Science and Mathematics Education Centre

The Role of Teaching Models and Chemical Representations in Developing Students' Mental Models of Chemical Phenomena

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

Signature: …………………………………………….

Date: ………………………...

Dedication

This thesis is dedicated to my husband, Mark who has provided continual support and encouragement to me and to the memory of my father, the late Bill Taprell.

Abstract

Chemical representations play a vital part in the teaching and learning of chemistry. The aim of this research was to investigate students' understanding of chemical representations and to ascertain the influence of chemical representations on students' developing mental models of chemical phenomena.

Three primary threads flowing through the thesis are models, representations and learning. Each thread was found to play a vital part in students' learning of chemical content, in their learning of the scientific process and in their learning about the process of learning itself. This research with students from Year 8 to first year university level comprised four studies that provide comparisons between ages, abilities, learning settings and teaching and learning approaches.

Students' modelling ability was observed to develop and improve through instruction and practice and usually coincided with an improvement in their understanding of chemical concepts. While students were observed to actively use models to make predictions and test ideas, some were not aware of the predictive nature of models when asked about it. From the research, five characteristics of scientific models have been identified: scientific models as multiple representations, scientific models as exact replicas, scientific models as explanatory tools, how scientific models are used, and the dynamic nature of scientific models. A theoretical framework relating the four types of models – teaching, scientific, mental and expressed – and a typology of models that highlights the significant attributes of models, support the research results. The data showed that students' ability to describe the role of the scientific model in the process of science improved with their increasing age and maturity.

The relationship between the three levels of chemical representation of matter – the macroscopic level, the sub-microscopic level and the symbolic level – revealed some complexities concerning the representational and theoretical qualities and the reality of each level. The research data showed that generally most students had a good understanding of the macroscopic and symbolic levels of chemical representation of matter. However, students' understanding of the sub-microscopic

level varied, with some students being able to spontaneously envisage the sub-microscopic view while for others their understanding of the sub-microscopic level of chemical representation was lacking. To make sense of the sub-microscopic level, students' appreciation of the accuracy and detail of any scientific model, or representation upon which their mental model is built, depended on them being able to distinguish reality from representation, distinguish reality from theory, know what a representation is, understand the role of a representation in the process of science, and understand the role of a theory in the process of science.

In considering learning, the importance of an individual's modelling ability was examined alongside the role of chemical representations and models in providing clear and concise explanations. Examining the links forged between the three levels of chemical representation of matter provided an insight into how students were learning and understanding chemical concepts. Throughout this research, aspects of students' metacognition and intention were identified as being closely related to their development of mental models.

The research identified numerous factors that influenced learning, including internal factors such as students' prior chemical and mathematical knowledge, their modelling ability and use of chemical representations, motivation, metacognitive ability and time management as well as external factors such as organisation, assessment, teaching resources, getting feedback and good explanations. The choice of learning strategies by students and instructors appeared to be influenced by those factors that influenced learning.

Feedback to students, in the form of discussion with classmates, online quizzes and help from instructors on their understanding was observed to be significant in promoting the learning process. Many first year university non-major chemistry students had difficulties understanding chemical concepts due to a limited background knowledge in chemistry and mathematics. Accordingly, greater emphasis at the macroscopic level of representation of matter with contextual references is recommended. The research results confirmed the theoretical construct for learning chemistry – *the rising iceberg* – that suggests all chemistry teaching begins at the macroscopic level, with the sub-microscopic and symbolic levels being introduced as needed. More of the iceberg becomes visible as the students' mental model and depth of understanding increases.

In a variety of situations, the changing status of a concept was observed as students' understanding in terms of the intelligibility, plausibility and fruitfulness of a concept developed. The research data supported four aspects of learning – epistemological, ontological, social/affective and metacognitive – as being significant in the students' learning and the development of their mental models. Many university students, who are mature and are experienced learners, exhibited strong metacognitive awareness and an intentional approach to learning. It is proposed that the intentional and metacognitive learning approaches and strategies could be used to encourage students to be more responsible for their own learning.

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CHAPTER 1

MODELS, REPRESENTATIONS AND LEARNING

Chapter Outline

This chapter provides some background as to the origin of the research and the nature and scope of the research. It also outlines the main themes of the research, which are models, chemical representations and learning; and the three objectives of the research that they correspond to. For each research objective there are a number of research questions that focus on a particular aspect of each objective. This chapter discusses the significance and justification of this research, providing some insight into why the research is important and worthwhile. A glossary of terminology that is used in this research is provided in this chapter along with a description of the remaining seven chapters that constitute this dissertation.

1.1 Introduction

Chemistry is not an easy subject to understand. Many people regard chemistry as being too hard, too abstract, too mathematical and only for very bright students (Gabel, 1998). As a result a negative attitude has developed about chemistry with students claiming chemistry is boring (Stocklmayer & Gilbert, 2002). Yet chemistry pervades most aspects of our lives and is extremely relevant to all of us. This unfavourable reputation – true or not – has created a problem when trying to teach chemistry and for students trying to learn chemistry. Realising that this situation exists means that there is an opportunity for improvement and investigating how and why students learn chemistry could help to better understand whether or not chemistry deserves this reputation.

Chemical models and representations play a vital part in the teaching and learning of chemical concepts. This research is an in-depth analysis of how students at high school and university level use models and representations in the learning process. Since chemistry is based on representations, this study on models, representations and learning, is most appropriate to investigate and gain a better understanding of how students develop their own personal mental models in the process of learning chemistry.

1.2 Background

Chemistry is unique because, unlike other subjects, it is based on one main theory – the particulate nature of matter – that is used to explain and describe processes at the sub-microscopic level of matter. Consequently, the way students understand the particulate nature of matter can be significant in forming a foundation for future learning. Issues arise such as the reality versus the theory of the sub-microscopic level; the reality versus the representation of the sub-microscopic level; the magnitude of the sub-microscopic level – understanding the actual size of an atom versus the size of an ion or a molecule; the dynamics of the sub-microscopic level; and being able to relate the theory to observations and experiences.

For meaningful learning to occur, the learning process needs to engage learners in an active manner such as processing data, making inferences and comparisons, developing skills, generating hypotheses, testing ideas, finding patterns, asking questions and reflecting on what they have learned (Skamp, 1996). This is consistent with Einstein’s description as described by Coll and Taylor (2001) in which a holistic approach to the teaching and learning of chemistry motivates and engages students in an active way and promotes a positive attitude towards chemistry (Zarotiadou & Tsaparlis, 2000). It is easy to theorise about how meaningful learning should occur, but not all learning environments are ideal and students are individuals with individual differences, so that meaningful learning is not guaranteed. This description may be naïve and idealistic in situations where for example the pressures of examinations drive the learning and students are more concerned with passing than learning; or situations where the students’ background knowledge is poor and they feel the concepts in chemistry beyond their reach; or where the prescriptive chemistry syllabus lacks contextual references that may make the chemistry more meaningful. There are a multitude of factors that influence learning: recognising, understanding and addressing them can make the learning more meaningful.

Being employed as a Research Associate provided the opportunity to do educational research, improve my background knowledge and develop research skills. My work as a researcher was the impetus for my doctoral study. The course of the research has evolved from general and scientific models to chemical models and chemical representations. The evolution of the research has been influenced by ideas and concepts in the literature, namely, Gilbert and Boulter's (1995) description of models; Johnstone's (1982) three levels of chemical representation of matter – the macroscopic, sub-microscopic and symbolic levels of chemical representation of matter; the conceptual change theory of learning (Posner, Strike, Hewson, & Gertzog, 1982; Tyson, Venville, Harrison, & Treagust, 1997); intentional conceptual change; and metacognitive awareness (Pintrich & Sinatra, 2003). These theoretical frameworks have been invaluable in showing the direction and meaning of the research and have provided foundations from which to expand new ideas.

1.3 The Nature and Scope of the Research

This research is of a descriptive and interpretive nature, uses both qualitative and quantitative data and consists of four separate studies:

Study 1 – Learning Introductory Organic Chemistry in Secondary School

Study 2 – Secondary School Students' Views on Models

Study 3 – Learning Introductory Chemistry for Non-majors

Study 4 – Learning Introductory Chemistry and the Implementation of Online Pre-laboratory Exercises for Non-majors

Study 1 involved observing senior high school chemistry students using chemical models to learn introductory organic chemistry; Study 2 collected survey data from Years 8, 9 and 10 students from two metropolitan high schools concerning their perceptions of scientific models; Study 3 investigated the learning habits and chemical understanding of first year university, non-major, chemistry students; and Study 4 continued the research of Study 3 and in addition investigated the impact of introducing online pre-laboratory exercises. The research extended over three and one-half years and the studies are reported in chronological order. The three primary threads that flow through the thesis – models, chemical representations and learning – correspond to the three objectives of the research described in the next section.

Both the process of learning and the chemical content that is being learnt are examined because they are intricately woven together. The focus of the research is the learning and understanding by the student of chemical concepts. With each of the four studies, the detail of the situations and the particular content being learnt provide the raw data from which generalities about learning chemistry can be drawn.

1.4 Research Questions

The aim of this research is to investigate students' understanding of teaching models and chemical representations and to ascertain the influence of models and chemical representations on developing students' mental models of scientific and chemical phenomena. The research is comprised of three objectives, each with several research questions to investigate.

1.4.1 Objective 1

To investigate students' understanding of models and their modelling ability.

Four research questions address this objective:

1.1 What are students' perceptions of the role and purpose of generic models and scientific models?

1.2 What are the criteria that students identify as being significant when classifying scientific models?

1.3 How does students' modelling ability affect their use of models and their ability to understand chemical concepts?

1.4 How and why do models help students learn?

1.4.2 Objective 2

To investigate students' perceptions of chemical representations of matter at the macroscopic, sub-microscopic, and symbolic levels.

Four research questions address this objective:

2.1 What are students' perceptions of the role and purpose of chemical *representations, including chemical models, teaching models, chemical equations, diagrams and pictures in learning chemistry?*

2.2 What are students' understandings of each level of chemical representation in relation to the chemical phenomena they experience?

2.3 How does this understanding enable students to effectively transfer from one representational level to another?

2.4 How do the variety of representational forms which students' encounter in chemistry, impact on the epistemology, ontology and social factors that have been shown to contribute to conceptual change?

1.4.3 Objective 3

To investigate students' learning of chemical concepts in terms of the development of the learners' personal mental models, considering the intentions of the learner, the metacognition of the learner and conceptual change that is occurring to the learners' understanding.

Four research questions address this objective:

3.1 What are the factors that influence how and why students learn chemistry?

3.2 What learning strategies do students use in learning chemistry?

3.3 How do learning strategies contribute to the development of students' personal mental models of chemical phenomena?

3.4 How does students' metacognitive awareness influence their learning of chemistry?

The term "understanding" that appears in the research questions is used in a general way; however, in the research it applies to particular content and contextual domains. Wandersee and Griffard (2002) define understanding "as a dynamic epistemological status conferred on individuals by a consensually recognised referent group within a community of scholars, based upon criteria of intersubjectivity, parsimony, coherence and conceptual transparency" (p. 29). This definition highlights the complexity of the term. To assess students' understanding we commonly ask questions to gain insight into their understanding. There is a range of levels of understanding that are discussed in chapter 2. The terms ‘models’ and ‘representations’, that also appear frequently in the research questions can become confused. A model is a copy or replica according to the traditional definition but models do not always fit this definition, so the definition of a model as a representation is often more accurate. A representation means something that represents another. Representations include a huge variety of forms and usually help the learner to construct a personal mental model. Models can be considered as a subset of a larger category of representations. This issue is discussed further in chapter 2.

1.5 Significance of the Research

This research is important because it looks at the learning of chemistry and tries to explain why some students find this abstract subject difficult. The findings may help instructors to better understand the way students learn chemistry and consequently the instruction can be changed to better suit the learner.

As a chemical educator, there is a social responsibility to provide students with some degree of chemical literacy in order to be able to communicate about chemistry in general, including skills such as being able to understand information in the news about chemistry in society; being able to handle chemicals and analyse results and evidence; and have an appreciation of the hazards and risks associated with chemistry (Lagowski, 2000; Nuffield Curriculum Projects Centre, 2001; Schwartz, Hofstein, & Ben-Zvi, 2003). Gabel refers to “the chemistry needed to be a good citizen or to lead a fruitful life” (1999, p. 553). Similarly, responsible chemical educators should be able to provide a curriculum that meets the needs of individuals. The importance of chemistry is becoming more apparent to the general population with a growing awareness of the role of chemistry in areas such as environmental chemistry, nanotechnology, food analysis, pest control, cosmetics, medicine and forensic science.

There are an increasing number of people working in science-related industries as a result of more job opportunities in areas such as health sciences, biomedical sciences, biotechnology, agriculture, environmental sciences and aquaculture. The university courses catering for these professions commonly require students to undertake some education in chemistry. This research provides an opportunity to address the needs of these students by investigating how and why they are learning chemistry.

This research examines high school and university students' understanding of models and chemical representations highlighting how students use them in the learning and understanding of chemical and scientific concepts. Because the representations are the focus of many scientific and chemical explanations, students' understanding of them is critical to their value. Equally important is the students' appreciation of the role of the model and/or representation in the scientific process – looking at their understanding of the concepts of theory, model, fact and reality that are inherent in their epistemological understanding. The comparison of student responses from Year 8 to first year university is examined to identify any differences with age and maturity.

This research provides an insight into the value of a variety of student-centred learning tasks including model-building, collaborative discussion and laboratory experiments. The value of the tasks in helping students to learn and understand chemical concepts is examined under a constructivist framework.

In addition, the research looks at the chemical language and the chemical way of knowing that needs an understanding of the sub-microscopic level of matter. Students' understanding of the abstract and theoretical sub-microscopic level of matter is usually dependent on understanding the models and chemical representations that are used to represent it.

This research into understanding how students learn chemistry includes multiple areas of significance that have the potential to improve learning and instruction.

1.6 Justification of the Research

The overall reason for the research is to improve the understanding of how students learn chemistry. The study has focused on the issue of representations because representations are the basis of chemical explanations. Students' learning results in the building of their own mental models from the representations, they communicate ideas and understandings with the representations, and models are a type of representation. Several aspects of students' learning are examined and implications for learning are made. Aspects such as understanding what students think about models and chemical representations and observing how they use the models and representations, both physically and mentally are specific to learning chemistry. More general aspects include the value of particular learning tasks, investigating how students are learning chemical concepts and examining things that affect how students are learning chemistry.

Justification of the research comes through the communication of the findings and the implementation of changes – improvements – to teaching and learning as a result of the research. Despite the revolution in scientific knowledge and in technology, at times there does seem to be little that is futuristic about the everyday approach to teaching chemistry (Gabel, 1999). It is indeed disappointing that the impact of chemical educational research on the teaching and learning of chemistry has been minimal (Gabel, 1999). This outcome is frustrating and emphasises the futility of research that is not communicated or acted upon. There is evidence of significant changes to chemistry curricula globally. The top-down approach, with departments or institutions requiring the implementation of new curricula founded on constructivist philosophies adopting outcomes-based and context-based teaching approaches, may be necessary to force teachers to adopt the changes that have been shown in educational literature to enhance learning.

1.7 Definitions and Terminology

There are numerous terms that are used in this thesis to convey particular meanings. To prevent any misunderstandings and clarify any ambiguities, definitions are provided.

A sub-microscopic view – being able to think spontaneously of atoms and molecules at the sub-microscopic level.

Chemical epistemology – an understanding of the knowledge of how chemical ideas are built and an understanding of the way of knowing about chemical processes.

Chemical literacy – providing students with skills to understand chemistry in a social, democratic, cultural and utilitarian sense (Nuffield Curriculum Projects Centre, 2001).

Conceptual change – a model of learning initially proposed by Posner et al. (1982).

Conceptual model – the mental model.

Consensus model – an expressed model which has been subjected to testing by scientists and which has been socially agreed by some of them as having merit (J. K. Gilbert, 1997) . It is similar to scientific model.

Constructivism – a philosophy of learning in which knowledge is built up from within by a thinking person (Staver, 1998).

Epistemology – knowledge of how ideas are built up. "Epistemology is about how you know what you know" (Monk, 1995, p. 129).

Expressed model – that version of a mental model that is expressed by an individual through action, speech or writing.

Instrumental understanding – knowing how to do something but not knowing why (Skemp, 1976).

Intentional conceptual change – characterised as "the goal-directed and conscious initiation and regulation of cognitive, metacognitive, and motivational processes to bring about a change in knowledge" (Sinatra & Pintrich, 2003, p. 6).

Intentional learning – refers to cognitive processes that have learning as a goal rather than an incidental outcome (Bereiter & Scardamalia, 1989, p. 361).

Macroscopic – observable; able to be seen or experienced.

Mental models (general) – "are psychological representations of real, hypothetical, or imaginary situations" (Johnson-Laird, Girotto, & Legrenzi, 1998, p.

1).

Mental models (referring to chemistry) – a personal representation of the sub-microscopic level of matter.

Metacognition – being aware of one's conscious and deliberate thoughts.

Model – defined by Gilbert and Boulter as "the representation of an object, an event or an idea" (1995, p. 1)

Modelling Ability – a three tiered scheme from Level 1 to Level 3 describing "students general understanding of models as related to epistemological viewpoints" (Grosslight, Unger, Jay, & Smith, 1991 p. 803).

Non-major – chemistry is not the major area of study, but is often a compulsory component of a course.

Ontology – a network schema of knowledge. "Ontology is about the nature or status of things in the world" (Monk, 1995, p. 129).

Relational understanding – "knowing what to do and why" (Skemp, 1976, p. 20).

Representation (mental) – to call up in the mind by description or portrayal or imagination (Hughes, Mitchell, & Ramson, 1995).

Representation (physical) –a likeness used to describe or depict (Hughes et al., 1995).

