the

differences are over 20%. Since the instruments used in both cases are different, one cannot rule out the effect of a differential sensitivity of the two instruments to the detection of misconceptions.

This study was based on one particular chemical system. Hence, caution must be exercised in generalizing the student misconceptions to all chemical equilibrium systems.

#### Approach To Equilibrium

Rates. Only Hackling and Garnett (1985) have reported misconceptions in this area. They found that many students (23%) believed that the forward reaction rate increases as the reaction gets going. Another misconception was that the reverse rate is the same as the forward rate. The latter misconception was held by 17% of the students in their sample. In the present study these two misconceptions were held by 27% of the Maldivian students.

Concentrations. Misconceptions of concentration changes as the system approaches equilibrium had not been reported previously. This study found that a very common misconception (47%) was that as equilibrium approaches, the concentrations of the reactants decrease and the concentration of the products increase becoming equal at equilibrium.

### Characteristics of Chemical Equilibrium

The nature of the equilibrium, and the factors affecting the equilibrium condition of a chemical system are the most widely misunderstood notions in this topic. The findings of this study are in concordance with previous studies. Individual misconceptions are discussed below.

Rate vs extent. A pervasive misconception among chemistry students appears to be a confusion between rate and extent of a reaction. Some students believe that rate governs the extent, others think that the forward and reverse rates are constantly changing. The confusion between rate and extent was first reported by Driscoll (1960). Since then Wheeler and Kass (1978), Camacho and Good (1989), and Cachapuz and Maskill (1989) had reported the misconception. Half of the students in this study thought that at equilibrium, the rates of forward and reverse reactions are changing but equal.

Chemical equilibrium as a static phenomenon. Students commonly believe that chemical equilibrium is not a dynamic phenomenon. Previously reported misconceptions in this area include reversibility as a physical reversing of movement (Cachapuz & Maskill, 1989); left- and right-handedness (Gorodetsky & Gussarsky, 1986; Johnstone et al., 1977) and chemical equilibrium when everything is equal (Cachapuz &

Maskill, 1989). Left- and right-handedness relates to the notion that equilibrium consists of two independent and separate compartments rather than the one whole. Akin to these static notions of equilibrium is the misconception that the concentrations of reactants and products vary constantly as the reaction oscillates between reactants and products. The latter misconception had an incidence of 70%, the second highest found in this study.

Equilibrium concentrations. The Western Australian study by Hackling and Garnett (1985) found that students believe that there is a simple arithmetical relationship between the concentrations of reactants and products; in their study 50% of the students had this misconception. The corresponding figure found in this study was 47%. The most common misconception was that the concentrations of reactants and products are given by the coefficients of the respective species in the reaction equation. Gorodetsky and Gussarsky (1986) found that 31% of the students in their sample interpreted the constant composition at the equilibrium state as being identical to the stoichiometry of the reaction. In this study, the frequency for this particular misconception was 33%. Cachapuz and Maskill (1989) found the related idea of equilibrium when everything is equal was a prevalent notion among students. Two other difficulties

students seem to have in this area are an inability to appreciate that,

(a) certain substances display a fixed or constant concentration in certain chemical reactions (Wheeler & Kass, 1978), and

(b) the proportionality between concentration and partial pressure is true only for certain conditions (Camacho & Good, 1989).

Both these misconceptions were not addressed in this study as they involve concepts not included in Year 12 syllabuses.

#### Changing Equilibrium Conditions

The misconceptions about the effects of changing equilibrium conditions arise from faulty statements of Le Chatelier's Principle and its application to systems not in thermodynamic equilibrium (Driscoll, 1960; Gorodetsky & Gussarsky, 1986). Hackling and Garnett (1985) reported several instances where the Principle was applied with erroneous results. The major misconceptions are found in students' ideas about the initial effects of changing the conditions, the equilibrium rates after a change and the effect on equilibrium constant following a change. They also found that students had misconceptions about the variables that influence the value of the equilibrium constant. Camacho and Good (1989) found similar misconceptions. However, the corresponding

misconceptions found in this study had an incidence lower than the threshold frequency (25%). It is possible that classroom instruction in this area addressed student misconceptions, albeit, unwittingly. More research needs to be done to find the cause of the lower incidence.

In the study by Hackling and Garnett (1985), the average frequencies of misconceptions about the initial effects of changing conditions on reaction rates was 54%. In this study the same misconceptions had a frequency of 53%. However, there was a wide variation in the two studies between frequencies of misconceptions about the rates of reactions when equilibrium is re-established. Hackling and Garnett (1985) stated an average frequency of 31% for these misconceptions, whereas the frequency found in this study is 64%.

### Catalysts

Students have the misconception that there are separate catalysts for the forward reaction and the reverse reaction. All the other misconceptions they have about catalysts seem to be derived from this misconception and are consistent with it. Students believe that if a catalyst favours the forward reaction, then the reverse reaction rate is unaffected and the product concentration will increase. The findings of this study are in exact concordance with

those of Johnstone et al. (1977), Gorodetsky and Gussarsky (1986) and Hackling and Garnett (1985).

#### Other misconceptions

Two misconceptions found in some other studies were not considered in this study because they were outside the syllabus requirements of Grade 12 chemistry. They are about heterogeneous systems and systems which contain more than one equilibrium. Students fail to identify the relevant or irrelevant elements in a heterogeneous system when considering a chemical equilibrium state. As an example, many students try to apply Le Chatelier's Principle to find the response to changes in the amount of solids. The second misconception is displayed by the students who fail to consider the effect of a particular change on all equilibria which may be involved.

Despite the differences, the overall impression conveyed by the results is that the same pattern of learning difficulties exist between students in the Maldives and those in Western Australia. They, in turn, point to almost "natural" causes for these misconceptions within the students' cognitive structure. These issues are discussed in the following sections.

The Origin of Misconceptions  
about Chemical Equilibrium

This section briefly describes the origin of misconceptions about chemical equilibrium. The discussion is based on experience-based conjectures arising from the author's involvement in the development of the CAI package, testing and remediation of students and related literature.

Most students who study chemical equilibrium have come across the concept of equilibrium previously. In the author's sample, the majority of students concurrently study physics in addition to chemistry. All of them had studied Ordinary Level physics in high school. There are a number of instances in physics where the different concept of equilibrium is taught and learned. The study of moments, is an example. However, in this context and in everyday balancing situations, equilibrium acquires attributes of staticity and oscillation that are characteristic of these instances. Students could transfer this knowledge easily to chemical equilibrium where the system although appearing to be macroscopically static and stable is, in fact, dynamic at a microscopic level. The related notion of right- and left-handedness could also be attributed to students' association of chemical equilibrium with equilibrium in physics. Gussarsky and Gorodetsky (1990) gave a similar explanation for this misconception.

Many students thought that the concentration of reactants decreases and the concentration of products increases, becoming equal at equilibrium. Forty-seven percent of the students had this misconception. This could have been derived easily from the physics concept of equilibrium where the clockwise and anti-clockwise moments must be equal.

The frequencies of misconceptions regarding the rates of reactions when equilibrium is re-established after changes, were generally high (> 63%). The majority of the students seem to think that equilibrium reaction rates are unchanged following changes to reaction conditions. It is possible that students were trying to apply their knowledge of the staticity of physical equilibrium to chemical equilibrium.

As systems approach equilibrium, many students believe that the rates of both forward and reverse reactions increase. This misconception may result from their everyday experiences and chemistry lessons. Many reactions increase their rates as they get underway. Burning and heating are instances with which every student would be familiar. Most students are familiar with exothermic reactions in which the liberated heat increases the rate, further increasing the heat liberated. For example, when a piece of magnesium ribbon is placed in dilute acid it takes several seconds before the surface oxide layer is dissolved and

rapid evolution of hydrogen takes place. Such reactions do increase their rate as time goes by. The physics concept of overcoming inertia for acceleration could also contribute to this misconception.

A common misconception among students is the tendency to interpret the constant composition at the equilibrium state as being identical to the stoichiometry of the reaction. This misconception may be attributed to the considerable emphasis placed on reaction stoichiometry in introductory chemistry topics (Hackling & Garnett, 1985).

The application of Le Chatelier's Principle has been reported as another area of student difficulty. However, the level of misconceptions about the Principle found in this study is comparatively low. Driscoll (1960) argued that the difficulties arise from faulty statements of the Principle taught in school. Wheeler and Kass (1978) stated that the limitations of the Principle are not taught to students and examples of systems where the Principle cannot be used are not discussed in classes. These twin factors could explain many of the difficulties students have in using the Principle.

If students understand the action of the catalysts in lowering the activation energy, it is unlikely that they would display misconceptions about them. Many students have transferred their ideas of catalysis from

completion reactions to equilibrium systems. In completion reactions, the two-way reaction path between products and reactants are not generally discussed, that is, the reverse reaction is not considered. This omission abets the student to tacitly, and justifiably, form the view that catalysts are specific for one particular direction of a reversible system.

Many of the misconceptions held by students, therefore, appear to result from previous exposure to various concepts of chemistry and everyday experience, and the failure of teachers and textbook writers to directly address these misconceptions. There is a need to undertake research to determine the origin of misconceptions; the above discussion is based on conjectures as mentioned previously.

#### The Effectiveness of the Intervention

A conceptual change strategy is only effective if it is successful in changing misconceptions and these changes are retained in the long term. The directional hypothesis of the intervention aspect of this study would be that there is an increase in the number of correct responses on the test following the intervention.

As shown in Tables 6 and 7, there was a marked change in the student responses following the intervention with some of the individual changes being

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As shown in Tables 6 and 7, there was a marked change in the student responses following the intervention with some of the individual changes being

particularly striking. The changes were highly significant and the directional hypothesis can be accepted. In the rest of this section an attempt is made to relate the different extent of change to features of the remedial programme. For ease of discussion, the changes can be divided into two groups, those items which show changes greater than 50% and those less than 30%. If key features of the package that resulted in large conceptual changes could be identified, improvements in the package could be effected. The findings could also lead to recommendations for the development of other packages.

#### Large Changes (i.e. > 50%).

The items that showed very large changes were: 8a, 9a, 14a, 22a, 27b, 29b, 30a, 32a, 38c, 39a, 41d and 43d. In all these cases, the misconceptions were emphasized by Hackling and Garnett (1985). Therefore, the misconceptions were thoroughly addressed by individual modules in the CAI packages. For example, items 8a and 9a relate to the misconception that the concentration of products and reactants are equal at equilibrium. The change is large probably because in the package a lot of emphasis is placed on remediating this misconception; in particular, stress is placed on the fact that the concentration of all species are not equal, but represent a constant ratio at equilibrium. A number of dynamic graphs and interaction opportunities were provided for this conception. The

greater part of Module 4 is devoted to bring about this change. The conceptual change model is closely followed in the module.

Misconceptions represented by items 41d and 43d showed significant changes. Here the misconceptions relate to the incorrect notion that a catalyst can affect the rates of forward and reverse reactions differently. In the package, considerable emphasis is placed on this misconception. In module 6 the student is first prompted to predict the effect of the catalyst on the rate of a system. The cognitive conflict involved the display of a graph which showed that both forward and reverse rates increased equally when a catalyst is added. The explanation phase discussed the reduced activation energy required in the presence of a catalyst, and that a low-energy reaction path is available for both forward and reverse reactions. The application phase involved prediction of the effect of a catalyst on concentrations and reaction rates of various systems.

#### Small Changes (i.e. <30%).

The items which showed small changes were 2b, 10a and 46d. These are discussed individually below.

Item 2b of the multiple choice test. The identification of this misconception regarding reaction rates approaching equilibrium involved interpreting graphs. In the distractor corresponding to this

misconception the forward rate and reverse rate were shown graphically as the system approaches equilibrium. Two graphs were used; one for the forward rate and the other for the reverse rate. In the package, there are many rate graphs but in all the cases, both rates are plotted on the same axes. It is possible that difficulties about the interpretation of the graphs in the test contributed to the small change from the pretest score to the posttest score. Further research is needed to clarify this possibility.

Item 10a of the multiple choice test. There are possibly a number of causes for the small change in the student scores between the pretest and posttest in this case. In the test item corresponding to this misconception, the student has to mark true or false for the following statement:

When equilibrium is established, the concentrations of reactants and products vary constantly as the reaction oscillates between reactants and products.

It is possible that the wording of the question may be responsible for the small change. The notion of oscillation is often used in connection with equilibrium in physics. The misconception is related to the idea of left- and right-handedness and staticity of chemical equilibrium, a misconception widely held as reported in a number of research articles. Because

Hackling and Garnett (1985) did not make explicit mention of this misconception it was not specifically addressed in the development of the package.

Item 46d of the multiple choice test. The misconception indicated by this distractor is closely related to those indicated by 44d and 45d. These misconceptions relate to the notion that the catalyst's effect on concentration is dependent on whether the catalyst favours the forward or reverse reaction. This misconception was common as this study showed. However, these misconceptions were not reported in Hackling and Garnett (1985). The effect of the catalyst on concentrations was, therefore, not specifically addressed in the design of the package. No attempt was made to create cognitive conflict in these two frames.

As the previous discussion shows, the large changes correspond to those instances where the conceptual model was closely followed, generated cognitive conflict, and where the simulation, explanation and application phases use meaningful and striking graphics. The small changes are associated with the lack of emphasis on those misconceptions in the package. The implications of these findings are important for future revisions of the package to make it more suitable for remediation in different school populations.

Hewson and Thorley (1989) have noted that students may change their misconceptions following intervention for a while but may revert back to the original misconceptions after some time. Similar concerns have been noted by Happs (1985). The delayed posttest was administered to address these concerns. It was held exactly 30 days after the initial posttest. As shown in Figures 7 and 8, most of the changes have remained intact after the 30-day period. The retention of these changes probably indicates that conceptual exchanges have taken place and that the old misconceptions have been superseded by new correct conceptions. In other words, accommodation of the new conceptions has occurred (Posner et al., 1982). Very long-term permanence of these conceptions have not been investigated.

In summary, misconceptions about chemical equilibrium are similar and widespread among students in both Western Australia and the Maldives. This chapter discussed these misconceptions and their origin. The most important objective of this study was to develop a computer-assisted instructional strategy based on a model of conceptual change and determine its effectiveness in changing previously identified misconceptions about chemical equilibrium.

The results indicate that the package based on a conceptual change strategy was effective in remediating misconceptions about chemical equilibrium. A significant number of changes have been retained in the long term. The implications of these findings for chemical education are discussed in Chapter 7.

## CHAPTER 7

### Conclusions and Implications

#### Introduction

This chapter summarizes the findings of the study by discussing the answers to the research questions. The implications for teaching and further research are then outlined. A large number of general implications for teaching have been stated by previous researchers of conceptual change (Hewson & Hewson, 1988). The intention of this chapter is to outline only those implications that have a direct bearing on the teaching of chemical equilibrium based on the findings of this study.

#### Conclusions of the Study

The discussion of the conclusions is structured around the research questions. The first research question of the thesis sought to identify misconceptions about chemical equilibrium held by Year 12 chemistry students in the Maldives. The subsidiary research question sought to compare the identified misconceptions with those held by Western Australian students (Hackling & Garnett, 1985).

The answers to these two research questions have been presented in Tables 4 and 11 respectively. The

general conclusions that can be drawn from these results are that (1) misconceptions about chemical equilibrium are common, and (2) there are close similarities in the misconceptions held by students from different backgrounds. Similarities in experience and educational background of students would be likely to result in similarities in students' misconceptions (Finley, 1985). An important finding of this study is that these similarities exist among students from quite different cultures and native languages.

Descriptive studies to identify misconceptions in most frequently taught content domains are an ongoing feature of research in conceptual change. Such studies have been advocated by many researchers (Driver & Erickson, 1983; Finley, 1985). It is clear that the existence of misconceptions among students at all levels presents a challenge for science educators. Only when descriptions of misconceptions are available is it possible to design curriculum and instruction to challenge these misconceptions.

The second research question sought to determine the extent to which misconceptions about chemical equilibrium are changed as a result of working through the CAI programme based on a model of conceptual change. Table 9, discussed in the previous chapter, showed that significant and lasting changes have taken place in students as a result of the intervention. Based on these results, it can be concluded that (1)

the CAI package was effective in fostering significant conceptual change, (2) the modified conceptual change model, as implemented in the package, is effective in bringing about conceptual change, and (3) microcomputer-based instruction is a feasible method of implementing the conceptual change model.