Scientific model – an expressed model that has been subjected to testing by scientists and has been socially agreed by some of them as having merit.

Social/affective – an aspect that encompasses a students' motivational beliefs about the self and learning, their role in the classroom and in their learning (Pintrich, 1999).

Sub-microscopic – the atomic or molecular level of chemical representation of matter.

Symbolic – a representation of the sub-microscopic or macroscopic level.

Teaching model – a specially constructed model used by teachers to aid the understanding of a consensus model.

WebCT – “Web Course Tools is a learning management system that provides functionality to publish lecture notes, administer online quizzes, create bulletin boards, real-time chat rooms, and provide other features in a secure web environment with full student authentication, grading and tracking, all under the control of the lecturer. Both student and staff interfaces are accessed using any standard web browser on any Internet-connected computer” (Curtin University of Technology, 2003a http://www.startup.curtin.edu.au/online/webct.html).

1.8 The Organisation of the Thesis

The organisation of the thesis is based on the research objectives. In addition to the first chapter, the thesis consists of a further seven chapters:

Chapter 2 Literature Review: Models and Chemical Representations

Chapter 3 Literature Review: Learning Chemistry

Chapter 4 Research Methodology

Chapter 5 Models and Modelling Ability

Chapter 6 The Three Levels of Chemical Representation of Matter

Chapter 7 The Development of Personal Mental Models

Chapter 8 Conclusion and Implications for Future Research

Chapter 2 describes the literature pertaining to models and chemical representations. Examples of using the three levels of chemical representation of matter in learning chemistry and a variety of teaching approaches particular to chemistry are included. As a result of the analytical review of the literature, two theoretical constructs are proposed – the rising iceberg and the exploding triangle to help explain common difficulties in learning chemistry.

Chapter 3 describes the literature pertaining to learning with a critical review of the literature on a constructivist approach to teaching and learning chemistry including the conceptual change theory, relational learning, metacognition and mental models. A theoretical framework relating the role of four types of models – teaching, scientific, mental and expressed – in learning is proposed.

Chapter 4 contains the research methodology. It begins with a general description of the research methods adopted such as data collection, analysis, interpretation, validity, reliability and ethics and then describes in detail the methodology for each of the four studies comprising this research.

Chapter 5, 6 and 7 contain the results of the research. Chapter 5 addresses the first objective of the research concerning students' understanding of models and their modelling ability. Relevant data from the studies are presented and conclusions are made about students' general understanding of models and their modelling ability.

Chapter 6 addresses the second objective concerning the role of each level of chemical representation of matter in learning chemistry. Data are presented to illustrate students' understanding of each level of chemical representation of matter and their ability to transfer between levels of chemical representation of matter.

Chapter 7 addresses the third objective of the research concerning the learners' mental model, metacognition and conceptual change. Data from the studies provides insight into students' learning experiences. The data are analysed in terms of the epistemological, ontological and social/affective perspectives of conceptual change (Posner et al., 1982; Tyson et al., 1997).

Chapter 8, the final chapter, summarises and draws together the findings of the research. The implications of the results of the research are discussed along with suggestions of areas for future research.

Each chapter begins with an outline that provides an overview of the contents of the chapter. The end of each chapter has a conclusion, which summarises the findings and interpretations that have been reported within the chapter. All abbreviations are summarized in Appendix A. When referring to other parts of the thesis the appropriate section, table or heading number is used only, for example Table 3.1, the first number, "3" refers to the chapter number and the "1" refers to the number of the table in that chapter, and section 6.2, the first number “6” refers to the chapter and the second number to the section of that chapter. The page number can be located from the contents list at the front of the thesis. Diagrams and figures are presented as they appeared to students. Diagrams 6.5, 6.7, 6.9, 6.10, 6.12, and 6.13 are copied with permission from Silberberg (2000).

1.9 Summary

This chapter has provided an overview of the research and some background information. The statements of significance and justification of the research support the main objectives and research questions. The chapter concluded with a glossary of terminology that is used in the thesis and an outline of the contents of the following seven chapters.

CHAPTER 2

LITERATURE REVIEW: MODELS AND CHEMICAL REPRESENTATIONS

Chapter Outline

This chapter reviews literature that pertains to objectives 1 and 2 concerning models, modelling ability and chemical representations of matter. The first section of this chapter is a discussion of the dilemmas faced in understanding chemistry. The way the three levels of chemical representation of matter, macroscopic, sub-microscopic and symbolic, are utilised when learning about chemical phenomena is examined as well as the difficulties in comprehending the specialised language used in chemistry and distinguishing it from the everyday meanings of identical or similar terms. The second section of this chapter examines explanatory tools, in particular chemical representations, which are encountered in the research including chemical models, chemical equations, diagrams and pictures. The third section explores the importance of students' modelling ability in being able to use the explanatory tools, such as chemical models in learning chemistry. The fourth section describes modelling ability – a skill that is examined in this research and is relevant to students' use and understanding of models and representations. Section five reviews popular typologies of models and proposes a typology that is drawn on in the analysis of the results. Section six examines how the three levels of chemical representation of matter are used in a variety of teaching approaches that are experienced in this research including problem solving, laboratory work and cooperative learning. Section seven uses Johnstone's three levels of chemical representation of matter (Johnstone, 1982) as the basis of two frameworks, the exploding triangle and the rising iceberg to describe the learning of chemistry. Section eight is the conclusion and relates the importance of chemical representations in explanatory tools to understanding chemistry.

2.1 IntroductIon

Students' learning and understanding of chemistry is dependent on clear explanations of abstract chemical concepts. Explanatory tools such as models and chemical representations are central to the learning of chemistry. They are used in explaining scientific and chemical concepts to enhance students' learning and understanding and develop learners' mental models for chemical concepts and the sub-microscopic level of chemical representation of matter (Johnson-Laird, 1983).

The extensive applications to industry at the nanoscale with items such as semi-conductors, digital imaging and digital information emphasises the value and significance of understanding the sub-microscopic level of chemical representation of matter. In spite of this, there is a perception by some students at the undergraduate level at university and at high school that chemistry is too hard, too boring and there is too much to learn (I. Ritchie, 2003; Rowe, 1983). These applications and advances have enormous potential to promote the value and significance of chemistry to the learner. However, there appears to be a chasm between the chemistry of nanotechnology and the chemistry taught at school and first year university.

Teaching and learning is a holistic process influenced by a large variety of aspects and this is particularly true for chemistry (Coll & Taylor, 2001). This review looks at a variety of aspects that influence the learning of chemistry, but consistently through all aspects the underlying principle of the three levels of representation of matter – macroscopic, sub-microscopic and symbolic levels (Johnstone, 1982) is evident.

2.2 The Dilemmas of Understanding Chemistry

Chemistry is a difficult subject to understand because it has many abstract concepts that are totally unfamiliar to students whose mental models are often in conflict with scientifically accepted explanations. Although the rote learning of chemical formula and facts are essential for long-term memory, this alone does not challenge or ensure the learner's understanding. Only a personal reconstruction of the chemical concepts by the learner helps achieve meaningful learning (Johnstone, 1997). Indeed, based on a study in Singapore of Grade 12 students' understanding of chemical bonding, Boo (1996) reported that students can produce correct answers to particular questions without understanding the chemical concepts. Many students did not have an understanding of the nature of science and she inferred that this compounded the effects of their understanding of the chemistry. This anomaly of achieving correct answers despite using conceptually unacceptable strategies also has been identified in the areas of stoichiometry and equilibrium (BouJaoude & Barakat, 2000; Huddle & Pillay, 1996; Spencer, 1999).

Human beings are naturally curious and when observations are made which seem bizarre or different, they try to explain what is observed. Indeed, at an early age, children already have personal, well-developed approaches for generating their own explanations (Metz, 1998). According to Nakhleh and Krajcik (1994), difficulties in learning chemistry can be attributed to the students not constructing a sound mental picture of basic chemical concepts so that there is no foundation upon which to build advanced concepts. Students' conceptions that differ from the commonly accepted scientific meaning are referred to as misconceptions or alternative conceptions depending on the author's understanding of the nature of knowledge (Patrick J. Garnett, Garnett, & Hackling, 1995b; Nakhleh & Krajcik, 1994). While chemistry introduces students to new ideas and a new vocabulary, Renstrom, Andersson, and Marton (1990) conclude that science teaching only "changes their [students'] views of things in the world around them to a very limited extent" (p. 567). The inference is that students do not link or apply the new knowledge that they learn at school to everyday life.

Research shows that what students already know, in other words their pre-conceptions, has a serious impact on their learning of new material as these are the foundations on which new knowledge is built (Patrick J. Garnett et al., 1995b; Taber, 1996). Consequently, students' everyday experiences and intuitive logic should be recognised by teachers in order to develop students' scientific explanations (Andersson, 1990). Teaching strategies based on constructivist principles include providing students with opportunities to restructure their conceptions through discussions and to reflect on their understandings, using demonstrations, experiencing conflict situations and taking greater responsibility for their own learning (Patrick J. Garnett, Garnett, & Hackling, 1995a).

2.2.1 Three Levels of Chemical Representation of Matter

The study of chemistry is essentially about the abstract concept of the atomic theory of matter that can be portrayed at various levels of representation corresponding to the scale and symbol being considered. Johnstone (1982; 1993) distinguished three levels of chemical representation of matter which are described as:

- The macroscopic level – comprising tangible and visible chemicals, which may or may not be part of students' everyday experiences.
- The sub-microscopic level – comprising the particulate level, which can be used to describe the movement of electrons, molecules, particles or atoms.
- The symbolic level – comprising a large variety of pictorial representations, algebraic and computational forms.

Johnstone (1982) describes the macroscopic as descriptive and functional, and the sub-microscopic level as representational and explanatory. An overview of the three levels of chemical representations of matter, presented diagrammatically in Figure 2.1 encourages the use of multiple representations, using all three levels simultaneously (Hinton & Nakhleh, 1999) and develops an understanding of the importance of the scale that is being represented. Examples of each of the three levels of chemical representation of matter are shown in Figure 2.2. Harrison and Treagust (2002) point out that for many Grade 8 students and even for some Grade 8–10 science teachers, their understanding of the particulate nature of matter, i.e. the sub-microscopic level is poor. The use of the term sub-microscopic refers to levels from the microscopic through to the nanoscopic level and even smaller. Research shows that many secondary school and college students, and even some teachers, have difficulty transferring from one level to another (Boo, 1998; Gabel, 1998). These findings suggest there is a need to emphasise the difficulty of transferring between different types of representations within each level, as well as transferring from one level to another (Treagust & Chittleborough, 2001). Johnstone (1997, p. 263) proposes the gradual development of the three interconnected levels and warns against introducing all three levels simultaneously with novices because the "working space" of our brains cannot handle all three levels simultaneously.

Erduran and Scerri (2002, p. 8) emphasise a philosophical approach to chemistry education and recommend that the "teaching and learning of chemistry can be improved through an understanding of the structure of chemical knowledge". This approach is not inconsistent to Johnstone's ideas that provide students with a means of understanding the nature of chemical knowledge. The current emphasis on the philosophy underpinning the knowledge of chemistry has the potential to re-energise the importance of the role of models and representations in the process of science.

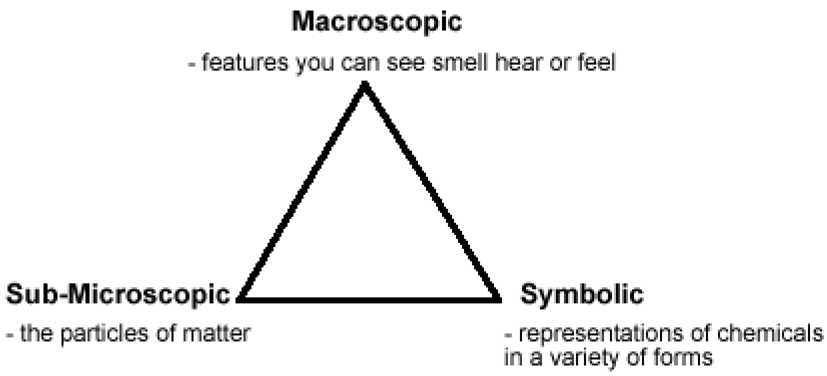


Figure 2.1 Three Levels of Chemical Representation of Matter (Johnstone, 1982)

2.2.2 Representation

The term representation may be used with different connotations generating possible misunderstanding or confusion. According to *The Australian Concise Oxford Dictionary* (Hughes et al., 1995), the definition of the word 'representation' means something that represents another. The word represents has numerous meanings including: to symbolise; to call up in the mind by description or portrayal or imagination; to place a likeness of before the mind or senses; to serve or be meant as a likeness of; to describe or to depict as. These terms reinforce the descriptive, symbolic and recognisable role of representations in explanations.

2.2.2a The metaphorical nature of representations

A metaphor provides a description of real phenomena in terms of something else with which the learner is more familiar. Under this broad definition, all representations such as models, analogies, equations, graphs, diagrams, pictures and simulations used in chemistry, can be regarded as metaphors because they are helping to describe an idea – they are not literal interpretations, nor are they the real thing. The metaphorical status and role of the symbolic representations used in chemistry is most important and needs to be understood if the metaphor is to be used successfully (Bhushan & Rosenfeld, 1995). Because scientific concepts are foreign to students and difficult for them to understand, metaphors are commonly used to provide links to familiar concepts and provide a foundation on which students can build new ideas. These considerations are in line with a constructivist approach to teaching in which the students' prior knowledge is the foundation on which to build further knowledge (Yager, 1991).

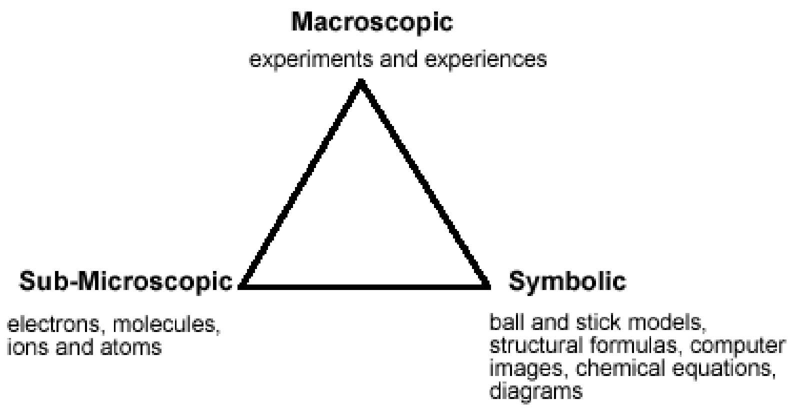


Figure 2.2 Examples of Each of the Three Levels of Chemical Representation of Matter

2.2.2b Representational levels of chemical representations

Johnstone (1993) refers to the level of chemical representation of matter, which must not be confused with the term representation commonly used for symbolic representations of chemical phenomena including almost any explanatory tool. Johnstone‘s hierarchical levels provide an overview of how chemical data are portrayed and presented whereas the term representation can be used for any chemical depiction that the learner encounters. Inherent in Johnstone's classification scheme is the understanding that the macroscopic and sub-microscopic levels of representation of matter are in fact reality not a representation. The differences between reality and representations are not often confronted as it is usually assumed that they are understood. However, from discussions with colleagues, it would appear that there is some ambiguity between chemists and educators as to the reality of the sub-microscopic level, with some chemists confident that it is real and some educators believing that it is a representation of a theoretical model – hence the dotted line in Figure 2.3. The difference between reality and theory needs to be considered here because the sub-microscopic level is based on the atomic theory of matter. The sub-microscopic level is as real as the macroscopic level – it is just the scale that distinguishes it, and the fact that the sub-microscopic level cannot be seen easily makes it hard to accept as real. Chemists are now able to observe atoms or molecules, using an electron microscope (but not always in real time), and so they can be classified as real rather than a theory; however, it is not possible to see how the atoms interact, so for this the chemist relies on theories. Theories rely on models – so when we picture an atom we are in fact picturing a model of an atom or a number of pictures of atoms based on various models (Taber, 2003).

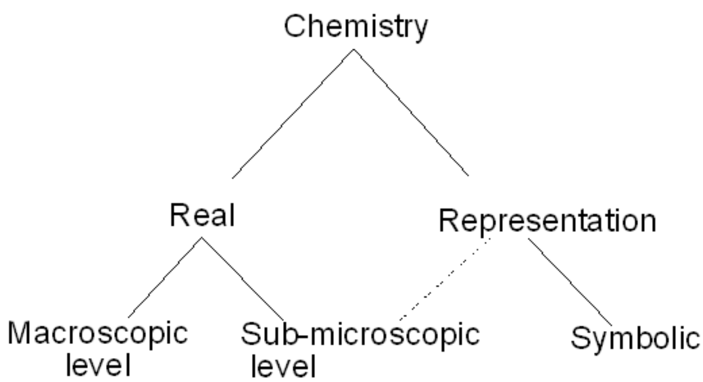


Figure 2.3 The Relationship Between the Three Levels of Chemical Representations and Real and Represented Chemical Data

For this study, the three levels of chemical representation of matter (Figure 2.4) are described as follows:

- The macroscopic level is real and able to be seen.

- The sub-microscopic level is based on real observations but still needs the theory to explain what is occurring at the molecular level and uses representations of theoretical models.
- The symbolic level is a representation of the reality

Johnstone (2000) emphasises the importance of beginning with the macroscopic and symbolic levels because "both corners of the triangle are visualisable and can be made concrete with models" (p. 12). The sub-microscopic level, by far the most difficult (Nelson, 2002), is described by the atomic theory of matter, including particles such as electrons, atoms and molecules and is commonly referred to as the molecular level. Johnstone (2000) describes this level simultaneously as the strength and weakness of the subject of chemistry: it provides strength through the intellectual basis for chemical explanations, but it also presents a weakness when beginning students try to learn and understand it. The lack of a mental model of many novice students appears to be a result of the sub-microscopic level being ignored or marginalised when compared to the macroscopic and symbolic levels of representation (Table 2.1) (Wright, 2003).