Microcomputers have at least two advantages which make them eminently suitable for conceptual change instruction. First, microcomputers can provide individualized instruction. Teachers seldom have the time to systematically probe commonly held misconceptions in normal class time. In addition, teachers have to read conceptual change literature to keep up-to-date with student misconceptions in various topics. Computer packages, especially if they are expert-systems, can undertake the remediation task with information drawn from extensive research. Individual teachers need to be highly capable and widely read to be competent in remediation. CAI packages can also undertake the diagnostic task in addition to remediation. Second, computers can simulate many scientific phenomena effectively. When real-world phenomena are too fast, they can be slowed down and when they are too slow they can be speeded up. Among other advantages of simulations is the ability to control the variables of the phenomena.

In conclusion, computer-based instruction provides a promising approach to the widespread problem

of misconceptions and the need for challenging instruction to be specific and definitive for each particular misconception.

#### Implications for Teaching

The need to identify misconceptions before instruction begins has been reiterated by all researchers in the field (Hashweh, 1986). This need cannot be over-emphasized in view of the findings of this study. The pre-existing misconceptions used by the students to interpret the various concepts of equilibrium must be diagnosed and the teacher should endeavour to lower the status of these misconceptions in as many ways as possible.

Another educational implication points towards the clear explication of certain terms used in teaching this topic. Many scientific terms are used as an integral part of everyday language with the result that non-scientific and ambiguous meanings have come to be attached to them. A case in point is the word "equilibrium". The fact that "chemical equilibrium" is a different notion from "static equilibrium" in the physics topic of mechanics and the distinguishing features of both must be discussed at the start of the teaching sequences on these topics. Such a discussion would be likely to dispel the notions of staticity and left- and right-handedness students are known to attribute to chemical equilibrium.

Similarly, the differences between extent and reaction rate must be emphasized. The stress placed on teaching the position of equilibrium tends to detract students' attention from reaction rates. An important part of instruction on chemical equilibrium is Le Chatelier's Principle. The emphasis on this Principle subtly reinforces the misconception that the Principle can be used to predict reaction rates.

Le Chatelier's Principle itself presents students with many difficulties. A correct statement of the Principle would be a good starting point. Teachers tend to consider examples in which this Principle can always work. The limitations of the Principle must be illustrated by well chosen examples. Graphs of rates versus time and concentrations versus time should be used in teaching. Graphical representations may help students to visualize the processes taking place in the reaction systems more meaningfully.

When teaching the chemistry topic of "catalysts", it is useful to explain the increased rates in terms of lowered activation energy barriers. The two-way path between the reactants and products must be clearly discussed. The fact that catalysts do not affect equilibrium concentrations should be emphasized. The failure to discuss the non-effect of catalysts on the concentrations reinforces some students' belief that catalysts change

concentrations. Many textbooks state that equilibrium constant is not altered by changing any reaction condition except temperature. The reasons why changes in temperature alter the constant is explained in only a few books.

When using analogies to describe the nature of equilibrium, their limitations must be pointed out to students. Students should be urged to make frequent checks on the consistency of their concepts. Whenever inconsistencies do occur, students must be encouraged to discuss them in the class. Ultimately, if students can be persuaded to monitor the consistency, intelligibility, plausibility and fruitfulness of their own concepts, conceptual change can occur with little intervention (Hewson & Thorley, 1989).

#### Implications for Further Research

The use of microcomputers for conceptual change appears to be a promising avenue for research. The implications of this research discussed in this section deal with the refinement of the computer-based conceptual change package for the topic of chemical equilibrium.

An important limitation of the package was that it addressed the misconceptions identified in only one study (Hackling & Garnett, 1985). Certain important misconceptions, such as that catalysts affect

concentrations, have not been incorporated in the design of the package. Before a widely applicable package can be developed, there is a need to carry out further descriptive research of student misconceptions in this topic. A meta-analysis of previous research coupled with the approach to the construction of misconception identification tests as outlined by Treagust (1988) might be very fruitful in arriving at a more complete list of misconceptions about chemical equilibrium. Hence, effort should be invested in developing a very comprehensive diagnostic test to form the backbone of the package design.

Although the modified model of conceptual change used in the study has proved to be useful, there is a need for further testing of the modified model. To improve the portability of the package, it should be implemented on more widely used microcomputers such as those manufactured by Apple Inc. and IBM or those compatible with them. The use of these microcomputers will enable more realistic simulations and effective programming methods to be used. The larger memory sizes and faster clock speeds would also be distinct advantages. A number of authoring languages such as Hypercard and Authorware Professional are available for these computers. The applicability of these packages for implementing conceptual change strategies must be evaluated. A lot of programming effort would be saved

if ready-made authoring packages can be used for the development.

If a comprehensive diagnostic test is available, it would be possible and comparatively easy to implement the test on microcomputers. This would allow a degree of artificial intelligence to be built into the package. If the package can be made more "intelligent" several important enhancements are possible such as invoking remedial sequences only in instances where the student has indicated the prevalence of a certain misconception. Checks can be made to ensure whether the change has really taken place. If the strategy was unsuccessful alternative remedial instruction can be provided.

A concern among researchers (Eylon & Linn, 1988; Hewson, 1986;) is that a new conception does not replace the misconception but both exist together as an unresolved anomaly, that is, the knowledge is compartmentalized. A promising way to study this behaviour is to develop a diagnostic program which requires the students to rate the confidence in the responses. Murray et al. (1988) designed a remediation program which included such confidence checks. In their program students have to select a response and rate their confidence in the selected response on a scale from 1 to 5. The methodology can be fruitfully adapted in the diagnostic phase of conceptual change studies.

Research in the directions outlined above would ultimately enable conceptual change packages on chemical equilibrium to find practical use in classrooms. Accompanied by worksheets and user guides, such a package could contribute greatly to students' understanding of chemical equilibrium.

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## APPENDIX 1

## Chemical Equilibrium Worksheet

## 1. COMPLETION REACTIONS

1. What is a completion reaction?

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2. In the following reaction  $\text{Ca}(\text{OH})_2$  reacts with excess  $\text{CO}_2$  to form  $\text{CaCO}_3$  according to the reaction:  

$$\text{Ca}(\text{OH})_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}.$$

If the initial concentration of  $\text{Ca}(\text{OH})_2$  is high what would you expect the concentration of  $\text{Ca}(\text{OH})_2$  and  $\text{CaCO}_3$  to be at the end of the reaction?

(a)  $[\text{Ca}(\text{OH})_2]$  \_\_\_\_\_ (b)  $[\text{CaCO}_3]$  \_\_\_\_\_

3. In general, what can you say about the initial concentration of the products in completion reaction?

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## 2. REVERSIBLE REACTIONS

1. What is a reversible reaction?

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2. Indicate which of the following is TRUE by ticking the appropriate box.

- In a reversible reaction the concentration of the reactants never become zero.
- In a reversible reaction the products and reactants are continually being formed and then broken down.
- A reversible reaction reaches a dynamic equilibrium after some time.
- In a reversible reaction, at equilibrium the forward reaction rate is always greater than the reverse rate.

3. How can we recognize when a reversible system has reached equilibrium?

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### 3 EQUILIBRIUM CONSTANT

1. For the reaction,  $\text{H}_2 + \text{I}_2 \rightleftharpoons 2\text{HI}$ , write down the expression for the equilibrium constant,  $K$ .

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2. If a system has a large  $K$  what can you say about the concentration of its products and reactants at equilibrium?

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### 4. EQUILIBRIUM CONCENTRATIONS

1. Why do the concentrations of all the substances in reversible reactions at equilibrium do not change with time?

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2. For the reaction,  $\text{H}_2 + \text{I}_2 \rightleftharpoons 2\text{HI}$ , the equilibrium constant at a certain temperature is 54. Assuming that the initial concentration of  $\text{H}_2$  and  $\text{I}_2$  is 1 mole per litre, sketch the change in the concentrations of all the species as the system approaches equilibrium.



### 5. EQUILIBRIUM RATES

1. When a system is in equilibrium what can you say about the rate of forward and reverse reactions?

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3. How can we recognize when a reversible system has reached equilibrium?

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### 3 EQUILIBRIUM CONSTANT

1. For the reaction,  $\text{H}_2 + \text{I}_2 \rightleftharpoons 2\text{HI}$ , write down the expression for the equilibrium constant,  $K$ .

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2. If a system has a large  $K$  what can you say about the concentration of its products and reactants at equilibrium?

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### 4. EQUILIBRIUM CONCENTRATIONS

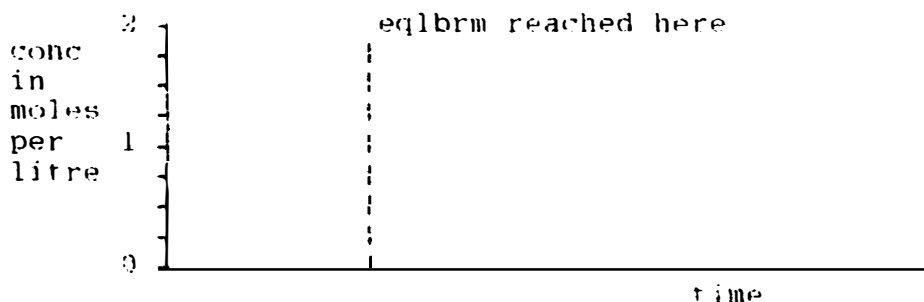
1. Why do the concentrations of all the substances in reversible reactions at equilibrium do not change with time?

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2. For the reaction,  $\text{H}_2 + \text{I}_2 \rightleftharpoons 2\text{HI}$ , the equilibrium constant at a certain temperature is 54. Assuming that the initial concentration of  $\text{H}_2$  and  $\text{I}_2$  is 1 mole per litre, sketch the change in the concentrations of all the species as the system approaches equilibrium.



### 5. EQUILIBRIUM RATES

1. When a system is in equilibrium what can you say about the rate of forward and reverse reactions?

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2. Which of the following will increase the rate of forward reaction of a system in equilibrium? Tick all which may lead to an increase in the forward reaction rate.

- decreasing external pressure
- increasing the concentration of products
- reducing the volume
- increasing the temperature

3. Which of the following will increase the rate of the reverse reaction?

- decreasing the external pressure
- increasing the concentration of products
- reducing volume
- increasing the temperature

#### 6. EFFECT OF CATALYSTS

1. Which of the following is/are TRUE?

- A catalyst affects the rate of either the forward or reverse reaction only.
- When a catalyst is added the rate of forward reaction is generally higher than the reverse reaction rate.
- A catalyst does not affect the equilibrium constant.
- The addition of catalysts increases both the forward and reverse reaction rates equally.
- Catalysts affect the concentration of some of the substances in a reversible system.

2. Explain why the rate of the reverse reaction of reversible system is unaffected/affected by the addition of a catalyst?

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#### 7. LE CHATELIER'S PRINCIPLE

Which of the following is/are true?

- Le Chatelier's Principle can be used to predict the rate of reactions in a reversible system.
- L. Chatelier's Principle is applicable to all reversible systems.
- The Principle can be used to predict the extent of reactions in systems which are already in equilibrium.

## 8. LCP and CONCENTRATION

1. A reversible system in equilibrium is disturbed by INCREASING the concentration of one of the reactants. Which reaction will be favoured?

[ ] forward                      [ ] reverse

2. Would the adjusted concentration of the reactant change as the system tries to re-establish equilibrium? If yes, how?

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3. When equilibrium is re-established what can you say about the concentration of all species?

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4. When equilibrium is re-established how would the rates of reactions compare with the initial rates before equilibrium is disturbed?

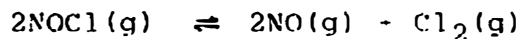
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5. When equilibrium is re-established would the concentration of any species change with time?

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## 9 LCP and VOLUME



The above system at equilibrium is disturbed by increasing the volume of the system. How would this affect

1. the concentration of all species present in the system?

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2. the rates of reactions?

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3. the equilibrium constant?

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4. When equilibrium is re-established how would the rates of both forward and reverse reactions compare with the initial equilibrium rates?

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#### 10 LCP and TEMPERATURE

1. A reversible system contains one endothermic reaction and one exothermic reaction. When temperature is INCREASED which reaction will be favoured?

[ ] Endothermic reaction      [ ] Exothermic reaction

2. A reversible system at equilibrium is upset by increasing the temperature. After some time, equilibrium is re-established. How would the rates of reactions now compare with the initial equilibrium rates.

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#### 11 CHANGING EQUILIBRIUM CONSTANT

Explain why changes in only temperature change the value of equilibrium constant (and not volume, pressure and concentration changes.)

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## APPENDIX 2

Propositions Concerning Chemical Equilibrium  
(Hackling & Garnett, 1985)

## APPROACH TO EQUILIBRIUM

1. The concentration of (a) NOCl increases, (b) NO decreases, and (c) Cl<sub>2</sub> decreases.
2. The rate of the
  - (a) forward reaction decreases as the concentrations of reactants decrease.
  - (b) reverse reaction
    - (i) is initially zero
    - (ii) increases as the concentrations of products increase.

## CHARACTERISTICS OF CHEMICAL EQUILIBRIUM

3. After equilibrium has been established the concentrations of all the species present remain constant with time.
4. At equilibrium the concentrations of reactants and products are related by the equilibrium law

$$K = \frac{[\text{NOCl}]^2}{[\text{NO}]^2[\text{Cl}_2]}$$

5. A large equilibrium constant indicates that the equilibrium concentrations of products are large relative to the concentrations of reactants; a small equilibrium constant indicates that the equilibrium concentrations of products are small relative to the concentrations of reactants.
6. At equilibrium the forward and reverse reactions
  - (a) continue to occur
  - (b) have equal rates.

## CHANGING EQUILIBRIUM CONDITIONS

7. Le Chatelier's Principle. If a system is at chemical equilibrium, and some change is made to the conditions, the system adjusts to re-establish equilibrium in such a way as to partially counteract the imposed change.

*Changing the concentration of one of the reacting species*

After equilibrium has been achieved the [NO] is instantaneously increased (but the volume remains unchanged).

8. The concentrations change in such a way that they partially counteract the imposed change (an increase in [NO]). Thus the system adjusts to reduce the [NO]; the [NO] and [Cl<sub>2</sub>] decrease and the [NOCl] increases.
9. When equilibrium is re-established the
  - (a) [NO] will be
    - (i) less than its adjusted value
    - (ii) higher than its initial equilibrium value
  - (b) [Cl<sub>2</sub>] will be less than its initial equilibrium value
  - (c) [NOCl] will be greater than its initial equilibrium value.
10. When the [NO] is increased the rate of the
  - (a) forward reaction will instantaneously increase
  - (b) reverse reaction will
    - (i) be initially unchanged
    - (ii) gradually increase.
11. When equilibrium is re-established the rate of the
  - (a) forward and reverse reactions will be equal
  - (b) forward and reverse reactions will be greater than at the initial equilibrium.
12. When equilibrium is re-established the equilibrium constant is the same as under the initial conditions.

*Changing the temperature of the system*

After equilibrium has been achieved the temperature is instantaneously increased (but the volume remains unchanged).

13. The concentrations change in such a way that they partially counteract the imposed change (an increase in temperature). Thus the system adjusts to favour the endothermic reaction; the  $[\text{NO}]$  and  $[\text{Cl}_2]$  increase and the  $[\text{NOCl}]$  decreases.
14. When equilibrium is re-established the
  - (a)  $[\text{NO}]$  will be greater than its initial equilibrium value
  - (b)  $[\text{Cl}_2]$  will be greater than its initial equilibrium value
  - (c)  $[\text{NOCl}]$  will be less than its initial equilibrium value
15. When the temperature is increased the rate of the
  - (a) forward reaction will increase
  - (b) reverse reaction will increase
  - (c) reverse reaction will be greater than the rate of the forward reaction.
16. When equilibrium is re-established the rate of the
  - (a) forward and reverse reactions will be equal
  - (b) forward and reverse reactions will be greater than at the initial equilibrium.
17. When equilibrium is re-established the equilibrium constant is smaller than under the initial conditions.

*Changing the volume of the system (or the pressure of the system)*

After equilibrium has been achieved the volume of the system is decreased (but the temperature remains unchanged).

18. The concentrations of all gaseous species in the system will instantaneously increase.
19. The concentrations change in such a way that they partially counteract the imposed change (an increase in the concentration of gaseous particles). Thus the system adjusts to favour the reaction producing the smaller number of gaseous particles; the  $[\text{NOCl}]$  increases and the  $[\text{NO}]$  and  $[\text{Cl}_2]$  decrease.
20. When equilibrium is re-established the
  - (a)  $[\text{NO}]$  will be less than its adjusted value
  - (b)  $[\text{Cl}_2]$  will be less than its adjusted value
  - (c)  $[\text{NOCl}]$  will be greater than its adjusted value
21. When the volume is decreased the rate of the
  - (a) forward reaction increases
  - (b) reverse reaction increases
  - (c) forward reaction will be greater than the rate of the reverse reaction.
22. When equilibrium is re-established the rate of the
  - (a) forward and reverse reactions will be equal
  - (b) forward and reverse reactions will be greater than at the initial equilibrium.
23. When equilibrium is re-established the equilibrium constant is the same as under the initial conditions.