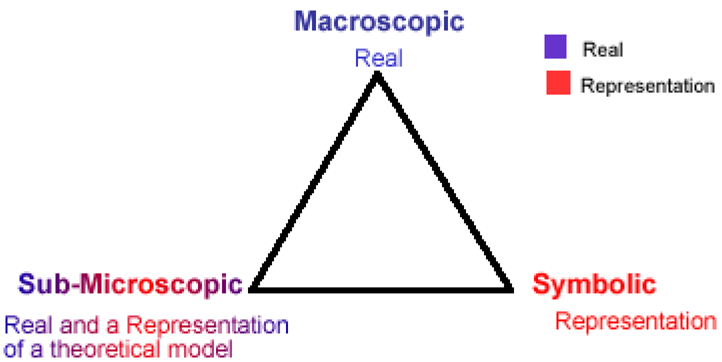


Figure 2.4 The Reality or Representational Status of the Three Levels of Chemical Representation of Matter

The sub-microscopic level cannot easily be seen directly, and while its principles and components are currently accepted as true and real, it depends on the atomic theory of matter. The scientific definition of a theory can be emphasised here with the picture of the atom constantly being revised. As Silberberg (2000) points out, scientists are "confident about the distribution of electrons but the interactions between protons and neutrons within the nucleus are still on the frontier of discovery" (p. 58). This comment demonstrates the dynamic and exciting nature of

Table 2.1 Description of the Rusting of Iron at Each Level of Chemical Representation of Matter

The rusting of iron	Level of Representation		
	Macroscopic	Sub-microscopic	Symbolic
Observations	Solid iron nail has a brown flaky coating on it that comes off easily when touched.	Iron metal has iron atoms all closely packed together to form the solid nail. Some of the iron atoms next to the surface have reacted with the oxygen molecules forming a bond between an iron atom and an oxygen atom according to the formula Fe_2O_3.	The chemical equation summarises the reaction showing the number of iron atoms and oxygen atoms involved in the reaction. A ball-and-stick model and a computer simulation can depict the solid iron atoms being attacked by the oxygen molecule.
Real or Representation	Real	Real - but too small to be seen with the naked eye.	Representation.
Description	Tangible; quantitative;	The particulate or molecular level according to the atomic theory of matter.	A depiction which may or may not be accurate but helps to provide a mental image.
Perception	Visible	Can't be seen with the naked eye, so mental image is based on descriptions, diagrams, explanations	The model is a tool to help understand the real entity.

chemistry. Appreciating this overview of how scientific ideas are developing may help students to expand their epistemology of science.

The recent sudden increase of images at the sub-microscopic level through advances in nanotechnology has the potential to provide the visualisation required to teach this level more adequately, even though the projections are still representations (Stevens, Owens, & Wuhrer, 2002). Nanotechnology describes research where the dimensions are less than about 1,000 nanometres (remembering that one nanometre is one-millionth of a millimetre) with descriptions and vision of particular atoms.

2.2.2c Explanatory power of symbolic and sub-microscopic levels of chemical representation of matter

It is the theoretical nature of the sub-microscopic level that is essential for chemical explanations. Symbolic representations of atoms and molecules are usually a snapshot of an instant in time focussing on the single successful reaction only, for example a reaction mechanism or an equation. By focusing only on the successful reaction, the unsuccessful reactions are forgotten and the probability of success is not represented. There is a risk that the kinetic molecular theory relating to the motion of the sub-atomic particles such as the magnitude of the number of chemical species in the vessel and the constant movement and the many unsuccessful collisions is not appreciated (Krajcik, 1991). This omission in understanding the events of the kinetic molecular theory highlights the risk that a representation can be taken out of context and the meaning jeopardised. Explanations of chemical phenomena usually rely on the behaviour of the sub-microscopic particles that are represented symbolically. Consequently, the students' understanding of all three levels is central to the success of any explanation.

As Kozma and Russell (1997) point out, "understanding chemistry relies on making sense of the invisible and the untouchable" (p. 949). Explaining chemical reactions demands that a mental picture or model is developed to represent the sub-microscopic particles in the substances being observed. Observations at the macroscopic level of changes in colour or volume of a reactant, or the evolution of a gas for example, reveal nothing about the sub-microscopic behaviour of the chemicals involved. Yet, explanations are nearly always at the sub-microscopic level

– a level that cannot be observed – but is described and explained using symbols by which personal mental models are constructed.

Unfortunately, students often transfer the macroscopic properties of a substance to its sub-microscopic particles, observing for example that sulfur is yellow, so believing that the atoms of sulfur are yellow also. Indeed, this is not surprising considering the graphical representation of yellow circles in textbooks to represent the atoms (Andersson, 1990; Patrick J. Garnett et al., 1995b). To overcome this problem, Gabel, Briner, and Haines (1992) recommend that teachers provide physical examples or at least descriptions of the chemicals in the problems, in addition to the representations, so that students can establish their own links between the three major levels for portraying the chemical phenomena. In a study into students' understanding of acids and bases, Nakhleh and Krajcik (1994) reported that students' explanations made many more references to the macroscopic level than the sub-microscopic level and more about the sub-microscopic than the symbolic, indicating that they are more confident describing these chemicals at the macroscopic level. Given this not unexpected finding, which is supported by other studies, it is somewhat surprising that so few chemistry curricula emphasise the chemistry of students' everyday experiences (Patrick J. Garnett et al., 1995b) or embed the chemical concepts in a familiar or relevant context for the learner.

Fortunately, there are now exceptions to the atomic structure approach of the sixties and seventies that emphasised the abstract symbolic and sub-microscopic levels (Fensham, 1994). The use of familiar items in chemistry laboratory work has been used to reinforce the link between chemistry and home, resulting in improved students' perceptions of chemistry (Ramsden, 1994; Roberts, Selco, & Wacks, 1996). In England, the Salters Chemistry course incorporated a constructivist approach using familiar chemicals as the starting point to motivate students and create a positive classroom climate (Campbell et al., 1994). Nelson (2002) has had positive results with "teaching chemistry progressively" (p.215) by beginning with student observations at the macroscopic level to provide the examples and foundation to learn the atomic and molecular level, followed by the electronic and nuclear level. Wright (2003) supports the approach of introducing students to atoms and molecules early in their middle years of schooling so that students have a sound foundation before introducing the sub-atomic level. Forgoing content chemistry for contextual chemistry alone is not the solution; moreover, a change in the philosophical approach is needed whereby the unique nature of the structure of chemical knowledge underpins the direction of changes to the curriculum (De Vos, Bulte, & Pilot, 2002; Erduran & Scerri, 2002).

2.2.3 Alternative Conceptions

In a similar way, commonsense and first hand experiences support students' belief in the continuous nature of matter – a homogeneous or conglomerate medium. However, in school chemistry lessons the discontinuous or particulate nature of matter is introduced and used to explain scientific phenomena. Not surprisingly students retain the belief in the continuous nature of matter when one considers the small amount of evidence provided to students, the limited time spent teaching this radical idea and the young age at which it is often introduced. And yet the particulate nature of matter forms the foundation of all chemical explanations and it is often assumed that students accept and understand the concept of the particulate nature of matter. One outcome of this dichotomy is for students to use both beliefs simultaneously (Krnel, Watson, & Glazar, 1998; Renstrom et al., 1990). There may be no value in destroying the continuous model of matter for the particulate model because they can be used side by side. Macroscopic, continuous descriptions are used for continuous meaning and chemical symbols should be restricted to the sub-microscopic, discontinuous meanings where molecules and atoms are involved. However, the confusion between macroscopic and the sub-microscopic nature of matter is well documented (Andersson, 1990; Patrick J. Garnett et al., 1995b; Krnel et al., 1998) and gives rise to students confusing chemical phenomena such as:

a) dissolving and melting.
b) associating heat with weight and matter – so heat adds weight to what is being heated.
c) having difficulty accepting the conservation of matter and mass when some substances appear to disappear.
d) understanding the transformation of water from solid to a liquid but being unable to transfer this phenomena to other substances.
e) accepting the "disappearance" of liquids during evaporation.

f) believing that if a gas is formed then it changes into air.

2.2.3a Anomalies in chemical explanations

The chemistry teacher faces a formidable intellectual challenge because attempts to simplify chemical concepts often lead to confusion such as students only associating elements with atoms and molecules with compounds (Fensham, 1994). Other confusions are when teachers and textbooks categorise processes as chemical or physical even though these changes are not absolute categories but are more of a continuum (Palmer & Treagust, 1996). Similarly, melting and dissolving often do not occur in isolation and the categorisation of a process, as only one type is not always possible. Fensham (1994) provides examples of these anomalies: "heating washing soda leads not to melting as it would appear, but to sodium and carbonate ions dissolving in the solid's water of crystallisation; hydrogen chloride gas reacts with water as it dissolves to form ionic species that were not present in the original gas" (p. 19). In other situations, students apply the octet rule for molecular bonding indiscriminately – in areas where it is not appropriate – leading to the reference of 'molecules' of sodium chloride based on the electronic transfer of one electron from a sodium atom to a chlorine atom (Taber, 1997; 1998; Taber & Coll, 2002). General chemistry courses use most examples with gases or aqueous solutions; however, the most prevalent state of the chemical materials encountered in everyday life is solid (Dungey, Lisensky, & Ciondren, 2000).

Learning chemistry is not simple, and well-informed teaching practices such as reinforcing the links between the three major levels portraying chemical phenomena – macroscopic, sub-microscopic and symbolic – are needed to ensure students do not develop entrenched alternative conceptions.

2.2.4 Relating Chemistry to Everyday Life

Many chemistry courses fail to show the relevance, usefulness and applicability of chemistry to everyday life. One way to achieve this might be to use common terms alongside chemical names so that students can relate the chemicals with everyday experiences; simple examples are sodium bicarbonate as baking soda, acetic acid as vinegar and sodium chloride as common salt. Another aspect of relevance is to refer to everyday chemical events such as heating, combustion, solids, liquids and gases changing phase and, melting and boiling in the specific chemical context that also includes sub-microscopic and symbolic representations. Such a decision is important because it will challenge pre-conceptions or the alternative conceptions that many students have developed for these terms (Krnel et al., 1998). Although it is understandable how these alternative conceptions have arisen, they are not scientifically acceptable and have to be unlearnt or challenged so that new conceptions can be better understood. One way to address this difficult task is through cooperation and sharing of ideas between students (Patrick J. Garnett et al., 1995a; Schmidt, 1997) and for the teacher to be aware of common alternative conceptions and have strategies in place to help students reconstruct their conceptual frameworks (Taber, 1998). Teacher's awareness of students' background, ideas and experiences helps create a supportive classroom climate. The social constructivist approach outlined here is supportive of a Vygotskian perspective (Hodson & Hodson, 1998a) in which the contextual nature of learning is important (Howe, 1996).

In Western Australia, the new draft chemistry curriculum places greater emphasis on using "examples of important household, environmental and industrial chemical processes" as well as "studying applications of chemistry in areas such as biochemistry, materials production, forensics and environmental chemistry" (Curriculum Council, 2003, p. 1). In addition, the chemistry curriculum will provide students with an opportunity to complete vocational competency levels in laboratory operations. De Vos et al. (2002) in the Netherlands suggest a curriculum based on themes such as fire protection, oceans, food and water quality. These new proposals are consistent with educational trends towards more relevant content, contextual learning, understanding scientific methodology and developing chemical literacy in students.

2.2.5 Language

Chemistry has its own special language, but the same words used in everyday speech also have different meanings and these frequently give rise to learning difficulties. When terms are used in a scientific context, it is assumed that the scientific meaning will be understood (Patrick J. Garnett et al., 1995b). However, confusion and frustration arise when teachers and textbooks use the same vocabulary as used in everyday communication, in explanations of chemical phenomena, assuming that students understand the special chemical meanings of the terms being used (Nakhleh & Krajcik, 1994; Schmidt, 1997). In classrooms, often no distinction is made between the scientific meaning and the commonplace meanings of our vocabulary such as driving force, precipitation, energy, or bond (Boo, 1998). Even within chemistry, there are several meanings for the same word and students confronted with the same words with different meanings become confused (Selinger, 1998). For example, 'pure' can refer to the cleanliness of a substance, not its chemical nature; 'mixture' refers to something physically combined together, not the chemical nature of, for example, glass or blood or drinking water. Students' experiences are mainly with mixtures; however, their perception is that these substances, such as brass, lemonade, wine or tap water are chemically pure. Words as different as dissolving and melting, which are obvious to teachers, are frequently confused when used by students who have insufficient background or experience with which to distinguish these terms and consequently the teacher's meaning is not communicated clearly (Fensham, 1994). These basic alternative conceptions reveal a weak foundation on which to build further chemical knowledge.

Particular words such as particle, molecule, ion, atom and substance are often misused and misinterpreted. Terms such as donated, shared and accepted, which were initially used metaphorically, now have developed new literal meanings in their chemical use (Taber, 1998). The historical development of chemical terms means that some names are misleading; for example, Schmidt (1997) reported that many students conclude that the prefix 'ox' in oxidation indicates that oxygen is involved in all redox reactions. However, a more enhanced understanding of oxidation and reduction can only be achieved with a more universally acceptable definition of the concept using oxidation numbers (Pamela J. Garnett & Treagust, 1992). Similarly, students' understanding of the terms neutralisation and neutral that result from common and historical meanings conflicts with the acceptable chemical meaning because as Schmidt (1997) explains, "in proton transfer reactions, acids and bases never consume each other" (p. 132). Nevertheless, the issue of changed meaning over time can be used to advantage by discussing the historical development of the phenomena and why the particular term now is considered misleading (Schmidt, 1997).

The anthropomorphic use of language in chemical explanations such as the commonly used phrases 'the atom wanted or needed to gain or lose electrons' and 'the atom was happy' are used with the intention of helping students identify with the topic. However, those explanations develop misunderstandings such as students associating forces between the nucleus and the electrons as only applying to the atom's "own" electrons (Taber, 1998; Treagust & Harrison, 1999). When teachers speak about water being made of oxygen and hydrogen, students can interpret this to mean that water is a mixture of the two gases; such an interpretation can be confusing when it contradicts students' knowledge of the properties of water (Renstrom et al., 1990). Garnett and Treagust (1992) report that the movement of ions in solution is often described with phrases like "ions carry a charge" (p. 132), which may be misinterpreted to mean that the ions carry the electrons. Research has shown that the precise and consistent use of language along with detailed particulate descriptions of the sub-microscopic nature of matter can improve students' interpretations (Fensham, 1994; Patrick J. Garnett et al., 1995a).

2.3 Symbolic Representations of Chemical Phenomena

Symbolic representations are used extensively in chemistry and are the physical teaching tools used to help explain the macroscopic and sub-microscopic levels of chemistry. Symbolic representation of chemical phenomena include chemical models such as ball-and-stick models, space-filling models, structural formula, chemical equations and computer models (J. K. Gilbert & Boulter, 1998), as well as verbal descriptions, diagrams, analogies, metaphors, pictures, ideas, simulations or anything that can be used to develop learners' mental models. These tools are used in conjunction with the conceptual model that the learner uses for understanding the new scientific concept (Duit & Glynn, 1996).

Chemists and chemistry teachers readily use different representations of molecular structures such as the ball-and-stick model or space-filling models to explain features and functions of a molecule under investigation. However, typically secondary students do not perceive these different representations in the same way as their teachers, more often regarding each representation as something new to learn rather than a tool to help them learn. As previously mentioned (section 1.4) models can be considered as a subset of representations. Models in science and chemistry can take on a variety of forms. Consequently, the term model when used in referring to scientific and chemical models has a broad meaning whereas the term model when used in general everyday use refers to a copy, replica or image. As learners assimilate new information provided by the various representations they build up a personal mental model of the concept being studied. This section highlights characteristic features of chemical representations that can be useful in classification and examines three broad types of chemical representations that are encountered in this study: chemical models, diagrams and pictures and chemical equations.

2.3.1 Chemical Models

The use of models and modelling in chemistry is arguably constructivist and it is likely that students' visualisation of models fosters conceptual development and conceptual changes by inducing gestalt shifts in learners' mental models (Norman, 1983). Model-based teaching and learning is consistent with personal and social constructivist theories of learning where the focus is on the learner, with all learning being dependent on language and communication (Cosgrove & Schaverien, 1997). Indeed, the introduction of model-based reasoning is a highly desirable skill, but it does require extensive instruction and practice within the culture of the classroom (Stephens, McRobbie, & Lucas, 1999) that would require professional development for teachers. The use of models can encourage discussion and the articulation of explanations encourages students to evaluate and assess the logic of their thinking (Raghavan & Glaser, 1995). However, more often, students perceive a different representation as a new thing to learn rather than a means to explain what is to be learnt. Commonly, students approach learning with a focus on the content that has to be understood – failing to appreciate alternative aspects of learning including understanding the chemical way of thinking, analytical styles and explanatory tools such as models.

2.3.1a Chemical models as copies or replicas of reality

The use of models and modelling in chemistry teaching is a common practice that engages students by helping them to develop their own mental models of chemical compounds. It is practically impossible for chemical phenomena to be explained without the use of models. However, despite this common use of models, studies have shown that students misunderstand the reasons for using models and modelling (Renstrom et al., 1990). Many secondary students view models only as copies of the scientific phenomena (Grosslight et al., 1991) and their understanding of the role of models frequently is seen as being simplistic (Treagust, Chittleborough, & Mamiala, 2003). Even university students have limited experience with models and only a small percentage of these students have an abstract understanding of model use in chemistry (Ingham & Gilbert, 1991). In a cross-age study, Coll and Treagust (2001) describe similar outcomes when undergraduate and postgraduate students tended to use simple teaching models learned in high school to explain chemical bonding. Because no single model provides the total evidence for the structure and function of a molecule, each student's understanding is reliant on realising the limitations and strengths of each teaching model (Hardwicke, 1995). Teachers' level of understanding of models also has been described as limited because they have a simplified understanding of models and modelling in science (Justi & Gilbert, 2002b; Van Driel & Verloop, 1999). Nevertheless, modelling is a common, intrinsic behavior used in everyday life and also in the chemistry laboratory. Understanding models and their role in the development of scientific ideas is part of the chemistry teachers' personal philosophy of science and is central to his or her pedagogy (Selley, 1981). Gilbert (1997) and Harrison and Treagust (1996) recommend that teachers be educated to use models in a more scientific manner and Johnstone (2000) suggests that "the intelligent use of models" (p.12) should be an integral part of teaching.

2.3.1b Chemical models – real or representations?

The use of concrete models and pictorial representations has been shown to be beneficial to students' understanding of chemical concepts (Gabel & Sherwood, 1980; Harrison & Treagust, 1996). However, the extensive and accepted process of using models has made the model appear as 'fact' to many teachers and students (Boo, 1998; Renstrom et al., 1990). Indeed, teachers and textbooks often represent atoms and molecules as real and factual, forgetting the origins of their evolution as representations of theoretical models of matter. Frequently, students do not differentiate between models and they do not regard models differently from the observed characteristic that the model is trying to explain. For example, teachers do not emphasise the representational nature when referring to CH_4 saying that it is methane, whereas the phrase CH_4 represents a methane molecule would be more accurate. This lack of emphasis reinforces the dilemma of some students viewing models only as copies of the scientific phenomena. While it is assumed that students understand the representational nature and the analogical relations within the chemical language (Duit & Glynn, 1996), the strengths and limitations of each model need to be discussed so that students can assess its accuracy and merit (Hardwicke, 1995a, 1995b).

Shusterman and Shusterman (1997) recommend the use of computer-generated three dimensional models of electron density distributions to provide a more student-friendly way of describing electronic orbitals, which otherwise are often too difficult for students to comprehend. Obviously, particular models need to be appropriate to the learners' level of understanding and the role of the model in learning and explaining needs to be appreciated. A more accurate approach may be to represent the acceptable explanations as making use of particular chemical models which when used consistently explain an observation (Justi & Gilbert, 1999). Recent textbooks and software present all three levels of chemical representation of matter simultaneously, reinforcing the existence of the three levels (Dalton & Tasker, 2001; Silberberg, 2000).

Taber (2002a; 2002b) uses examples of the students' application of ideas from the molecular level to the macroscopic level to illustrate misconceptions. Most significant in this field is the exponential advances in technology at the sub-microscopic level – nanotechnology – that now provide excellent projections and images of the sub-microscopic level – the level that has so far been the least understood by students. As a result of these representations being incorporated into teaching, there is the possibility of a dramatic change in students' perceptions of the sub-microscopic level because the new technology will provide the 'pegs' on which students can hang their understanding and develop their own personal mental models (Robinson, 1998). These advances will replace the current vague, nebulous and ill-defined nature of the sub-microscopic level with a precise and accurate model. In terms of the typology of representations, the current representation will be replaced with one that has more visual, quantitative and responsive qualities.

In comparing the perceptions of experts and novices on a variety of chemical representations, Kozma and Russell (1997) concluded that novices used only one form of representation and rarely could transform to other forms, whereas the experts transformed easily. Novices relied on the surface features, for example lines, numbers and colour, to classify the representations, whereas experts used an underlying and meaningful basis for their categorisation. The study highlighted the need for representational competence including an understanding of the features, merits and differences of each form and showed the significance of computer animations in linking the various representations. A computer-based chemistry visualising tool, *e-Chem*, was found to help students significantly to construct models and translate representations in a study with 11th grade high school students, in addition to the possibility of generating mental models (Wu, Krajcik, & Soloway, 2001).

2.3.1c Visualising the particulate nature of matter

Chemical models generated by computer graphics provide excellent detail and dynamics to illustrate molecular size, shape, bonding and electronic structure of chemical compounds, as is shown, for example, in the electron density distributions by Shusterman and Shusterman (1997) which may help overcome the difficulties that students have in visualising the particulate nature of matter (Barnea, 2000; Williamson & Abraham, 1995). In comparing a computer package DTMM (Desktop Molecular Modeler) with traditional instructional methods, Barnea (2000) reported that the 15 year old chemistry students using the computer molecular modelling program had improved visualisation of chemical substances, better understanding of the model concept, as well as a better understanding of the bonding structure of molecules. Similarly, Copolo and Hounshell (1995) reported improved retention on a test of isomeric identification by students using both computer and ball-and-stick models, indicating the effectiveness of concrete instructional aids in teaching abstract concepts. However, these students performed poorly on items using two-dimensional representations, illustrating the difficult task of mental transference that needs to be given consideration by teachers because it is pivotal in developing mental models (Copolo & Hounshell, 1995; Kozma & Russell, 1997). This difficulty may be enhanced through the use of computer programs that are able to transfer between the three different levels of representation from macroscopic, sub-microscopic and symbolic so students can compare representations (Herron & Nurrenbern, 1999). This suggestion is supported by Wu et al. (2001) who observed substantial improvements in students' understanding of chemical representations over a 6 week period after using *e-Chem*, which allows students to build molecular models and view multiple models simultaneously. These results confirm the value of computer, graphical and physical aids in helping students to visualise the sub-microscopic level. There has been a significant increase in the availability of computer modelling technology for teaching and learning chemistry in recent years. Capitalising on these resources requires their use in a pedagogically sound manner (Beckwith & Nelson, 1998).

2.3.2 Diagrams and Pictorial Representations

Illustrative diagrams are seen as descriptions using pictures and have been shown to improve laboratory work (Robinson, 1998). There is a large variety of diagrams including two and three dimensional drawings, graphs, cartoon figures, sketches at sub-microscopic level, diagrammatic representations and photographs, simulations and videos. However, research with drawings of the sub-microscopic level creates difficulties of scale, accuracy and representations in time because the particles are constantly moving. By the very nature of representations, there are limitations, so students and teachers must use them with those limitations in mind.

2.3.2a Diagrams enhancing visualisation

The term visualisation is used extensively in chemical education research because of the need to provide a visual link to the abstract particulate nature of matter. The sub-microscopic level cannot be seen but it is an essential component of chemistry and in order to teach about it, representations such as diagrams, models and computer images are utilised to achieve this. An explanatory tool such as a diagram or an image can provide the learner with a way of visualising the concept and hence developing a mental model for the concept (Gabel, 1998). The value of a diagram in making the link with an abstract concept depends on it being consistent with the learners' needs and being pitched at the learners' level of understanding (Giordan, 1991).

2.3.2b Diagrams providing conceptual links

Gobert and Clement (1999) suggest that diagrams can have more than just illustrative purposes, expanding the purpose of diagrams to model construction and reasoning. Similarly, Nahkleh and Krajcik (1994) refer to V-diagrams and concept maps as diagrams that encourage learners to diagrammatically represent their understanding. V-diagrams are a method of displaying and thinking about the processes involved in knowledge construction by linking the laboratory work with the concepts that are trying to be understood. Concept maps are diagrammatic representations of key concepts, usually structured hierarchically in which the relationships between concepts are indicated by linking words or phrases that help to visualise knowledge (Nakhleh & Krajcik, 1994). Concept maps are proven instructional tools used to create meaningful learning because they require learners to reveal their conceptual understandings and misunderstandings of the interrelationships of various concepts. The re-conceptualisation of ideas that challenge incorrect conceptions can be assisted with concept maps (Novak, 1990).

2.3.3 Chemical Equations

Chemical equations exemplify the international language of chemistry and understanding the symbolic representations inherent in chemical equations demonstrates a high level of chemical literacy. Chemical equations embody numerous chemical concepts such as conservation of mass and charge, chemical formula, and relating mass, gas volume and solution volume to the number of atoms and ions and molecules present (Hinton & Nakhleh, 1999). The chemical equation portrays symbolically a quantitative summary of the sub-microscopic level and can be related to the macroscopic observations.

When writing and balancing equations, there are numerous assumptions that the novice learner cannot understand and the experienced learner assumes to be understood. Oversby (2001) identified some contradictory meanings of the symbols used in chemical equations, for example, the addition symbol on one side of an equation means ‘to react with’ whereas the addition symbol on the other side of an equation means ‘and’, where the meaning depends on the direction of the reaction being considered. Obviously students’ awareness of these differences is an important consideration to their understanding of the symbolic representation.

Students' lack of understanding of the particulate nature of matter and their inability to visualise the dynamic process of a reaction on a particulate level lead to problems in solving chemical equations (Patrick J. Garnett et al., 1995b). The dilemma that students see chemical equations as independent of chemical reactions reinforces the notion that students do not link the symbolic and macroscopic levels of chemical representation. A study by Hinton and Nakhleh (1999, pp. 24-25) about the mental representations of chemical reactions used by six freshman college students provides evidence that:

a) the students were able to identify the macroscopic phenomena of chemical reactions.

b) the students were able to mathematically balance chemical equations.

c) none of the students demonstrated a clear understanding of the sub-microscopic nature of polyatomic ions.

d) students who used the terminology for the sub-microscopic level inexactly did not necessarily demonstrate a poor understanding of the sub-microscopic concepts.

e) students who did not use the terms atom or molecule also had some misunderstanding of the sub-microscopic aspects of chemical reactions.

f) students receiving similar course grades sometimes had very different conceptual understandings of the three representational levels.

These results highlight the difficulty that students have in understanding the sub-microscopic level. Despite being able to perform algorithmic exercises on chemical equations, students often lack the conceptual understanding and the background of the sub-microscopic level that is assumed in a chemical equation. Similarly, Fensham (1994) confirms that balancing equations is learning a set of rules. The algorithmic tasks of balancing equations and doing calculations that are common assessment tasks provide little evidence of students' meaningful understanding.

Hinton and Nakhleh (1999) conclude that making students aware of the three levels of chemical representation of matter through the use of multiple representations and also providing means within lessons or lectures to reveal students' ideas may improve students' conceptual understanding. The novice and expert have very different understandings of chemical equations and this could be due to their difference in understanding of the particulate nature of matter and the kinetic molecular theory on which the chemical equation is based. Krajcik (1991) distinguishes various aspects of chemical equations with each aspect relying to some degree on the integration of two or three levels of chemical representation. These aspects are:

- Structural – chemical symbols, the molecular structures and states of matter (Macroscopic/Sub-Microscopic/Symbolic).
- Interactive – the breaking and forming of bonds including reaction mechanisms that constitute a chemical reaction (Sub-Microscopic/Symbolic).
- Dynamic – the continual movement and collisions of a multitude of particles, that may or may not lead to a reaction (Sub-Microscopic/Symbolic).
- Quantitative – the stoichiometric and energetic aspects of the reaction (Macroscopic/ Sub-Microscopic/Symbolic).
- Macroscopic – the physical properties of the reactants and products (Macroscopic/Symbolic).

Each aspect covers distinct understandings of chemical equations and each aspect adds to the users' understanding. Krajcik (1991) describes the value of these various aspects in "constructing meaning" and "demonstrates the integrated conceptual framework that a chemist develops and applies when describing and explaining a chemical reaction" (p. 122). Both Johnstone (2000) and Krajcik (1991) refer to visualising the breaking of bonds from the information in the chemical reaction. But Hinton and Nakhleh (1999) and Garnett et al. (1995b) report that students do not do this easily. It appears that the full potential of the chemical equation is not being utilised because students lack an understanding of the sub-microscopic level. The stoichiometric qualities are well utilised but the links between the symbolic chemical equation and the sub-microscopic level appear to be poor.

2.4 Modelling Ability

2.4.1 Modelling-Based Skills

Models and modelling are explanatory tools for the learner. Modelling at a rudimentary level requires the user to relate the target to the analogue (Duit, 1991). Stephens et al. (1999) distinguished lower order and higher order relational mapping and explain users' need to understand the connections between the model and the target in order to construct explanations. Raghavan and Glaser (1995), working with sixth grade students, reported an improvement in the development of students' model-based reasoning skills in predicting, testing and evaluating ideas as a result of specific model-based instruction. White (1993) experienced success and failure working with models, emphasising the importance of how the models are used, reminding of the need for activities "to be carefully designed and sequenced to build gradually on students' interests and intuitions" (p. 70) and for the teacher to scaffold discussion. Despite this, White recognised the potential of model-based learning to produce autonomous, motivated learners. Justi and Gilbert (2002a) identify modelling as one of the main processes in the development of scientific knowledge and as such it has the potential to drive changes in the approaches to learning

2.4.2 Three Levels of Modelling Ability

Grosslight et al. (1991) developed a scale to describe students' modelling ability consisting of three levels: at Level 1, models are considered to be "copies of actual objects or actions" (p. 817); at Level 2, students "realise that there is a specific, explicit purpose that mediates the way the model is constructed" (p. 817); and at Level 3, "the model is constructed in the service of developing and testing ideas rather than as serving as a copy of reality itself" (p. 818). In their study, Grosslight et al. (1991) based their classification on six dimensions: the role of ideas, the use of symbols, the role of the modeller, communication, testing and multiplicity. These authors found that 23% of the 11^{th} grade students were pure Level 1, 36% were mixed 1–2 Level and 36% were pure Level 2 and no students were classified as Level 3 modellers.

Modelling ability is closely aligned to model-based reasoning as described by Stephens et al. (1999) who investigated the factors affecting electrical resistance in which the model of electron drift was used. Students used the model to explain their experimental results, engaging in model-based reasoning. The types of reasoning used by students to explain their observations were classified as: phenomenon-based, relation-based, model-based reasoning with lower-order relational mapping and model-based reasoning with higher-order relational mapping. The lower order and higher-order relational mapping is consistent with Grosslight et al.'s (1991) Level 1 and Level 2 of modelling ability. The defining of levels of modelling skill provides a scale for comparison and a useful descriptive reference (Figure 2.5).

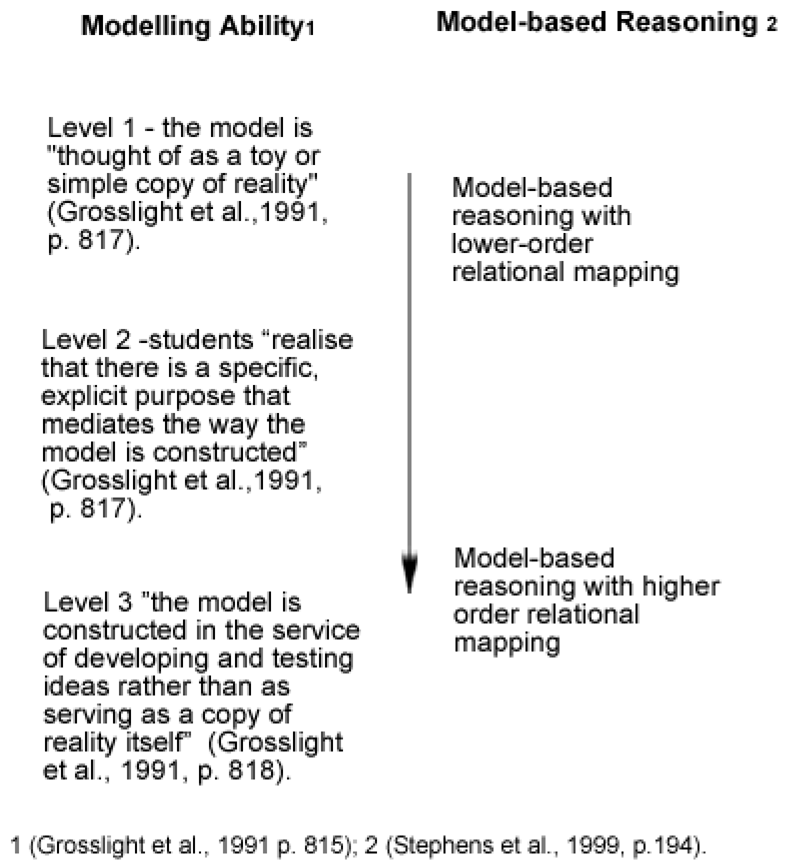


Figure 2.5 Comparison of Two Schemes for Modelling Skills

Harrison and Treagust (2001) consider modelling ability, conceptual status and intellectual ability to be closely related recommending that "model-based instruction should be sensitive to the intellectual ability and needs of the students" (p. 51). The modelling ability scale is consistent with the rising iceberg theoretical framework that is described in section 2.7, with the horizontal line in the triangle moving to a lower position, revealing more of the iceberg, as the modelling ability improves.

2.5 Typologies of Models

A variety of classification schemes have been proposed for models. Gilbert and Osborne (1980) using ideas proposed by Black, identified five main categories: scale, analogical, mathematical, theoretical and archetype. Hardwicke (1995a) used the first four types in his modelling typology to classify molecular models. In the meantime, Gilbert and Boutler (1995) proposed a typology based on the way the model is used – resulting in four main categories:

- Teaching model – A specially constructed model used by teachers to aid the understanding of a consensus model.
- Consensus model – An expressed model, which has been subjected to testing by scientists and which has been socially agreed by some of them as having merit – a scientific model.
- Expressed model – That version of a mental model, which is expressed by an individual through action speech or writing.
- Mental model – A personal private representation of the target.