*Adding a catalyst*

After equilibrium has been achieved a catalyst is added to the system.

24. The rate of the
    - (a) forward reaction is increased
    - (b) reverse reaction is increased
    - (c) forward and reverse reactions are equal.
  25. The concentration of
    - (a)  $[\text{NO}]$  is unchanged
    - (b)  $[\text{Cl}_2]$  is unchanged
    - (c)  $[\text{NOCl}]$  is unchanged.
  26. The equilibrium constant is the same as under the initial conditions.
-

*Changing the temperature of the system*

After equilibrium has been achieved the temperature is instantaneously increased (but the volume remains unchanged).

13. The concentrations change in such a way that they partially counteract the imposed change (an increase in temperature). Thus the system adjusts to favour the endothermic reaction; the  $[\text{NO}]$  and  $[\text{Cl}_2]$  increase and the  $[\text{NOCl}]$  decreases.
14. When equilibrium is re-established the
  - (a)  $[\text{NO}]$  will be greater than its initial equilibrium value
  - (b)  $[\text{Cl}_2]$  will be greater than its initial equilibrium value
  - (c)  $[\text{NOCl}]$  will be less than its initial equilibrium value
15. When the temperature is increased the rate of the
  - (a) forward reaction will increase
  - (b) reverse reaction will increase
  - (c) reverse reaction will be greater than the rate of the forward reaction.
16. When equilibrium is re-established the rate of the
  - (a) forward and reverse reactions will be equal
  - (b) forward and reverse reactions will be greater than at the initial equilibrium.
17. When equilibrium is re-established the equilibrium constant is smaller than under the initial conditions.

*Changing the volume of the system (or the pressure of the system)*

After equilibrium has been achieved the volume of the system is decreased (but the temperature remains unchanged).

18. The concentrations of all gaseous species in the system will instantaneously increase.
19. The concentrations change in such a way that they partially counteract the imposed change (an increase in the concentration of gaseous particles). Thus the system adjusts to favour the reaction producing the smaller number of gaseous particles; the  $[\text{NOCl}]$  increases and the  $[\text{NO}]$  and  $[\text{Cl}_2]$  decrease.
20. When equilibrium is re-established the
  - (a)  $[\text{NO}]$  will be less than its adjusted value
  - (b)  $[\text{Cl}_2]$  will be less than its adjusted value
  - (c)  $[\text{NOCl}]$  will be greater than its adjusted value
21. When the volume is decreased the rate of the
  - (a) forward reaction increases
  - (b) reverse reaction increases
  - (c) forward reaction will be greater than the rate of the reverse reaction.
22. When equilibrium is re-established the rate of the
  - (a) forward and reverse reactions will be equal
  - (b) forward and reverse reactions will be greater than at the initial equilibrium.
23. When equilibrium is re-established the equilibrium constant is the same as under the initial conditions.

*Adding a catalyst*

After equilibrium has been achieved a catalyst is added to the system.

24. The rate of the
    - (a) forward reaction is increased
    - (b) reverse reaction is increased
    - (c) forward and reverse reactions are equal.
  25. The concentration of
    - (a)  $[\text{NO}]$  is unchanged
    - (b)  $[\text{Cl}_2]$  is unchanged
    - (c)  $[\text{NOCl}]$  is unchanged.
  26. The equilibrium constant is the same as under the initial conditions.
-

## APPENDIX 3

## Chemical Equilibrium Interview

I'd like you to consider the reaction



Let's say the reaction takes place in a closed container and that initially there are equal concentrations of NO and Cl<sub>2</sub> present but no NOCl.

1. Can you explain to me what happens from the very start of the reaction, i.e, from when the NO and Cl<sub>2</sub> are mixed together.
2. What happens to the concentrations of each of the substances?
  - (a) NO
  - (b) Cl<sub>2</sub>
  - (c) NOCl
3. Can you draw a graph showing the concentrations of each of the substances from the start of the reaction until equilibrium is achieved?
  - \* give prepared graph paper - draw equilibrium time line.
  - \* qualify if necessary - only a qualitative graph is required.
  - \* can you explain the changes you have shown on the graph?
4. Can you tell me about the concentrations of the substances involved when equilibrium has been achieved? (looking for macroscopic constancy once equilibrium is established)
  - \* qualify if they say equal - what do you mean by that?
  - \* qualify if they discuss the relative concentrations of reactants and products - can you tell me how the concentration of each substance changes with time once equilibrium has been achieved?
  - \* qualify if necessary - can you show me on your graph?
5. Can you tell me what happens to the rates of the reactions from the very start of the reaction?
6. Can you draw a graph showing the rates of the reactions from the start of the reaction until equilibrium is achieved?
  - \* give prepared graph paper
  - \* qualify if only one graph is drawn - is this the only reaction occurring?

7.
  - \* Can you explain the changes you have shown on the graph?
  - \* Why does the rate of the forward reaction decrease?
  - \* Why does the rate of the reverse reaction increase?
  
8. Can you tell me about the rates of the reactions at equilibrium?  
(looking for equality once equilibrium is established)
  - \* qualify if necessary - can you show me on your graph?
  
9. Can you write an equation to calculate the equilibrium constant for this reaction?
  - \* qualify if concentrations are not stated - what are these terms - those in square brackets!
  - \* qualify if say concentrations - which concentrations?
  
10. What does it mean if K is very small?

7.
  - \* Can you explain the changes you have shown on the graph?
  - \* Why does the rate of the forward reaction decrease?
  - \* Why does the rate of the reverse reaction increase?
  
8. Can you tell me about the rates of the reactions at equilibrium?  
(looking for equality once equilibrium is established)
  - \* qualify if necessary - can you show me on your graph?
  
9. Can you write an equation to calculate the equilibrium constant for this reaction?
  - \* qualify if concentrations are not stated - what are these terms - those in square brackets!
  - \* qualify if say concentrations - which concentrations?
  
10. What does it mean if K is very small?

11. Can you define Le Chatelier's Principle?

I'd now like you to apply Le Chatelier's Principle to the reaction we've been looking at before.

Let's assume the reaction is at chemical equilibrium. On the graph I've marked the equilibrium concentrations of NO, Cl<sub>2</sub> and NOCl.

Let's say we add more NO to the container but all the other conditions remain the same. The concentration of NO will instantaneously increase, like this (draw in on the graph).

12. Can you show me on the graph what happens to the concentrations of all the substances until equilibrium is re-established?

\* qualify if not explained - can you explain the graph to me?

13. What can you say about the concentrations of all the substances when equilibrium is re-established?

\* what is the NO concentration in relation to its initial concentration? '

14. Can you explain in terms of Le Chatelier's Principle the changes you have shown on the graph?

I want to ask you about the rates of the reactions. Let's assume the system is at equilibrium as before.

15. If more NO is added to the system can you tell me how this will affect the reaction rates?

\* How will it affect the rate of the forward reaction?

\* How will it affect the rate of the reverse reaction?

16. When equilibrium is re-established what can you tell me about the rates of the forward and reverse reactions?

\* How do the rates of the forward and reverse reactions compare?

\* How do the rates of these reactions compare with the rates which previously existed?

17. What can you say about the value of K compared with its value at the previous equilibrium.

\* Bigger or smaller?

\* Can you explain why.

11. Can you define Le Chatelier's Principle?

I'd now like you to apply Le Chatelier's Principle to the reaction we've been looking at before.

Let's assume the reaction is at chemical equilibrium. On the graph I've marked the equilibrium concentrations of NO, Cl<sub>2</sub> and NOCl.

Let's say we add more NO to the container but all the other conditions remain the same. The concentration of NO will instantaneously increase, like this (draw in on the graph).

12. Can you show me on the graph what happens to the concentrations of all the substances until equilibrium is re-established?

\* qualify if not explained - can you explain the graph to me?

13. What can you say about the concentrations of all the substances when equilibrium is re-established?

\* what is the NO concentration in relation to its initial concentration? '

14. Can you explain in terms of Le Chatelier's Principle the changes you have shown on the graph?

I want to ask you about the rates of the reactions. Let's assume the system is at equilibrium as before.

15. If more NO is added to the system can you tell me how this will affect the reaction rates?

\* How will it affect the rate of the forward reaction?