Harrison and Treagust (2000) developed a typology of models considering both the way the model is used as well as the type of model. Drawing on the classification schemes of Gilbert and Boulter (1995) and Black as described by Gilbert and Osborne (1980), Harrison and Treagust (2000) generated four categories for the ten different model types as outlined:

- Scientific and teaching models
    - scale
    - pedagogical analogical model
- Pedagogical analogical models that build conceptual knowledge

    - iconic and symbolic models
    - mathematical models
    - theoretical models

- Models depicting multiple concepts and processes
    - maps diagrams and tables
    - concept process models
    - simulations

- Personal models of reality, theories and process
    - mental models
    - synthetic models

Boulter and Buckley (2000) proposed an operational typology of models based on model-based learning situations "which refers to the construction of mental models of phenomena through the recursive process of model formation, testing and rejection or revision" (p. 45). There are two dimensions of the typology – firstly, the mode of the representation, that may be three-dimensional, verbal, visual, mathematical or gestural, and include combinations of these types; and secondly, the attributes of the representation that may be quantitative/qualitative, static/dynamic, or deterministic/stochastic (referring to the reproducibility of dynamic models – consistent or variable). Boulter and Buckley (2000) claim that the "typology begins to give a structure and coherence to the field of models used in different situations" (p. 57).

Any typology, which caters for an extensive range of model types, uses, and functions, has limitations that need to be recognised. However, a typology provides a framework and an overview that some students may find useful as an organisational aid. Buckley and Boulter (2000) recognise the limitations of any typology and the difficulties in helping students to use models and model-based reasoning to develop mental models.

Through the development of the typologies of models it is clear that a description of the model type alone is not sufficient. The learner and the teacher need to be aware of the role of the model in learning as well. Aspects of models describing what they are and how they are used become an important part of this research.

2.6 Teaching Approaches

2.6.1 Problem Solving

Problem solving is a commonly used teaching method in chemistry because it challenges students' understanding of the subject matter and requires them to apply the concepts that they have learned (Bodner & Herron, 2002; Gabel & Bunce, 1994). The characteristics of good problem solvers, according to Herron and Greenbowe (1986), include a good command of the basic facts and principles, the ability to construct appropriate representations of the problem, the ability to use general reasoning strategies that allow logical connections among the elements of the problem and the ability to apply several verification strategies. When applying these skills, good problem solvers check the problem representation against the given facts, ensure that the solution is deemed logically sound, that the calculations are checked for errors and that the problem solved is the problem presented. Similarly, the methodology for problem solving outlined by Hanson and Wolfskill (2000) includes identifying the problem and the important issues, evaluating information, planning a solution, executing a plan, validating the solution and assessing an understanding of the solution.

Despite the existence of these strategies, students have difficulty solving chemistry problems because their understanding of the relevant concepts is often not sufficient, they use memorised algorithms without thinking, and have difficulty transferring between macroscopic and sub-microscopic levels of understanding (Staver & Lumpe, 1995). Chemistry teaching comprises both algorithmic problems, which can be completed on a formula basis and often do not indicate understanding, as well as conceptual problems, which require students to display their understanding. When faced with conceptual problems, research shows that students do not rely on their reasoning skills or conceptual understanding, but often resort to using algorithms without understanding the problem (Niaz & Robinson, 1992). Mason, Shell and Crawley (1997) report that students performed better at algorithmic problems compared to conceptual problems even though they take longer to complete the algorithmic problems; however, successful completion of algorithmic problems did not guarantee understanding of the chemical concepts. The large variety of problem solving strategies generated by students reveals competing and conflicting frameworks, which may be attributed to their alternative conceptions, reasoning strategies and prior knowledge (Astudillo & Niaz, 1996). Solving problems conceptually requires students to transfer between the three levels of chemical representation of matter and reconstruct the problem in terms of their own understanding.

Strategies to help improve problem solving ability include using analogies, models, diagrams and verbal and visual descriptions. Noh and Sharmann (1997) reported that pictorial materials at the molecular level do not improve students' ability to solve problems, but do improve their ability to construct correct scientific concepts. For solving problems on the mole concept, Staver and Lumpe (1993) described students' understanding of the mole concept as being vague and their inability to transfer between the macroscopic and sub-microscopic levels affected their ability to do the problems. They recommended that students use analogous representations for the mole to provide a more concrete experience such as using different sized shot gun pellets to represent different atoms and arbitrarily assigning one size as the standard mass and then measuring the other sized pellets relative to the assigned mass, so that an analogous Avogadro's constant can be determined. Gabel et al. (1992) demonstrated the advantages of integrating the three levels of understanding of chemical phenomena in solving chemical problems by ensuring students have seen or are aware of the macroscopic properties of the chemicals, by using three-dimensional models to represent the sub-microscopic level, and by using diagrams to represent the symbolic level of understanding.

A computer program called *The Mole Environment* contains graduated problem solving study-ware that specifically incorporates the concepts of the three levels of representation of matter, the idea that matter is particulate, and environmental awareness to promote a global understanding rather than algorithmic learning of the mole concept (Dori & Hameiri, 1998, 2003). This program resulted in improved student understanding of the mole concept and an appreciation of its application to environmental aspects. Alternative computer interactive problem sets in chemistry have been shown to be effective because they provide the students with immediate feedback, they can be personalised to suit individual students, and the results can be stored easily (Spain, 1996). The introduction of problem-solving teaching into the laboratory was shown by Gallet (1998) to improve students' interpretive capacities, motivation and communication skills.

2.6.2 Laboratory Work

Laboratory work is an essential and usually a compulsory component of any chemistry course with experiments carefully chosen to provide macroscopic examples of the concepts being taught. Because conceptual understanding is usually explained at the sub-microscopic and symbolic level, laboratory activities are an essential and often the only component of the macroscopic representation level. Nevertheless, laboratory work is often criticised for not being relevant to the coursework, and being a recipe task in which the students simply follow the instructions without understanding what they are doing (Gallet, 1998). Consequently, along with factors of cost, safety and time, the importance of laboratory work in chemistry has diminished in recent years, although computer simulations have increased especially for dangerous, expensive and time-consuming experiments (Lunetta, 1998).

A constructivist approach to learning chemistry in which "students construct their own knowledge derived from what they already know" (Spencer, 1999, p. 568) is believed to lead students to deeper learning, improve their integration of knowledge and develop a more sophisticated epistemology (Regis & Albertazz, 1996; Rukavina & Daneman, 1996). A constructivist approach to learning guards against equating knowledge acquisition with scientific content (Rukavina & Daneman, 1996). This constructivist process can be observed through laboratory activities in which students actively construct their knowledge, based on prior experiences and new information received (Nakhleh, 1994). The laboratory work provides students with many opportunities for the integration of knowledge in a meaningful way. This description of the value of laboratory activities supports the rising iceberg theoretical framework (section 2.7) that is based on the observable and experiential activities.

Coll and Taylor (2001) suggest that although constructivism is a worthwhile philosophy, at times it is not appropriate for learning chemistry because it is not practical for the students to construct all meaning, nor is it worthwhile for students to value their own interpretations above that of accepted science. The view of learning can be considered along a continuum from relativist/constructivism to positivist/transmission. Spencer (1999) identifies this range and considers neither extreme likely to be found. However, there are aspects of each philosophy that are valuable. Coll and Taylor (2001) describe how they still rely on the transmissive method for teaching simple factual material; however, they have found constructivist techniques including Predict-Observe-Explain (POE), concept mapping and interactive group work to be successful in the learning process.

2.6.2a Importance of laboratory work

Teachers have tried many innovative techniques to show the relevance of the laboratory tasks and promote an understanding of the purpose of the laboratory tasks. Adopting a constructivist approach and identifying students' preconceptions have proven to be successful by adapting experimental methods to promote inquiry through challenges, predictions and experimental design (Clough & Clark, 1994). These decisions also have implications for promoting team-work, interest and confidence such as adapting experiments that require students to include a publicly expressed prediction that promotes enthusiasm and rivalry (Plumsky, 1996). For example, after weighing and heating a sample of potassium chlorate until it completely decomposes, students are required to calculate the mass of the final product in the test tube. The teacher weighs the tube and the grade for the group is determined by the level of accuracy of their prediction within balance error. In a similar manner, the Predict-Observe-Explain (P.O.E.) approach, commonly used with demonstrations, requires students to make a prediction about the outcome of an experiment, then observe the demonstration of the experiment and finally explain their observations and prediction (Liew & Treagust, 1995). This active learning approach is aimed at promoting critical thinking, improving self-confidence and communication skills; the teacher observes and listens, gives students more thinking time and accepts students' ideas instead of judging them.

Clough and Clark (1994) maintain that teachers are the critical component in students' education through their effective articulation and communication to the students. The importance of pre-laboratory preparation is crucial considering that what students already know determines what they will learn. The laboratory can be used to serve important links between the macroscopic observations and the sub-microscopic representations and any techniques that facilitate these links are valuable. The teacher plays a key role in bridging the chasms between the three levels of representations of matter because the variety of methods, technology and style of laboratory work all contain inherent problems that can result in student misunderstandings. Research has shown that students' attitude towards chemistry is enhanced when the laboratory activities are related to the theory being studied and when the rules of behaviour expected in the laboratory are clearly outlined (Wong & Fraser, 1996).

Unfortunately, laboratory work is not always done in a scientifically correct or appropriate manner and this is exacerbated when students are more interested in obtaining predetermined or expected results than in understanding the significance of the results. Gallet (1998) refers to "student osmosis" (p. 72) in report writing, and Ritchie and Rigano (1996) to "fudging the results" (p. 13) when describing the scientific practices of the students. This is indeed disappointing, but is a result of using recipe-driven practicals designed to achieve near perfect results and rewarding these results. Teachers promoting intellectual honesty by practising authentic scientific processes in the laboratory can rectify this state of affairs. For example, there is greater value in doing open-ended experiments which do not have predetermined or expected results but do require students to explain their results in a scientific manner. Improvements have been seen in students' skills of identifying variables, hypothesising, planning, carrying out experiments and interpreting data through these methods (Patrick J. Garnett et al., 1995a).

2.6.2b Execution, recording and assessment of laboratory activities

The working space in the brain is limited and Johnstone (1997) is critical of the overload that instruction in laboratory manuals can demand, forcing students to adopt a recipe-like procedure. The technical, unfamiliar language often used in laboratory manuals puts additional demands on students' short-term memory reserves (Gabel, 1998). Robinson (1998) believes that symbolic representations in the form of visual images in laboratory manuals can assist students' understanding. This view is supported by Dechsri, Jones and Heikkinen (1997) who reported improved student performance in the cognitive, affective and manipulative domains of the laboratory as a result of including pictures and diagrams with the text. Pre- and post-laboratory discussions can be used to identify any alternative conceptions (Nakhleh, 1994). Laboratory activities should develop students' skills in experimental techniques such as observing, classifying, using laboratory equipment, as well as applying conceptual knowledge, developing procedural knowledge and applying inquiry tactics such as identifying variables and interpreting data (Patrick J. Garnett et al., 1995a). Writing and talking about chemistry improves the understanding of the concepts (Kozma & Russell, 1997) and using a critical peer review system can improve both the writing style and analysis of practical reports (Newell, 1998).The use of data-loggers and micro-computer-based labs are favoured by students but instruction in the use of the technology is an important aspect in their effectiveness (Nakhleh, Polles, & Malina, 2002). The video and animation powers of the computer and the use of chemical models can be utilised in chemistry tests so that the test items include the three levels of chemical representation of matter (Bowen, 1998). Indeed, a holistic assessment of laboratory investigations is recommended by Garnett et al. (1995a), with caution to over-valuing specific scientific skills at the cost of assessing the students' understanding of the whole investigation.

2.6.2c Relevance of laboratory activities to real life

Motivation and interest can be achieved by giving a real-life perspective to laboratory work such as simulating a forensic chemistry problem (Long, 1995), having a mock trial using role playing (Kimbrough, Dyckes, & Mlady, 1995) or managing the chemistry of a swimming pool (Bieron, McCarthy, & Kermis, 1996). Experiments exposing clear scientific method, using everyday items such as baking soda, vinegar, shampoo and sugar in practical assessment tasks have been used to "reinforce the connection between science and the students' out of school experience" (Doran, Chan, & Tamir, 1998). In a chemistry program in Germany, experiments to investigate environmental issues such as the presence of chloro-fluorides in household chemicals, helped students to apply chemical knowledge to everyday situations (Klemmer, Hutter-Klemmer, & Howard, 1996). In this way, laboratory tasks with real life applications integrate everyday concepts into the chemical concepts, providing a contextual framework consistent with a Vygotskian approach to learning (Howe, 1996). This emphasis on the macroscopic level supports a constructivist approach and is consistent with the rising iceberg theoretical framework, described in section 2.7.

2.6.3 Cooperative Learning

For students to construct meaningful knowledge networks, teaching needs to provide opportunities for being engaged in motivating and interactive activities. Ensuring that dialogue between students focuses on their understanding of chemical concepts can be beneficial in the construction of knowledge networks (Nakhleh, Lowrey, & Mitchell, 1996) and improvement of their attitude towards chemistry (Gabel, 1998; Patrick J. Garnett et al., 1995b).

Small group learning, which can be used for a problem-solving activity, laboratory work, concept mapping or research task, requires positive interdependence of the members of the group in order to develop teamwork skills. Approaches such as the jigsaw structure involve the formation of a transient group made up of one person from each base group. People in the transient group then become experts at solving one problem and return to their base group to explain to their group-mates how to solve this problem (Towns, Kreke, & Fields, 2000). Quality discussion can challenge alternative conceptions and provide a non-threatening forum for the learners to express their own ideas and gain feedback from others, instead of from the teacher in the form of marks or comments (Myers, Lim, Maschak, & Stahl, 1996). Strategies to promote purposeful talk include providing a positive classroom climate, ensuring that students have time to discuss, and developing structured tasks that promote student input. Process workshops in which students work in teams doing active learning tasks such as critical thinking, problem solving, guided discovery and reflection have been shown to improve attitude, interest and results among students (Hanson & Wolfskill, 2000). Bowen’s (2000) review of numerous studies into cooperative learning effects on both high school students’ and college students’ chemistry achievements concluded that “the medium students’ performance in a cooperative learning environment is 14 percentile points higher than in a traditional course” (p. 118). The collaboration generated from cooperative learning illustrates the value of thoughtful discourse in improving understanding, increasing confidence and developing teamwork skills.

2.7 Theoretical Framework for Understanding Chemistry

Drawing on the literature reviewed about models, modelling ability and chemical representations of matter, I have attempted to identify commonalities and trends to describe the learning process in chemistry. Johnstone's (1993) triangle which tries to explain why students find learning chemistry so difficult has become one of the main theoretical frameworks for this research and in considering how and why it is used, I have proposed two interpretations: the exploding triangle and the rising iceberg.

Currently, students are exposed to all three levels of chemical representation of matter in most chemistry curriculum. A common scenario would be in junior high school for students to perform experiments to observe simple chemical and physical changes; to be taught about the characteristics of the particulate nature of matter and to learn the symbols of atoms – briefly touching on all three levels of chemical representation of matter. In Studies 1, 3 and 4 of this research, students used all three levels to varying degrees. Curricula are often arranged as a spiralling concern, consistent with a constructivist philosophy, beginning with basic ideas, returning and repeating what has already been learnt and building on it in a recursive and repetitive manner. In terms of Johnstone's triangle, the students learn some chemistry at all three levels of chemical representation of matter and return and learn a bit more at all three levels of chemical representation of matter and so on moving from I to II to III (Figure 2.6). So the students' depth of knowledge at each corner of the triangle grows.

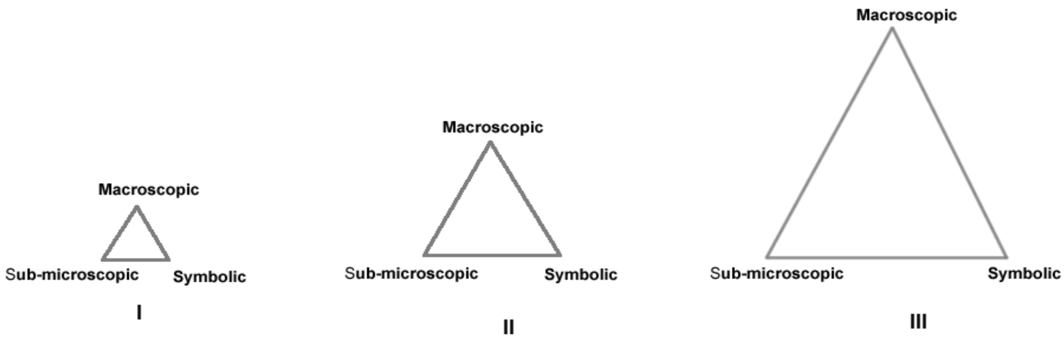


Figure 2.6 The Exploding Triangle – A Framework for Learning Chemistry

As students continue to understand more chemistry at the three levels they can make the connections between the three levels, but this is not always the case. As already discussed, the literature confirms that although students may have learnt chemistry at the three levels of chemical representation of matter, they do not always relate the three levels to each other. This interpretation of the learning process is based on the literature review, and the theoretical framework is an attempt to explain this process. I have titled this framework the exploding triangle because even though students learn more and more at each of the three levels, it is no guarantee that they relate the three levels to each other.

In contrast to the exploding triangle framework, another theoretical interpretation is suggested for consideration. I have titled it the rising iceberg because I like the three-dimensional image of an iceberg that the title creates – emphasising the extensiveness of chemical concepts; and the expanding triangle – the shaded triangle – determined by the position of the horizontal line in Figure 2.7 represents students' greater understanding. It is consistent with Johnstone's (1991) recommendation of starting with the macroscopic and symbolic levels and emphasises using the level(s) of chemical representation of matter that best suits the students' ability level. The macroscopic level of chemical representation of matter at the top corner of the triangle is always included, whereas the sub-microscopic and symbolic levels are only introduced as needed. A horizontal line is drawn across the triangle to indicate the depth of chemistry understanding to be achieved. Obviously the position of this horizontal line depends on the students' abilities, age and stage of chemical knowledge development. The shaded area above the horizontal line is deliverable and achievable for the particular students being considered. The three drawings I, II and III diagrammatically represent the rising iceberg (Figure 2.7). As the literature recommends that the macroscopic level is most appropriate for beginning students, so the chemistry should maintain an observable and experimental focus without having to use the particulate nature of matter. When students move to higher levels of understanding then more of the symbolic and sub-microscopic levels can be introduced.

This rising iceberg framework is based on the constructivist philosophy and is consistent with the literature recommendations of starting with the macroscopic, visible and observable chemical occurrences that are often part of students' everyday experiences and observations, thus providing a contextual learning experience. This was shown to be successful with the Salter approach (J. Ramsden, 1992). The intention of this framework is not to marginalise the sub-microscopic level – especially as it is nearly always the basis of chemical explanations, rather to reassess its role and importance, with evaluation of what detail of the sub-microscopic level is needed to be known in order to understand particular chemical concepts.

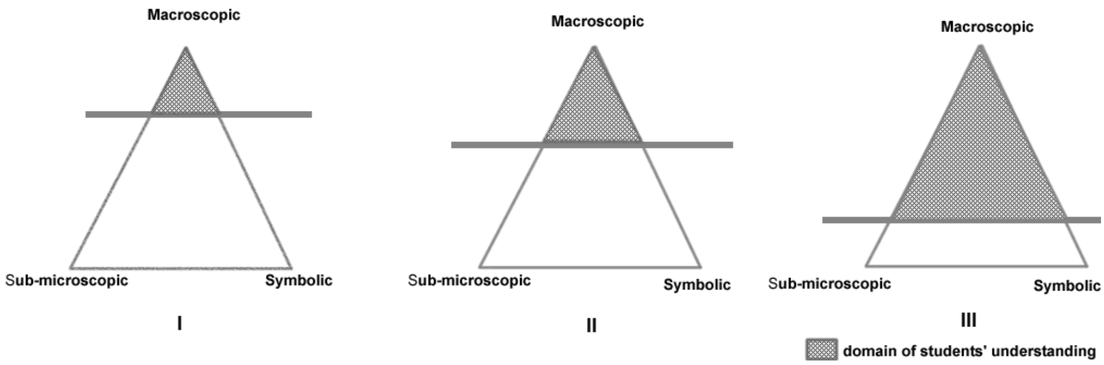


Figure 2.7 The Rising Iceberg – A Theoretical Framework for Learning Chemistry

The rising iceberg framework is designed to emphasise the importance of the macroscopic level, provide a contextual setting for learning and to critically evaluate how the sub-microscopic level is explaining the chemical phenomena. However, the literature reports that traditionally there is conflict between chemical ideas and everyday ideas; for example, everyday words adopt new and specific meanings in chemical settings; everyday experiences support a continuous nature of matter whereas the more theoretical particulate nature of matter depends on models and representations to help generate mental models; and confusion is evident between the sub-microscopic and macroscopic nature of matter. In order to combat these potential misunderstandings, a constructivist approach is recommended, with the students' understanding as a starting point. The literature emphasises the importance of students' prior knowledge and understanding for their future understanding.

2.8 Conclusion

This chapter has examined how models, modelling and representations are used to describe, explain and model the particulate nature of matter in the teaching and learning of chemistry. There are three levels of representation of matter as proposed by Johnstone (1982):

- Macroscopic Level – real and able to be seen.
- Sub-microscopic Level – real, but cannot be seen directly and is dependent on the atomic theory of matter. The theoretical nature of the sub-microscopic level is essential for chemical explanations. This level is the most difficult to comprehend but this situation is improving with advances in nanotechnology.
- Symbolic Level – a representation that can be a variety of type and number of representations of the sub-microscopic and macroscopic levels. These representations often form the basis of students' mental models of chemical phenomena. Recent technological advances can provide very accurate and precise representations.

The three levels of chemical representation of matter provide a framework for understanding the relationship between the various representational forms in which chemistry appears. Just as computers zoom in and out, the depiction of chemicals can change from the reality of the macroscopic level, visible and tangible to the sub-microscopic level that is not visible to the naked eye and is a manifestation of the atomic theory of matter. The standing of the sub-microscopic level is not always clear as it has qualities of reality, representation and theory. These qualities appear incongruous – but are not. Understanding not only the actual content of the sub-microscopic level but also its position and role in providing explanations is what makes the sub-microscopic level so important.

The symbolic representations that are the foundation for teaching and learning chemistry were examined in terms of their power in helping learners to build mental models of chemical concepts. The typology of chemical representations highlighted the characteristics of particular representations. The pedagogical value of chemical models and the modelling process, diagrams, pictures and chemical equations were examined with respect to their value in building students' understanding of chemical concepts.

The essential skill of modelling has been described and its importance in chemistry examined with respect to the portrayal of chemical phenomena at the macroscopic, sub-microscopic and symbolic levels of representation of matter. The typology of models is useful in identifying model attributes identified by students in understanding the role and nature of models.

This chapter has described research findings on different teaching approaches, common to those utilised in the study that have been shown to enhance student-learning outcomes. Significant and proven effective teaching approaches and strategies applicable to chemistry include the use of chemical models, problem solving, laboratory work and cooperative learning. Interestingly, Johnstone's (1982) three levels of chemical representation of matter can be applied to all these strategies and can be used to provide an overall perspective to the development of the learners' mental model of the chemical concept. Although sharing this theoretical framework with students has been shown to be beneficial to student learning, the framework is not commonly taught overtly, as part of chemistry curricula.

Through the analysis of the literature, two theoretical frameworks for learning chemistry which use Johnstone's three levels of chemical representation of matter were formulated and described, namely:

- The exploding triangle.
- The rising iceberg.

These frameworks, with subtle but significant differences, provide a way of thinking about learning chemistry and how the learning processes are occurring. The philosophical understanding of the learning process underpins the how and why of learning chemistry. The exploding triangle framework implies students are learning at each of the three levels – independently of the others. This framework that reflects more closely what is commonly occurring in classrooms does emphasise the links between the three levels, although these links would probably be forged with greater understanding. The rising iceberg framework demonstrates progressive learning that starts with the macroscopic level of chemical representation of matter and moves onto more theoretical explanations as required. This framework is underpinned with a constructivist philosophy and begins with students' existing knowledge and experiences, building on the concrete examples of the macroscopic level. The sub-microscopic level is introduced as needed to explain the chemical phenomena. The role and nature of symbolic representations in explanations are emphasised so that students do not confuse reality with representation. The rising iceberg theoretical framework promotes a contextual basis for chemical ideas – in everyday settings.

CHAPTER 3

LITERATURE REVIEW: LEARNING CHEMISTRY

Chapter Outline

This chapter reviews literature about learning – specifically learning chemistry and science – which concerns the third objective of this research. The close affinity of learning and understanding is evident in the various types of learning that are described in section two. The attributes of a constructivist approach to learning are described in the third section and are related to a number of learning theories including conceptual change, instrumental, relational and meaningful learning. Relevant aspects of the theory of conceptual change are discussed in section four, including the epistemological, ontological and social/affective perspectives. The fifth section describes metacognition and its role in intentional learning. Mental models – the product of learning – are described and discussed in section seven. The use of chemical representations and models in providing a clear and concise explanation is discussed in relation to learning in section eight. Section nine summarises the salient points of the chapter.

3.1 Introduction

Chemical education should be the integration of educational knowledge with chemistry knowledge. Chemical education experts provide guidance in the consideration of the choice of appropriate and meaningful chemical content alongside the choice of the most suitable and proven teaching and learning approaches. This guidance also takes into consideration the results of current chemical education research and the importance of individual learning differences in learning styles (Gabel, 1999; Lagowski, 2000). The links between teaching and learning sometimes appear weak; yet the teaching approaches are intended to enhance and improve the way students learn. This chapter examines the way students learn chemistry, focussing on learning styles, and learning strategies.

The third objective of this research looks at students' learning of chemical concepts in terms of the development of the learners' personal mental models. The question – How do students learn? – has continued to interest educational researchers and is indeed difficult to answer. Nevertheless, this question is most important, as Hewson, Beeth and Thorley (1998) explain "for teaching to be effective it needs to be rooted in an understanding of how students learn" (p. 199). Theories about how students learn and the corresponding frameworks that are used to interpret the learning process have evolved over time in response to psychological and educational ideas. Each theory provides an alternative perspective on the learning process although they are not always mutually exclusive (Marin, Benarroch, & Jime'nez G'omez, 2000).

The temptation to teach the content that students are required to understand can sometimes override the need to teach students how to learn the content themselves (Spencer, 1999). The belief that teachers can transfer their knowledge, transmissively to their students by explaining and demonstrating their understanding, is common (Skemp, 1976). However, the objective of teaching is to enable students to learn and hence to be able to explain and demonstrate understanding to their peers or their teacher. Is it better to teach students particular facts or to teach them the skills to be able to learn any fact? In the long term, the student who knows how to go and find out information and knows how to tackle a problem will be better equipped for the workplace than the student who knows only particular facts. Inherent in this simplistic description is the significance of learning the necessary skills for processing ideas, concepts and knowledge. The question of what to teach students is not important when compared to why it is taught, emphasising the process of learning. This discussion draws attention to the philosophy of teaching and learning – targeting the outcomes that educators want their students to realise (Scerri, 2000).

3.2 Types of Learning

Ausubel (1968) reminds us that "teaching and learning are not coextensive, for teaching is only one of the conditions that may influence learning" (p. 12). In attempts to describe the varying depth of the learning process, the following terminology is commonly encountered: shallow learning (Atherton, 2001), quick learning (Schommer, 1990), rote learning (Battino, 1992), algorithmic style learning

(Mason et al., 1997), instrumental understanding (Skemp, 1976), passive learning (Yager, 1991) and a surface approach to study (P. Ramsden, 1992). These approaches are characterised by a lack of conceptual understanding or cognitive effort. In contrast to this are meaningful learning (Ausubel, 1968), intentional learning (Bereiter & Scardamalia, 1989), relational understanding (Skemp, 1976), active learning (Duit & Treagust, 1998) and a deep approach to study (P. Ramsden, 1992). The latter approaches are characterised by student-focused learning with greater conceptual understanding resulting in higher order reasoning and thinking skills (Stephens et al., 1999), and deep processing of information and cognitive strategies of high elaboration (Hennessey, 2003). Learning is described in terms of the level of understanding that is achieved. Hennessey describes the term high elaboration to mean "deep processing of information, elaborate cognitive strategies of connecting and comparing existing conceptions with new information, and significant metacognitive reflection about what they were thinking and why" (p. 118). These descriptions of learning are useful and all educators have aspirations to achieve Hennessey's high elaboration level of understanding for their students; however, these descriptors tell us very little about how students learn.

3.3 Constructivist Approach

The most important single factor influencing learning is what the learner already knows (Ausubel, 1968) and this is the foundation of a constructivist epistemology that is an accepted process of knowledge construction (Novak, 1991). Learning is consistent with personal and social constructivist theories where the focus is on the learner, with all learning being dependent on language and communication. In this method, science has an evolving framework of concepts and conceptual relationships, which are constructed, not discovered, by the learner (Cosgrove & Schaverien, 1997). This social constructivist perspective provides authentic learning situations (Roth, 1995), situated cognition (Seely Brown, Collins, & Dugid, 1989) and cognitive apprenticeships (Hodson & Hodson, 1998b) that describe a way of knowing.

The abstract and difficult nature of chemistry often means that students fail to achieve meaningful learning or form relationships between various chemical concepts. The strategy of having students actively construct their own conceptual links throughout the course of study has proven to be successful in improving students' understanding (Novak, 1991). The terms 'build' and 'construct' appear alongside approaches where the student has to actively find ways of making the concepts understandable to him or herself (Zarotiadou & Tsaparlis, 2000). This approach necessarily puts a great deal of responsibility on the learner, but it is not without direction and guidance from the teacher who takes on the role of facilitator.

Implementing a constructivist approach requires a philosophical change in the mindset of the teacher. It is not a change to what is taught but more to how it is taught. Within the institutional confines of assessment, curriculum, time, existing attitudes and economics, change is not always easy to implement. However, there are numerous examples where a constructivist approach has been implemented successfully in all or parts of educational programs (Clough & Clark, 1994; Gilmour, 2002). In general, constructivist approaches have been proven to be valuable in enhancing learning; however, a purist constructivist approach would not be suitable for some topics in chemistry in which a transmissive style is more suited.

3.3.1 Individual Constructivism

Investigating the learners' personal construction of knowledge does not just occur in the classroom but is a process that has continued since birth (Tytler, 2002). The learning process of experiencing new ideas, cataloguing them into the learner's personal ontological framework, evaluating and assessing their significance in terms of the learner's understanding and finally accepting or rejecting the ideas is a simplistic description of how learning occurs through the personal or individual constructivist approach (Hodson & Hodson, 1998a, 1998b; Staver, 1998). This process reflects the Vygotskian perspective of learning initially at the inter-psychological or social level and then at the intra-psychological or mental level (Jones, Rua, & Carter, 1998) and assumes that learners will construct the necessary understanding (Hodson & Hodson, 1998b). Knowledge as a personal construction by the learner rarely occurs in isolation. A student-centred approach, targeting the needs of the individual, does not negate the importance of social interaction among learners and teachers through language, culture, contexts and experiences (Hodson & Hodson, 1998b)(Table 3.1).

Table 3.1 The Social, Individual, and Teacher Perspectives of the Process of Conceptual Change

Perspective	Process	Results
Individual Constructivist – intra-psychological or mental level	Dissatisfaction with existing conception; rivalry with new idea. Evaluation of new idea in terms of intelligibility, fruitfulness and plausibility; Evaluation of new concept in terms of a learner's ontology, epistemology and motivation.	Development and testing of students' mental models for the conception.
Social Constructivist – inter-psychological or social level	Social interaction, language, culture, negotiation, contextual, situated learning, experiences, activities, predictions, reflection, engagement, questioning, talking, listening, investigating, finding patterns (Skamp, 1996).	Verbalising ideas, Expressed mental model
Teacher Intervention	Scaffolding by teacher – in line with Vygotsky's approach acting as a facilitator to extend the learner in zone of proximal development. Strategies that promote metacognitive strategies and increase students' self-efficacy (Pintrich, 1999)	Using a variety of means to communicate ideas e.g. posters, physical models, concept maps, oral presentations, written reports, videos etc.

3.3.2 Social Constructivism

There is enculturation implicit in the constructivist learning theory that knowledge is shared and includes an appreciation of "the beliefs, practices, values and style of discourse of the community of scientists" (Hodson & Hodson, 1998b p.17). According to social constructivist learning theory, there is a responsibility on the teacher to provide learning opportunities in Vygotsky's zone of proximal development by scaffolding and including socially negotiated learning (Howe, 1996; Jones et al., 1998). Scaffolding refers to the teacher introducing appropriate learning tasks that are initially beyond the learner, but with instruction and interactive tasks the learner can advance his/her development to work independently without any scaffold or assistance (Hodson & Hodson, 1998a). However, scaffolding does not only refer to the teacher's approach but also to the learner's response. The adoption of a constructivist culture requires teachers to take risks, abandon their traditional roles and methods, hand over some responsibility to the learner, choose appropriate strategies and be flexible (Windschitl, 1999).

3.4 Conceptual Change Theory of Learning

The personal construction of ideas consistent with a constructivist theory of learning reveals why and how students have scientifically incorrect understandings – sometimes referred to as misconceptions or alternative conceptions (section 2.2.3). Students assimilate many experiences and ideas, generating their own conceptual understandings before and while they are introduced to the scientifically accepted theories. Commonly, students maintain two contextually independent and conflicting understandings – everyday and scientific (Krnel et al., 1998; Renstrom et al., 1990).

3.4.1 Individual Conceptual Change

Investigating the way that students generate a new understanding of scientific concepts is called the theory of conceptual change according to Posner et al. (1982). A student who is dissatisfied with their current understanding will evaluate new ideas in terms of:

- Intelligibility – is it understandable to the learner?
- Plausibility – is it reasonable and consistent with the learners' understanding?
- Fruitfulness – is it of value to the learner?

In this way, the learner's assessment of the status of a concept is pivotal to its acceptance (Hewson & Thorley, 1989). So the scientific concept has to be more understandable, reasonable and of more value to the learner than a rival conception for it to be accepted (Hodson & Hodson, 1998a; Posner et al., 1982). By introducing new and often provocative ideas, a student's accepted conceptions may be challenged, forcing a conceptual conflict that requires each student to re-evaluate their understanding (Trumper, 1997). Indeed, expressing their understanding in public can facilitate the process of conceptual change (Hennessey, 2003).

The change of meaning connected with learning and conceptual change has been associated with changes to learners' ontological frameworks. Chi (1992) distinguished two levels of conceptual change: conceptual change occurring within an ontological category and radical conceptual change requiring the learner to shift between ontological categories. According to Chi, the latter is "nearly impossible to accomplish" (p. 179). The former is more common, with conceptual change more likely to be a gradual development of ideas and understanding in conjunction with the incremental changes to the learners' ontological framework of knowledge. Such changes result in the evolution of ideas rather than a revolution (Harrison & Treagust, 2001; Tyson et al., 1997) and it may be difficult to pinpoint conceptual change. Conceptual change within an ontological category does not imply that it is simple, easy or common (Chi, 1992). Research has shown that the learners' age and level of cognitive development does impact on their potential for conceptual understanding (Tyson et al., 1997) and documented changes to conceptual understanding often results from intervention strategies targeting inadequate aspects of teaching and/or learning (Harrison & Treagust, 2001; Stavridou & Solomomidou, 1998).

3.4.2 Multiple Perspectives of Conceptual Change Theory

While multiple theoretical perspectives have been used to examine student conceptual understanding such as epistemological, ontological and social/affective aspects by Tyson et al. (1997) and modelling level and intellectual positions by Harrison and Treagust (2001), learning is a multi-faceted process that may involve one or many theoretical frameworks. The three perspectives described by Tyson et al. (1997) of epistemological, ontological and social/affective will be expanded upon.