\* How will it affect the rate of the reverse reaction?

16. When equilibrium is re-established what can you tell me about the rates of the forward and reverse reactions?

\* How do the rates of the forward and reverse reactions compare?

\* How do the rates of these reactions compare with the rates which previously existed?

17. What can you say about the value of K compared with its value at the previous equilibrium.

\* Bigger or smaller?

\* Can you explain why.

I'd now like you to apply Le Chatelier's Principle when a different change is made to the system.

Let's assume the reaction is at chemical equilibrium.

Let's say the temperature of the system is increased but all the other conditions remain the same.

18. Can you tell me what happens to the concentrations of all the substances as a new equilibrium is established?
19. Can you explain these changes in terms of Le Chatelier's Principle?
20. Can you describe what happens to the rates of the reactions when the temperature is increased?
  - \* forward
  - \* reverse.
21. What can you say about the rates of the reactions when equilibrium is re-established?
  - \* Compare the rates of the forward and reverse reactions.
  - \* Compare the rates of the reactions with the rates which previously existed.
22. What can you say about the value of  $K$  compared with its value at the previous equilibrium.
  - \* Bigger or smaller
  - \* Can you explain why?

I'd now like you to apply Le Chatelier's Principle when another change is made to the system.

Let's assume the reaction is at chemical equilibrium.

Let's say that the volume of the system is decreased (illustrate) but all the other conditions remain the same.

23. When the volume of the system is reduced what is the immediate effect on the concentrations of the substances?
24. Can you tell me what happens to the concentrations of all the substances as a new equilibrium is established?
25. Can you explain these changes in terms of Le Chatelier's Principle?
26. Can you describe what happened to the rates of the reactions when the volume was decreased?
  - \* forward
  - \* reverse
  - \* qualify if appropriate - are the rates increased equally or unequally?
27. What can you say about the rates of the reactions when equilibrium is re-established?
  - \* Compare the rates of the forward and reverse reactions.
  - \* Compare the rates of the reactions with the rates which previously existed.
28. What can you say about the value of K compared with its value at the previous equilibrium?
  - \* Bigger or smaller?
  - \* Can you explain why?

Finally, I'd like you to consider what happens if a catalyst is added to the system.

29. Can you describe what happens to the rates of the reactions when the catalyst is added?
- \* forward
  - \* reverse
30. Can you describe what happens to the concentrations of all the substances in the reaction?
31. What can you say about the value of  $K$  compared with its value before the catalyst was added?
- \* Bigger or smaller?
  - \* Can you explain why?

## APPENDIX 4

## Chemical Equilibrium Test

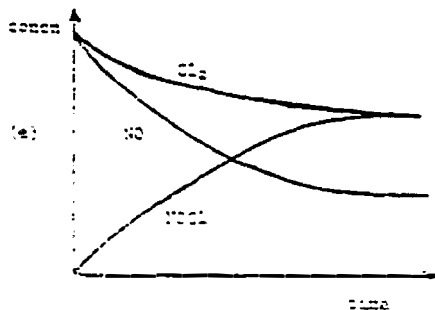
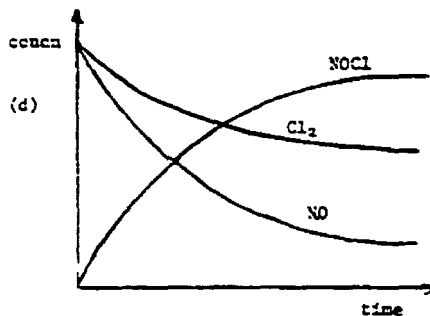
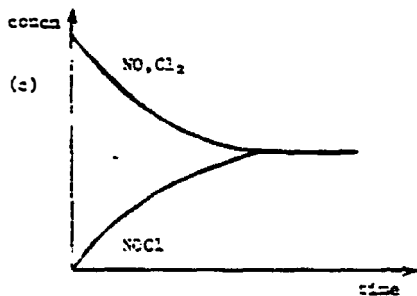
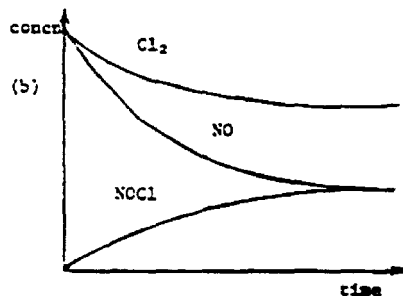
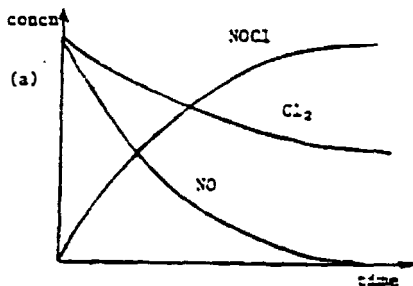
PG/ED/00345/25

EQUILIBRIUM TEST

Consider the following reaction

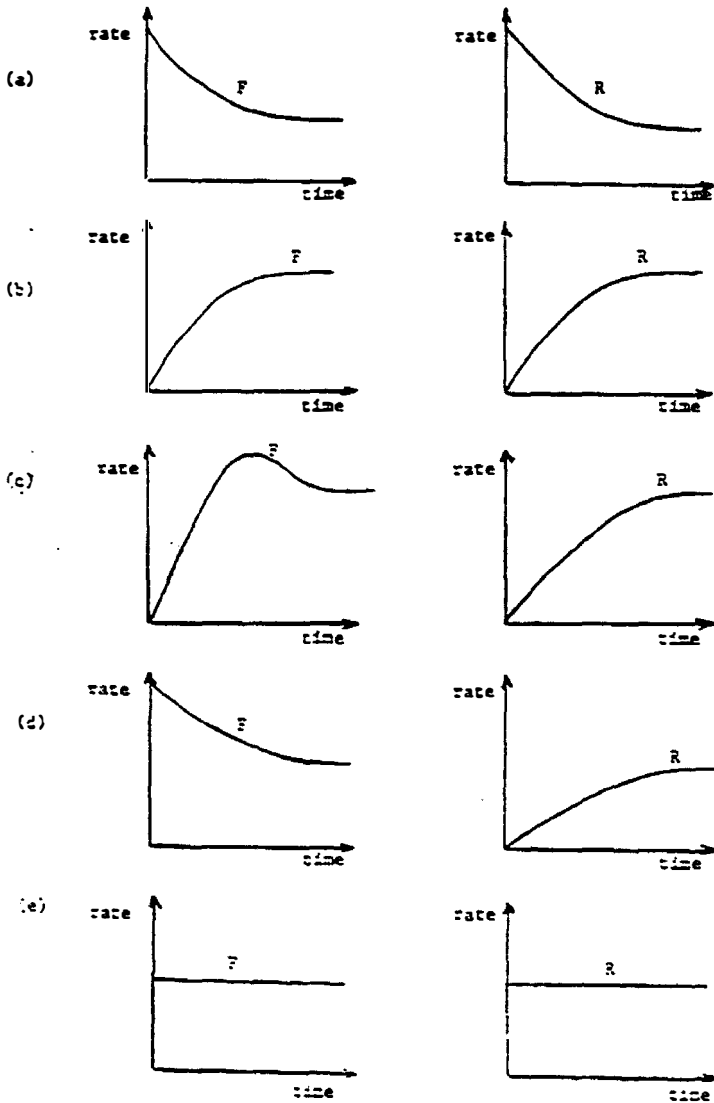


1. Equal concentrations of NO and Cl<sub>2</sub> are placed in a closed system and allowed to react. Assuming the reaction does not go to completion, which of the following graphs most probably represents the changes in concentration of the species until equilibrium is achieved:



2.

2. Which of the following pair of graphs best represents the change in rates of the forward (F) and reverse (R) reactions from the mixing of the reactants until equilibrium is achieved.



3.

3. The equilibrium constant ( $K$ ) for the reaction is equal to

$$(a) \frac{[\text{NOCl}]}{[\text{NO}] [\text{Cl}_2]} \quad (b) \frac{[\text{NOCl}]^2}{[\text{NO}]^2 + [\text{Cl}_2]}$$

$$(c) \frac{[\text{NO}]^2 [\text{Cl}_2]}{[\text{NOCl}]^2} \quad (d) \frac{[\text{NOCl}]^2}{[\text{NO}]^2 [\text{Cl}_2]}$$

$$(e) \frac{[\text{NOCl}]}{[\text{NO}] + [\text{Cl}_2]}$$

4. A large equilibrium constant indicates that at equilibrium

- (a) the concentrations of products are large compared with the concentrations of reactants
- (b) the concentrations of reactants are large compared with the concentrations of products
- (c) the rate of the forward reaction will be faster than the rate of the reverse reaction
- (d) the rate of the reverse reaction will be faster than the rate of the forward reaction.

5. Assume  $K$  for the reaction was 20 at a particular temperature. If the concentrations of each of the species in a particular reaction vessel were  $[\text{NOCl}] = 2 \text{ mol L}^{-1}$ ,  $[\text{NO}] = 0.1 \text{ mol L}^{-1}$  and  $[\text{Cl}_2] = 8 \text{ mol L}^{-1}$ , determine whether

- (a) the system is at equilibrium
- (b) the system is not at equilibrium - more products would be formed
- (c) the system is not at equilibrium - more reactants would be formed

## APPENDICES

4.

Answer questions 6 - 15

(a) if the statement is true

(b) if the statement is false

When equilibrium is established:

6. the concentrations of all the species remain constant with time
7. the concentrations of reactants are zero
8. the concentrations of reactants equal the concentrations of products
9. the concentration of NO equals the concentration of NOCl
10. the concentration of reactants and products vary constantly as the reaction oscillates between reactants and products
11. the concentrations of reactants and products are related through the equilibrium constant
12. the rates of the forward and reverse reactions are zero
13. the rates of the forward and reverse reaction are constant but equal
14. the rates of the forward and reverse reaction are changing but equal
15. the rates of the forward and reverse reactions are not equal.

5.

Questions 16-23 relate to the following:

After equilibrium has been established the concentration of NO is instantaneously increased but the volume and temperature remain constant:

When equilibrium is re-established:

16. The concentration of NO will be
  - (a) greater than the adjusted value
  - (b) equal to the adjusted value
  - (c) less than the adjusted value but greater than the initial equilibrium value
  - (d) equal to the initial equilibrium value
  - (e) less than the initial equilibrium value
17. The concentration of Cl<sub>2</sub> will be
  - (a) less than its initial equilibrium value
  - (b) equal to its initial equilibrium value
  - (c) greater than its initial equilibrium value
18. The concentration of NOCl will be
  - (a) less than its initial equilibrium value
  - (b) equal to its initial equilibrium value
  - (c) greater than its initial equilibrium value
19. When the [NO] is increased the rate of the forward reaction will be instantaneously
  - (a) unchanged
  - (b) increased
  - (c) decreased
20. When the [NO] is increased the rate of the reverse reaction will be instantaneously
  - (a) unchanged
  - (b) increased
  - (c) decreased

6.

21. When the  $[NO]$  is increased the rate of the forward reaction will instantaneously be
- (a) equal to the rate of the reverse reaction
  - (b) greater than the rate of the reverse reaction
  - (c) less than the rate of the reverse reaction
22. When equilibrium is re-established the rates of the forward and reverse reactions will be
- (a) equal to those at the initial equilibrium
  - (b) greater than at the initial equilibrium
  - (c) less than at the initial equilibrium
23. When equilibrium is re-established the value of the equilibrium constant will be
- (a) greater than at the initial equilibrium
  - (b) less than at the initial equilibrium
  - (c) equal to that at the initial equilibrium

7.

Questions 24 - 31 relate to the following:

After equilibrium has been established the temperature of the system is instantaneously increased but the volume remains unchanged.

When equilibrium is re-established:

24. The concentration of NO will be
- (a) less than at the initial equilibrium
  - (b) equal to that at the initial equilibrium
  - (c) greater than at the initial equilibrium
25. The concentration of Cl<sub>2</sub> will be
- (a) less than at the initial equilibrium
  - (b) equal to that at the initial equilibrium
  - (c) greater than at the initial equilibrium
26. The concentration of NOCl will be
- (a) less than at the initial equilibrium
  - (b) equal to that at the initial equilibrium
  - (c) greater than at the initial equilibrium
27. When the temperature is increased the rate of the forward reaction will be instantaneously
- (a) unchanged
  - (b) decreased
  - (c) increased
28. When the temperature is increased the rate of the reverse reaction will be instantaneously
- (a) unchanged
  - (b) decreased
  - (c) increased
29. When the temperature is instantaneously increased the rate of the forward reaction will be
- (a) equal to the rate of the reverse reaction
  - (b) Greater than the rate of the reverse reaction
  - (c) less than the rate of the reverse reaction

8.

30. When equilibrium is re-established the rates of the forward and reverse reactions will be
- (a) equal to those at the initial equilibrium
  - (b) greater than at the initial equilibrium
  - (c) less than at the initial equilibrium
31. When equilibrium is re-established the value of the equilibrium constant will be
- (a) greater than at the initial equilibrium
  - (b) less than at the initial equilibrium
  - (c) equal to that at the initial equilibrium

9.

Questions 32 - 40 relate to the following:

After equilibrium has been achieved the volume of the system is decreased but the temperature remains unchanged.

32. Instantaneously the concentrations of all the species are
- (a) unchanged
  - (b) increased
  - (c) decreased

When equilibrium is re-established:

33. The concentration of NO will be
- (a) greater than the adjusted value
  - (b) less than the adjusted value
  - (c) equal to the adjusted value
34. The concentration of Cl<sub>2</sub> will be
- (a) greater than the adjusted value
  - (b) less than the adjusted value
  - (c) equal to the adjusted value
35. The concentration of NOCl will be
- (a) greater than the adjusted value
  - (b) less than the adjusted value
  - (c) equal to the adjusted value
36. When the volume is decreased the rate of the forward reaction will be instantaneously
- (a) unchanged
  - (b) increased
  - (c) decreased
37. When the volume is decreased the rate of the reverse reaction will be instantaneously
- (a) unchanged
  - (b) increased
  - (c) decreased

10.

8. When the volume is decreased the rate of the forward reaction will be
- (a) equal to the rate of the reverse reaction
  - (b) greater than the rate of the reverse reaction
  - (c) less than the rate of the reverse reaction
9. When equilibrium is re-established the rates of the forward and reverse reactions will be
- (a) equal to those at the initial equilibrium
  - (b) greater than at the initial equilibrium
  - (c) less than at the initial equilibrium
10. When equilibrium is re-established the value of the equilibrium constant will be
- (a) greater than at the initial equilibrium
  - (b) less than at the initial equilibrium
  - (c) equal to that at the initial equilibrium

22.

Questions 41 - 47 relate to the following:

After equilibrium has been achieved a catalyst is added to the system but other conditions remain unchanged.

When the catalyst is added to the system:

41. The rate of the forward reaction will be
  - (a) unchanged
  - (b) increased
  - (c) decreased
  - (d) either unchanged or increased depending on whether the catalyst favours the forward or reverse reaction
42. The rate of the reverse reaction will be
  - (a) unchanged
  - (b) increased
  - (c) decreased
  - (d) either unchanged or increased depending on whether the catalyst favours the forward or reverse reaction
43. The rate of the forward reaction will be
  - (a) equal to the rate of the reverse reaction
  - (b) greater than the rate of the reverse reaction
  - (c) less than the rate of the reverse reaction
  - (d) either greater or less than the rate of the reverse reaction depending on whether the catalyst favours the forward or reverse reaction
44. The concentration of NO will be
  - (a) less than at the initial equilibrium
  - (b) equal to that at the initial equilibrium
  - (c) greater than at the initial equilibrium
  - (d) greater or less than at the initial equilibrium depending on the effect of the catalyst

45. The concentration of  $\text{Cl}_2$  will be
- (a) less than at the initial equilibrium
  - (b) equal to that at the initial equilibrium
  - (c) greater than at the initial equilibrium
  - (d) greater or less than at the initial equilibrium depending of the effect of the catalyst
46. The concentration of  $\text{NOCl}$  will be
- (a) less than at the initial equilibrium
  - (b) equal to that at the initial equilibrium
  - (c) greater than at the initial equilibrium
  - (d) greater or less than at the initial equilibrium depending of the effect of the catalyst
47. When equilibrium is re-established the value of the equilibrium constant will be
- (a) greater than at the initial equilibrium
  - (b) less than at the initial equilibrium
  - (c) equal to that at the initial equilibrium
  - (d) greater or less than at the initial equilibrium depending on the effect of the catalyst.