3.4.2a Epistemological perspective

Epistemologies of science refer to students' understanding of how scientific ideas are built up, including their knowledge about the process of knowing-about scientific knowledge (Songer & Linn, 1991). Teachers are role models – modelling the thinking required to understand a concept. Students are often dependent on their teacher as their primary and often only source of chemical explanations. Students' epistemology, that is, their understanding of how chemical ideas are built up does influence their learning. Research has shown that students' background knowledge does influence their ideas and that students generally do hold a surprisingly wide range of ideas that are resistant to change (Fensham, 1994; Gabel, 1998; Taber, 2002a).

Duit and Treagust (1998) express that "learning science is related to students' and teachers' conceptions of science content, the nature of science conceptions, the aims of science instruction, the purpose of particular teaching events, and the nature of the learning process" (p. 5). Students' views of science and its processes develop over time and are shaped and influenced by a variety of factors such as school, home, media and technology. Such views, which are all part of the students' epistemology, are a gauge of students' knowledge, their process of knowing and their understanding of how ideas are built up. The personal nature of students' epistemologies has a significant impact on their learning and is considered to be significant in a teaching and learning approach informed by constructivism. In a study by Carey, Evans, Honda, Jay, and Unger (1989), students' understanding of the nature of science was challenged and improved through specific experiments designed to encourage students to build, reflect and test their own scientific theories, resulting in significant improvement to the students' level of understanding. Gobert and Discenna (1997) identified a statistically significant correlation between each student's epistemology and his or her use of models in making inferences about scientific phenomena. Similarly, Songer and Linn (1991) categorised students' view of science into three groups – static, mixed and dynamic – and showed differences in the way that each group of students learn and relate to scientific ideas. Students with a more dynamic view of science managed to integrate new knowledge into their existing epistemological frameworks because it was compatible whereas students with a naïve epistemological view of science had greater interference to their knowledge acquisition. This finding supports Schommer's (1990) conclusion that the level of sophistication of students' epistemological beliefs does impact on their comprehension and critical interpretation of knowledge.

An epistemological perspective draws attention to the importance of foundation learning being presented in situ as part of a conceptual structure or schema. In this way, both contextual and historical aspects can be included. Although the epistemological perspective is significant it is not commonly taught directly, but more often indirectly, through example. Justi and Gilbert (1999; 2000) recommended a chronological approach investigating the successes and failures of particular scientific models to develop an understanding of the development of scientific enquiry, philosophy and history to address the epistemological perspective. This emphasis on history and philosophy is popular in science education (Tsaparlis, 2001) and the examples here commonly relate to general science education rather than chemistry education, possibly because of the pressures of prescriptive syllabi and external examinations. Harrison and Treagust (2002) recommend an historical approach for teaching the particulate nature of matter investigating "how chemical knowledge evolved and why the particle theory developed" (p. 207). This approach tackles the philosophy of chemistry education (Wandersee & Griffard, 2002).

3.4.2b Ontological perspective

The learning theory proposes that meaningful learning results in new and interconnected ideas and knowledge, inferring integration and then possible application of this knowledge. The ontological perspective refers to the nature or status of things in the world – the way students link their ideas and knowledge (Monk, 1995). Chinn and Brewer (1993, p. 17) explain it as the "students' beliefs about the fundamental categories and properties of the world". Ontological categories have originally been used in psychology with categories such as matter, events and abstraction being basic ontological categories. Individuals using their personal criteria develop original ontological networks.

Ontology is the description of a possible knowledge framework, designed to help understand how information is categorised in order to better understand the learning process. Aspects of an ontological framework for classifying entities as described by Chi (1992) include:

a) An ontological attribute is a property of an entity.

b) It is hierarchical - ontological categories exist at different levels e.g. major and basic, categories and trees (Chi, 1992, p. 133).

c) The ontological categories that distinguish one property from another must be recognised by the learner (Chi, 1992, p. 132).

d) Ontological categories are real and distinct.

e) New concepts develop gradually on new distinct trees.

Naïve intuitive meanings of scientific concepts can be understood using one ontological tree whereas the scientific explanation uses another ontological tree. This explains how some students hold two completely different concepts simultaneously and quite happily, as described by Andersson (1990) and Krnel et al. (1998). The students used the appropriate ontological tree to coincide with the way the entity is being used.

Information in long-term memory has some type of ontological arrangement, network and structure that does impact on understanding. This arrangement can be described as a mental schema which is central to learning (Brewer, 1999). Johnstone (1993) distinguishes the long-term memory from the working memory, emphasising that the limited size of the working memory must be considered especially when teaching chemistry because of the demands of the multiple levels of understanding as well as its new and foreign language. So learning strategies such as breaking large ideas into small ones, make no assumptions about previous understandings; identifying the processes needed to understand concepts; and providing active learning situations to correspond to their current schema, provide methods of handling small packets of knowledge at the working memory level before being assimilated to the long term memory. This process is supported by Johnstone's fourth educational commandment, which states "the amount of material to be processed in unit time is limited" (Cardellini, 2000, p. 1572).

Models of concepts or ideas can provide alternative levels of representation as is seen in chemistry with macroscopic, sub-microscopic and symbolic chemical representations of matter (Treagust et al., 2003). The respective positions of the three levels of representation of matter contribute to the foundation of a chemical ontological network; however, the students' appreciation of their reality, role and reason for their use is not always clear (Bhushan & Rosenfeld, 1995; Ingham & Gilbert, 1991; Nakhleh, 1994). Wilson (1998) studied students' understanding of acids and bases using their ontological network by comparing organising nodes, level of connectivity and integration to indicate the level of understanding. Declarative knowledge became more organised and differentiated as the level of expertise in the domain increased.

3.4.2c Social/affective perspective

The social/affective perspective refers to the socio-cultural factors of learning including the students' motivational beliefs and self-efficacious beliefs, the learning environment, the role of learners in the classroom and their discursive interactions (Mortimer, 1998; Tyson et al., 1997). This broad range of perspectives provides a useful framework in interpreting the process of conceptual change. Table 3.1 presents the theory of conceptual change in a diagrammatical form, comparing the social, individual (mental) and teacher perspectives (Krajcik, 1991; Tyson et al., 1997).

Conducive learning environments in which students are motivated and challenged can foster meaningful learning. Alternatively, absence from class, physical conditions, distractions and lack of motivation are obstacles to learning (Taber, 2002a). The time lag between being motivated and realising their desire to understand is the cause for many students to abandon chemistry – because it is too difficult (Johnstone, 2000).

3.4.3 Intentional Conceptual Change

The theory of conceptual change described above provides insight into the learners' mental processing of information, assuming that the learner reaches this stage of the learning process, unfortunately this is not always the case. Pintrich (2000) values the learners' "motivational beliefs about the self and learning" (p. 33) as pivotal in effecting conceptual change. Students' personal motivation or "goal orientations" (Pintrich, 1999, p. 35) can influence the way their learning is approached which in turn can influence the depth of understanding achieved. If students are not motivated, interested or confident of success then there is little chance of students reaching the stage where mental processing of information occurs. Consequently, no conceptual change or meaningful learning will occur.

Pintrich's work has been instrumental in promoting a new perspective for the theory of conceptual change specifically for when learners are aware of their learning, which is referred to as intentional conceptual change and is supplementary to the original theory. Conceptual change can occur unintentionally, when students are focused on the particular concepts and are not aware of the process of learning, but it can also be intentional with students aware of why and how they are trying to learn new concepts (Sinatra & Pintrich, 2003). These modifications reflect the dynamic nature of the theory of conceptual change continually undergoing incremental changes through the evaluation and re-evaluation of new perspectives resulting from the global collaborative efforts of educational researchers.

Sinatra and Pintrich (2003) define intentional conceptual change "as the goal-directed and conscious initiation and regulation of cognitive, and motivational processes to bring about a change in knowledge" (p. 6). Considering conceptual change as a means of describing and identifying meaningful learning, then intentional conceptual change and intentional learning are equivalent. Intentional learning is described by Bereiter and Scardamalia (1989, p. 363) "as having learning as a goal, rather than an incidental outcome." According to Pintrich (1999), the intentional learner has some control over his/her learning; is goal-directed with a focus on learning, understanding and mastering the task; can monitor and regulate his/her learning in a metacognitive manner; adopts a constructivist perspective; values the course material; and is developing higher levels of self-efficacy, i.e., building confidence and is adopting a belief in personal control of learning. Obviously, the motivation and intention of the learner will influence the process of learning but the theory of intentional conceptual change as described by Sinatra and Pintrich (2003) proposes that the learner is engaged in "intentional level processing [which] is goal-directed and under the learner's control" (p. 4).

This process assumes that the learners have metacognitive skills such as being aware of their own knowledge; being aware of their learning goals; being responsible for their own learning; being able to identify data that conflicts with their existing conception leading to dissatisfaction; being able to use knowledge to achieve their learning goals, and being able to evaluate the plausibility, fruitfulness and intelligibility of the new conception.

However, the motive for learning is not the same for all students. The theory of intentional conceptual change assumes that students who value learning and want to fully understand the concepts and master tasks are highly motivated to learn and are interested in the way they learn (Pintrich, 1999). There is a positive correlation between the students' intrinsic goals for learning and their deeper processing and understanding (Pintrich, 1999).

3.5 Metacognition

Described by Flavell as a "fuzzy" concept somewhat difficult to describe (Hennessey, 2003, p. 104), metacognition is thinking about ones' own thoughts, that is, being aware of ones' conscious and deliberate thoughts (Hacker, 1998). Metacognitive thoughts are "tied to the person's internal mental representation of that reality" (Hacker, 1998, p. 3). Therefore, the learners' mental models are their metacognitive understanding of a concept. There are four aspects of metacognition according to Flavell's model of metacognition and cognitive monitoring as described by Hacker (1998). Students have:

a) Metacognitive knowledge – an awareness of what he/she does and does not know;

b) Metacognitive experiences – personal experiences that can be applied to his/her knowledge;

c) Goals (or tasks) – an understanding of the demands of the task;

d) Actions (or strategies) – an ability to make choices of appropriate strategies to achieve the goal.

The model describes an active process, with conscious control of the processes by the learner (Hacker, 1998).

Metacognition is the process of learners consciously using strategies to enhance learning. Through learning metacognitive strategies, the learner is learning how to learn. Davidowitz and Rollnick (2001) present data to support Flavell's assertion that there is a link between cognitive actions and metacognitive knowledge and experiences. They claim that "metacognition is a necessary pre-requisite for deep [learning] approaches" (Davidowitz & Rollnick, 2001, p. 17). This position is supported by Hewson who claims that "teaching for conceptual change is explicitly metacognitive**"** (1996, p. 136). On the other hand, Sinatra and Pintrich (2003) claim that conceptual change can occur without the learners' intentions – inferring that deep learning can occur with and without metacognition.

With maturity and knowledge, students' metacognitive ability has been shown to improve (Bransford, Brown, & Cocking, 2000). Learning through intentional conceptual change assumes that learners are aware of their own learning and how they learn, and this places additional responsibility onto learners for the success of their own learning. The metacognitive process of self-regulation – "the ability to orchestrate one's own learning" (Bransford et al., 2000, p. 97) – can occur at quite a young age, whereas the metacognitive process of self reflection – "reflect[ing] on one's own performance" (Bransford et al., 2000, p. 97) – appears later in children's cognitive development. Therefore, the learners' age and cognitive development may impact on their metacognitive strategies. This assertion is supported by Hennessey's (2003) observation of students in Grade 1, when she describes them as "being involved in a form of self-interrogation, and introspection and an interpretation of past and on-going experiences" (p. 121). Hennessey goes on to describe the level of sophistication of these activities to be more advanced with Grade 6 students, further supporting the assertion.

3.5.1 Metacognitive Teaching Resources and Strategies

Metacognitive resources can be familiar teaching resources that are used in a metacognitive manner such as evaluative and reflective questions, concept mapping and Venn diagrams. They are designed "to generate information that will help people to be knowledgeable about, aware of, and in control of what they are doing" (Baird & White, 1996, p. 191), thereby acting on interpretations and increasing reflection. Many valuable pedagogical resources can be used in a metacognitive manner, when they are used in a purposeful inquiry that involves action and reflection, resulting in increased knowledge, awareness and control.

In a project called SMART Environments, where SMART stands for *Scientific and Mathematical Arenas for Refining Thinking*, Vye, Shwartz, Bransford, Barron and Zech (1998) focused on the metacognitive strategies of reflection, self-assessment and revision. Through authentic problem solving environments students were required to evaluate and choose resources upon which they obtained formative feedback. Baird and White (1996) in a *Project for Enhancing Effective Learning* (PEEL) observed the need for metacognitive development in teachers before metacognitive development in students. They identified four conditions necessary for the personal development of both teachers and students – time, opportunity, guidance, and support. Davidowitz and Rollnick (2001) designed the *Competency Tripod*, a device to help students describe their thought processes consisting of three legs – "declarative knowledge, communicative competence and procedural understanding [held together] by the link made by the students to achieve coherence of the three concepts" (pp. 3-4). These projects illustrate an improvement to learning through the use of metacognitive resources and strategies.

Similarly, Hennessey (2003) described how explicit representations were used by students to clarify their ideas and Rickey and Stacy (2000) illustrated the instructional effectiveness of concept maps, predict-observe-explain tasks and the model-observe-reflect-explain tasks from a metacognitive perspective. Vye et al. (1998), examining ecosystems with fifth and sixth grade students, provided "social and environmental support for monitoring, reflection and revision" (p. 341). Earlier, Novak (1984) used concept maps and Vee-diagrams extensively to promote meaningful learning.

An issue to be addressed in this context is that some students have a shallow level of understanding from memorizing rules and algorithms (Herron & Greenbowe, 1986). A metacognitive approach may induce a deeper level of understanding as proposed by Davidowitz and Rollnick (2001) and Hennessey (2003), who have described the success of the overt but routine use of metacognitive strategies in teaching and learning.

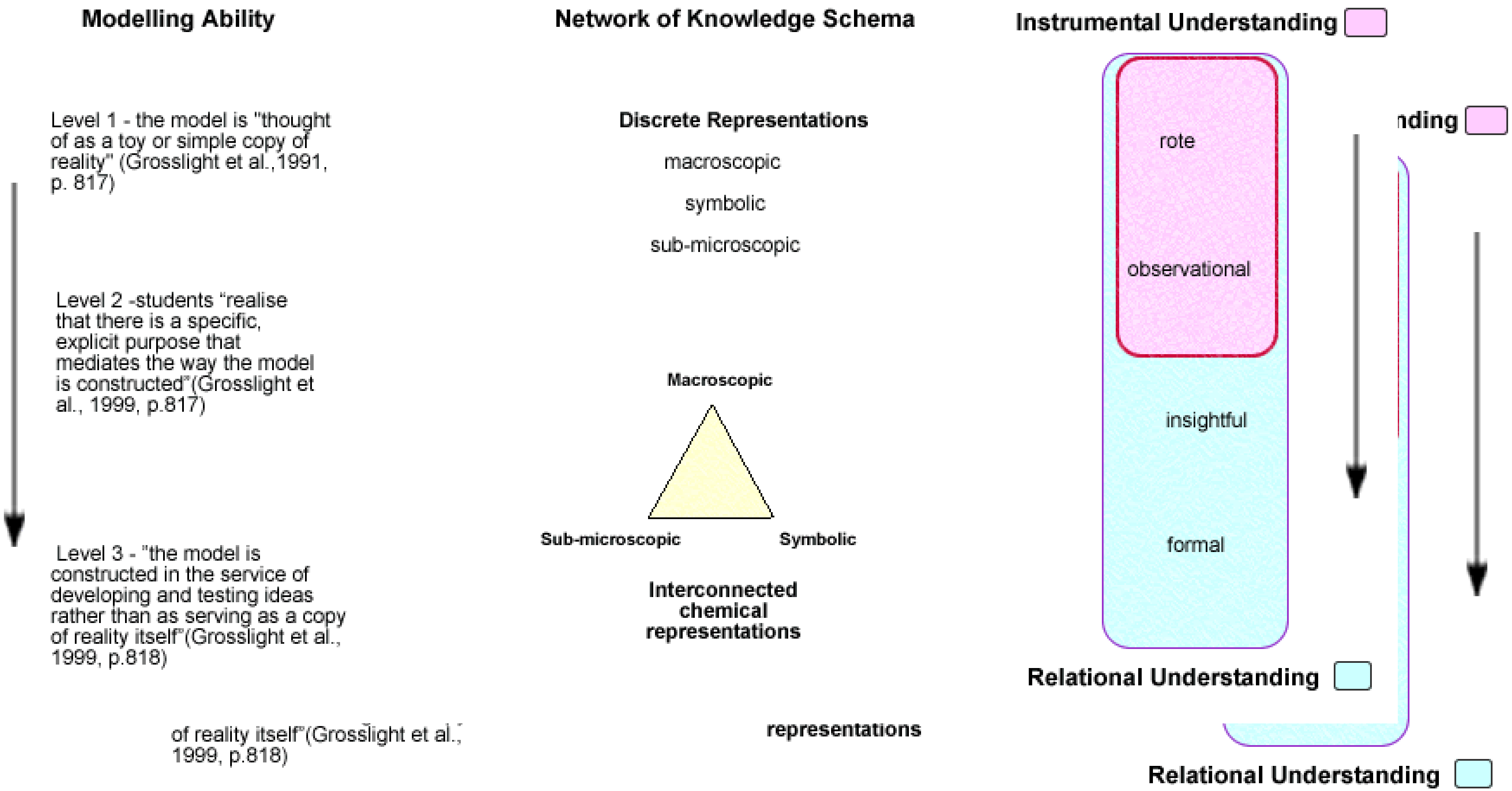
3.5.2 Metacognition and Conceptual Change

With a constructivist perspective to learning, as displayed in the conceptual change theory in Table 3.1, students learn actively, evaluating new ideas through collaboration and consensus building of new conceptual understanding. Hennessey (2003, pp. 124-26) identified two levels of metacognitive thought:

- A representational level – an inner awareness of one's mental model.
- An evaluative level – an ability to draw inferences and make predictions from one's mental model.