## EQUILIBRIUM TEST

NAME: \_\_\_\_\_

- |     |   |   |   |   |   |     |   |   |   |   |
|-----|---|---|---|---|---|-----|---|---|---|---|
| 1.  | a | b | c | d | e | 25. | a | b | c |   |
| 2.  | a | b | c | d | e | 26. | a | b | c |   |
| 3.  | a | b | c | d | e | 27. | a | b | c |   |
| 4.  | a | b | c | d |   | 28. | a | b | c |   |
| 5.  | a | b | c |   |   | 28. | a | b | c |   |
| 6.  | a | b |   |   |   | 30. | a | b | c |   |
| 7.  | a | b |   |   |   | 31. | a | b | c |   |
| 8.  | a | b |   |   |   | 32. | a | b | c |   |
| 9.  | a | b |   |   |   | 33. | a | b | c |   |
| 10. | a | b |   |   |   | 34. | a | b | c |   |
| 11. | a | b |   |   |   | 35. | a | b | c |   |
| 12. | a | b |   |   |   | 36. | a | b | c |   |
| 13. | a | b |   |   |   | 37. | a | b | c |   |
| 14. | a | b |   |   |   | 38. | a | b | c |   |
| 15. | a | b |   |   |   | 39. | a | b | c |   |
| 16. | a | b | c | d | e | 40. | a | b | c |   |
| 17. | a | b | c |   |   | 41. | a | b | c | d |
| 18. | a | b | c |   |   | 42. | a | b | c | d |
| 19. | a | b | c |   |   | 43. | a | b | c | d |
| 20. | a | b | c |   |   | 44. | a | b | c | d |
| 21. | a | b | c |   |   | 45. | a | b | c | d |
| 22. | a | b | c |   |   | 46. | a | b | c | d |
| 23. | a | b | c |   |   | 47. | a | b | c | d |
| 24. | a | b | c |   |   |     |   |   |   |   |

Graphic Dumps of Some Screens of Module Six  
(Frame 1)

## 6:1 CATALYSED REACTIONS

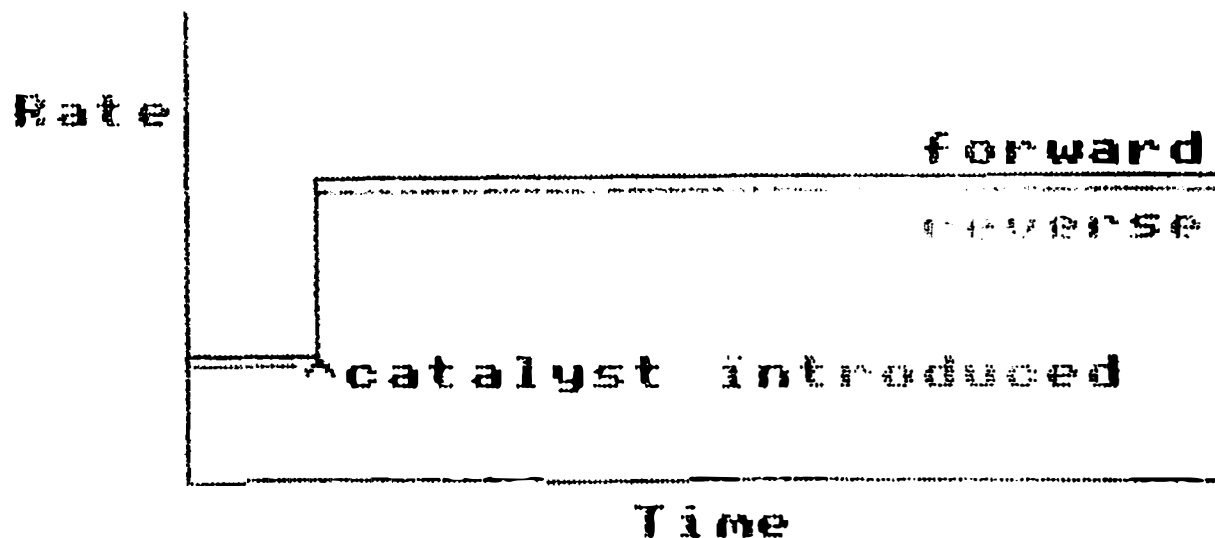
Many reactions that take place slowly can be made to take place rapidly by introducing other substances.

These substances are called CATALYSTS.

CATALYSTS take part in chemical reactions but are not used up in the reactions.

Press. Y

## 6:3 CATALYSED REACTIONS

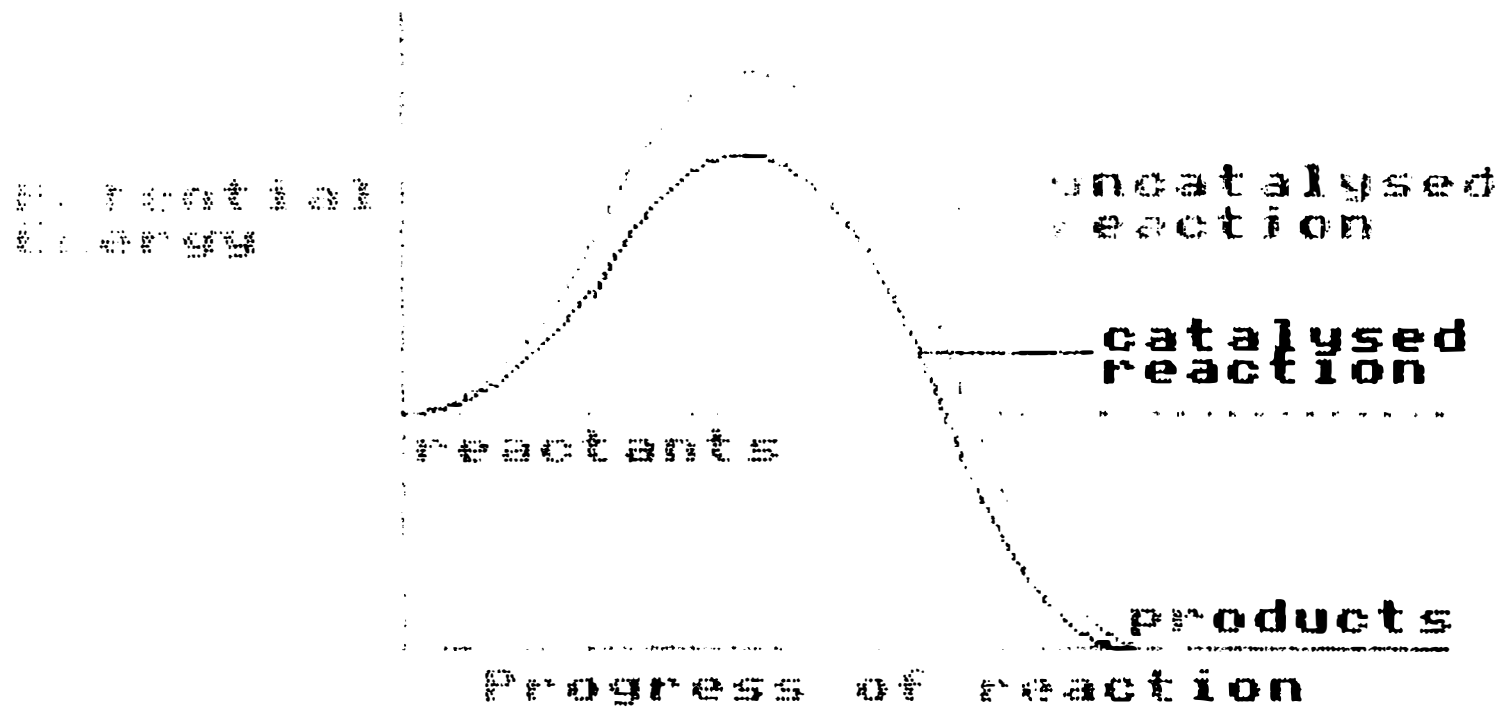


(Frame 3)

Catalysts increase the rate of both FORWARD and REVERSE reactions. The action of a catalyst on the reaction rate can be understood in terms of activation energy diagrams.

Press >

# 6.2 CATALYSED REACTIONS



(Frame 4)

The catalysts provide a low-energy path between the reactants and products.

More particles can get over the lower energy barrier per unit time. Thus, the reaction rate is increased.

(Frame 5)

## 6:6 CATALYSED REACTIONS

What happens if we add more catalyst to a system at equilibrium?

1. The reaction will not shift.

2. The equilibrium constant will not change.

3. The concentrations will change.

4. The response is 3.

5. The system will remain at original equilibrium. Concentrations will not be affected.

Press > or <

(Frame 6)