Hennessey (2003) related the representational level to a more algorithmic level of learning and the evaluative level to an intentional level of learning. This is consistent with Skemp's (1976) model of instrumental and relational learning (section 3.6.2) in which the complexity of learners' schema of knowledge is reflected in their level of understanding (Figure 3.1).

The conceptual change process requires learners to think about an idea, generate a personal mental model and evaluate it. Pintrich (1999) proposes that students' self-efficacy, referring to their "confidence in their own thinking and learning strategies" (p. 42), and their "ability to do a particular task" (p. 42) should facilitate conceptual change. The process of learning is closely associated with the process of metacognition (Patrick J. Garnett et al., 1995b; Hennessey, 2003; Hewson, 1996; Rickey & Stacy, 2000). From this, we can conclude that developing students' awareness of their learning and developing their metacognitive skills may enhance their level of conceptual understanding.



Modelling Ability
Level 1 - the model is "thought of as a toy or simple copy of reality" (Grosslight et al.,1991, p. 817)
Level 2 -students "realise that there is a specific, explicit purpose that mediates the way the model is constructed"(Grosslight et al., 1999, p.817)
Level 3 - "the model is constructed in the service of developing and testing ideas rather than as serving as a copy of reality itself"(Grosslight et al., 1999, p.818)
Network of Knowledge Schema
Discrete Representations
macroscopic
symbolic
sub-microscopic
Macroscopic
Sub-microscopic
Symbolic
Interconnected chemical representations
Instrumental Understanding
rote
observational
insightful
formal
Relational Understanding

3.6 Mental Models

A mental model is the learners' personal mental representation of an idea or concept. It is a window into the learners' understanding and can be used by the learner to give explanations, make predictions and provide reasoning. The personalised mental model of a learner is described by Norman (1983) as hazy, incomplete and messy and by Brewer (1999) as ambiguous. However, mental models are still considered to be of value.

A mental model has been described as the user's conceptual model (Young, 1983), a mental representation (Duit & Glynn, 1996), a mental image, an internal representation (Bodner & Domin, 2000; Kozma, 2000), a mental process, an unobservable construct (Hennessey, 2003), a personal cognitive representation and an internal model (J. K. Gilbert, Boulter, & Elmer, 2000). Incorporating these descriptions, mental models can be considered on two levels (Brewer, 1999; Franco & Colinvaux, 2000; Johnson-Laird, 1983) :

1) Representations of specific information that are imitations of reality.

2) A subclass of theories or constructed schemata that are explanatory frameworks.

These two broad levels can be associated with the representational and evaluative levels that Hennessey (2003) has used in assessing the metacognitive processes associated with learning. A mental model is not just the picture in the learners' mind; it incorporates the ontological network that students have personally constructed and use to assimilate new ideas. De Kleer and Seely Brown (1983) distinguished the construction of a mental model – called *envisioning* – and the result of the construction – the *running* or using a mental model. In understanding new concepts, learners look for patterns and commonalities with concepts that are already understood. This relates to teachers promoting strategies, identifying commonalities, grouping, and identifying differences so that learners are able to construct or envision a personal mental model. This approach is consistent with a constructivist approach and the ontological perspective of conceptual change learning theory. The personal mental model provides insight into the learners' mental processing of information.

The status of the learners’ mental model is a reflection of their understanding: with envisioning being similar to the intelligibility and plausibility of a concept and – using or running the mental model being similar to a fruitful conception – as described by Posner et al. (1982).

The personalised mental model of the learner is, according to Norman (1983), incomplete, undergoing constant modifications, unstable because learners forget the detail that was needed to construct the model, and not necessarily technically accurate but functional. Mental models are not precise and elegant like scientific models but rather nebulous, lacking detail and are often uncertain. Norman (1983) describes learners’ mental models as “messy, sloppy incomplete and indistinct structures that people actually have” (p. 14).

3.6.1 The Mental Model and Conceptual Change

A primary purpose of a mental model is predictability (Norman, 1983). Students test, validate and confirm their understanding by running their mental model, making predictions and inferences based on their understanding of a particular concept. The feedback they receive from the inferences and predictions may cause them to modify their thinking or it may confirm their ideas. Without feedback and the testing of understanding there is no evidence of learning. This recursive process, often resulting in changes to the learners’ mental models, is an integral component of the conceptual change process. This process is consistent with the four aspects of conceptual change proposed by Posner et al. (1982) in which the student is evaluating a concept – or a model that is representing a concept: performing thought experiments; assessing the intelligibility of the new concept; challenging any previously held conceptions; and either accepting or rejecting the model as fruitful and plausible. The learner, evaluating and revaluating concepts in light of new explanations, quickly and repeatedly performs the recursive behaviour. Gilbert and Justi (2002) building on the work of Clement (1989) describe the internal evaluation of the student at the mental model level as “a model of modelling” (J. K. Gilbert & Justi, 2002, p. 60) and is consistent with the description here. Because teachers provide information and explanations to the learner that are used to build a mental model, Norman (1983) recommends that teachers need to have a very clearly defined mental model themselves.

3.6.2 Instrumental/Relational Learning

Skemp (1976) uses the learners' mental model of the schema of knowledge to provide insight into the learners' understanding. He differentiates rote learning from meaningful learning on the basis of the interconnectedness of the learners' knowledge schema. Rote-learning is described as being easier and quicker to grasp, with a proposed knowledge schema represented by discrete units which reflects an instrumental level of understanding whereas meaningful learning is represented by a linked and interconnected schema of knowledge learning which reflects a relational level of understanding that is adaptable to new tasks and is "organic in quality" (Skemp, 1976, p. 24). The knowledge schema is a reflection of the students' mental model.

The significance and the subtlety of the differences between these two types of learning is that the students may know the same facts of the subject but their way of knowing is different (Skemp, 1976). This epistemological perspective draws attention to the importance of foundation learning being presented in situ as part of a conceptual structure or schema. This complements the theory of conceptual change whereby the way of knowing corresponds to the learner evaluating the intelligibility, fruitfulness, and plausibility of new ideas. With this in mind the way learners construct their knowledge is relevant.

Although Skemp differentiates rote and meaningful learning, rote-learning can be valuable learning and is often the most appropriate learning style for particular situations (Battino, 1992). This is especially true in chemistry when students need to build a foundation for future learning. To consider the two learning styles as opposed and antagonistic would be folly. This is not a linear scale from instrumental to relational; however, usually learning starts with an instrumental focus and move on to a more relational focus. Figure 3.1 has presented this diagrammatically but the diagram has limitations. Students use multiple learning styles and at times would be rote-learning one concept while learning another concept in a meaningful way. Although the framework has its limitations, based on the literature reviewed in this chapter, it is still a valid approach for considering the relationship between students' modelling ability, their network of knowledge schema, and their level of conceptual understanding.

3.6.3 Mental Models in Chemistry

Students' mental models, which are built up through their experiences, interpretations and the explanations that they use, reflect their understanding of the sub-microscopic level of chemical representation of matter. Research has shown that many students have very simple mental models of chemical phenomena (Chittleborough, Treagust, & Mocerino, 2002) with some secondary school students preferring models of atoms and molecules to be depicted as discrete, concrete structures (Harrison & Treagust, 1996), and often students did not have the skill to build mental models (Williamson & Abraham, 1995).

Learners' mental models are a function of the ideas, experiences, images, models and other resources that the learner has experienced, so the teacher has a significant effect on the students' mental model because he or she is often introducing these new ideas and concepts. Learners tend to resort to simple models that work for them, with Coll and Treagust (2001) reporting that students from secondary, undergraduate and postgraduate levels all "prefer simple, realistic mental models for chemical bonding" (p. 357) despite the older students having been exposed to sophisticated, abstract and mathematically complex images. Research in chemistry has shown that students' cognitive organisation of knowledge is surprisingly weak (Taagepera & Noori, 2000). Mental models are essential for the necessary tasks of learning chemistry including making predictions (Norman, 1983), testing new ideas and solving problems (Bodner & Domin, 2000).

Short-term memory overload has been identified as a learning difficulty in chemistry (Johnstone, 1993; Rowe, 1983). In 1983, Mary Budd Rowe (1983) suggested two-minute pauses during which time students could refresh their memory and discuss the concepts with peers, in addition to extending wait-time in discussions to at least three seconds to allow students to sort and reconstruct their responses. Rowe (1983) also recommended learning the chemistry in context – especially for non-major students. The fact that the same difficulties students encountered in learning chemistry 20 years ago are still present today, suggests that the recommendations by chemical educators in the past have not been implemented or have not had the desired effect (Gabel, 1999).

The ontological organisation of ideas by the student forms the basis of the mental model and generating an interconnected schema of knowledge as Skemp describes should promote more meaningful learning. Just like Mary Budd Rowe, educators try to identify teaching and learning strategies that promote this process such as concept mapping, discussion and predict-observe-explain tasks. In addition, learning frameworks, such as the rising iceberg and exploding triangle described in section 2.3, can provide an overview of the learning process. Despite these measures, implementing change in the way chemists teach chemistry does not necessarily follow.

3.7 Chemical Explanations

So far in this chapter on learning chemistry, the theoretical frameworks of theories of learning have been examined. This section examines the role of chemical models and representations in chemical explanations. Chemical models and representations are examples of external representations which Bodner and Domin (2000) describe as “physical manifestations of information” (p. 24) that can be contrasted to an internal representation which is “information that has been encoded, modified and stored in the brain” (p. 24). The use of chemical representations and models in teaching and learning chemistry has already been discussed extensively in section 2.3.

Chemistry is not a subject that can be learnt easily in isolation – the teacher and the teaching resources including chemical models and representations play a significant role in providing explanations of the abstract concepts. Explanations and the communication of ideas are fundamental to learning and explanations involving chemical phenomena are dependent on chemical representations. How the teacher uses them, and how the student perceives them, affects the interpretation of the explanation. Their widespread use, their diverse forms, and the significant role they play in producing mental models of chemical phenomena highlight the essential nature of representations. In appreciating the significance of the manner of representations, it becomes evident that the representations used in the teaching of chemistry should be identified and scrutinized more fully. The way these external representations contribute to the construction of the learners’ mental model or internal representation is pivotal to learning and is examined in this thesis.

Gilbert and Boulter (1995) describe a model “as an intermediary between the abstractions of theory and the concrete actions of experiment” (p. 54). In the learning process, models are proven teaching aids that provide analogous representations (J. K. Gilbert & Osborne, 1980). Similarly, Treagust and Harrison (1999) recognised the value of models in explaining difficult and complex concepts to students in a meaningful way. The model requires the learner to identify the analogue (the model) with the target (reality) (J. K. Gilbert & Boulter, 1995). Without the learner making this connection, the model has no value. As students use models discerningly, appreciating their role, purpose and limitations, links are formed between the analogue and the target, and each learner constructs a personal mental model for the concept.

Duit and Glynn (1996) describe mental models as the students’ personal knowledge and distinguish them from conceptual models that represent scientifically acceptable knowledge. Conceptual/scientific models and teaching models are on the opposite sides of the learning interface to mental models; the conceptual/scientific models and teaching models provide input into students’ understanding; the mental model is the product of the students’ learning that can be regarded as output; and the expressed model is the students’ expression of their own mental model. Consequently, when investigating meaningful learning of chemical concepts, both conceptual models, teaching models, mental models and expressed models need to be considered. This framework proposed in Figure 3.2 that relates the four types of models and presents the role of models in learning, has been devised on the basis of the research literature.

3.8 Conclusion

This chapter has drawn together constructs that are pertinent to learning. Under a constructivist umbrella and focussing on the theory of conceptual change, a number of significant constructs have been identified in attempting to answer the question: *How do students learn?*

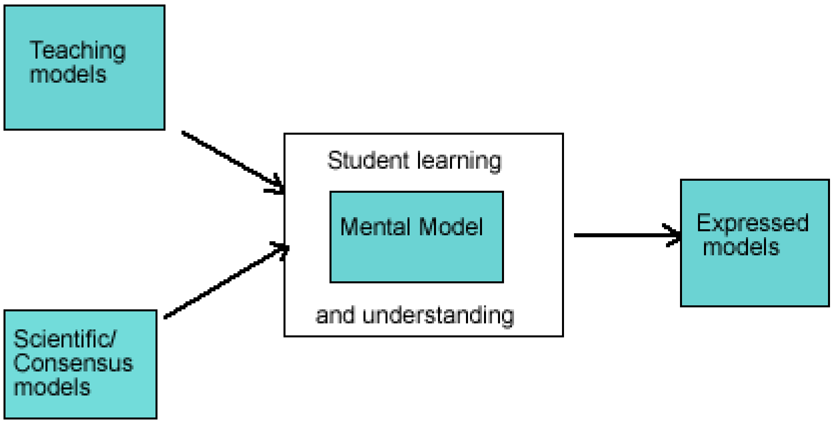


Figure 3.2 A Theoretical Framework Relating the Four Types of Models: Teaching, Scientific, Mental and Expressed

There are individual and social aspects that influence learning. The evolution of ideas and understanding is a dynamic but gradual process that is personal for each learner. The evaluation of ideas in terms of their plausibility, intelligibility and fruitfulness is undertaken by the learner accidentally, surreptitiously, or intentionally but is influenced by the learners' own epistemology, ontological network and motivation.

Keen students, intent on learning, consciously undertake metacognitive tasks to improve their understanding – being aware of why and how the tasks are enhancing learning. The mental activity associated with learning produces mental models that are in essence the learners' understanding of the concept. The learners' interpretation of external tasks and resources that have been received and processed produce their mental model. The learners' recognition of their personal mental models and the metacognition of thinking about how and why they have developed form the foundations of the learning process.

The mental model, which is constantly under review, reflects a learner's ontological network of knowledge. Students construct mental models and then use them for tasks such as solving problems, answering questions or making predictions. However, research has shown that students tend to resort to simple mental models of chemical phenomena even if they have learnt more sophisticated models, indicating a lack of confidence in the chemical knowledge schema.

Because learning chemistry is dependent on the use of chemical representations, the relationship between the various types of models – teaching, scientific/consensus, mental and expressed – and representations were considered. Learning is dependent on clear explanations. Chemical explanations rely on students' understanding of the role and purpose of chemical representations. The theoretical constructs for models, chemical representations and learning have been described because they are used in this research in the analysis of the learning of chemistry.

CHAPTER 4

RESEARCH METHODOLOGY

Chapter Outline

This chapter initially examines the methodological issues common to all four studies followed by the specific details for each study. Section one considers the overall legitimacy of the methodological approaches used in the research. The second and third sections provide an overview of the type of quantitative and qualitative data sources collected during the period of the research, respectively, including data collection, analysis, and interpretation. Section four examines the validity and reliability of the data sources. Section five discusses the ethical considerations of the research. Section six outlines the relationship between each of the four studies and the objectives of the research are provided. Because this research is a compilation of four distinct studies, the detail can be complicated and confusing. To overcome this problem for each study, the specific methodologies are dealt with separately with the purpose, design and procedure, data sources and analytical procedures explained in detail. Section seven details Study 1 – Learning Introductory Organic Chemistry in Secondary School. Section eight details Study 2 – Secondary School Students' Views on Models. Section nine details Study 3 – Learning Introductory Chemistry for Non-majors. Section ten details Study 4 – Learning Introductory Chemistry and the Implementation of Online Pre-laboratory Exercises for Non-majors. Finally, section eleven provides an overview of the chapter.

4.1 Methodology of Educational Research

The aim of chemical education research is to "improve teaching and learning through research" (Eybe & Schmidt, 2001, p. 214) and it should "be relevant to practise" (Eybe & Schmidt, 2001, p. 222). The perceived lack of connection between research and practice is well-documented (Kennedy, 1997; Schoenfeld, 1999). However, Gabel (1999) is critical that the proven results of chemical education research do not appear to have been adopted or implemented in most classrooms or in textbooks. Referring to the extensive work in educational research on common misconceptions in chemistry she claims that “nine out of ten instructors are not aware of these misconceptions” (Gabel, 1999, p. 552). Without the implementation of the findings of research at the classroom level, research is a futile exercise. Practising instructors, working in the classroom while conducting educational research are probably the best means of disseminating new ideas. Indeed, incentives may be needed to encourage practising instructors to become involved in educational research.

Reported and recognised educational research has to be robust, rigorous, valid, reliable and recognised by peer-review for it to attain an acceptable standard. Yet the incidental research conducted by teachers as part of their professional duties, for example, introducing new resources, trying out new ideas and implementing new curricula, which is not always reported in an academic fashion, occurs as part of the everyday teaching process. This research may not be rigorous or robust and is more likely to be impressionistic, but may actually be more beneficial to teachers and students than the research conducted by educational researchers.

Drawing on my secondary school teaching background, I recognised a dilemma in research that is typical in teaching: the dilemma is the age-old one of content versus process. In teaching there is content that has to be covered, and in research there are findings that need to be made. But just as significant is the process: in teaching the process of learning is crucial and in the case of research, the methodology of research is most important. If the processes in each case are not set in place properly then the value of the content that is learnt – in the case of teaching – or the findings that are made – in the case of research – are jeopardised. There is a dependence of these aspects on each other, necessitating the need to find the balance between them. There are many aspects to the process of educational research including research design, research style, choosing appropriate data sources, data collecting techniques, interpreting data and drawing conclusions. Throughout this chapter, the choices that have been made in this research are discussed and justification is given for their selection.

The four studies comprising this research were undertaken over a three and one-half year period. As outlined in chapter 1, the four studies are:

Study 1 – Learning Introductory Organic Chemistry in Secondary School.

Study 2 – Secondary School Students' Views on Models.

Study 3 – Learning Introductory Chemistry for Non-majors.

Study 4 – Learning Introductory Chemistry and the Implementation of Online Pre-laboratory Exercises for Non-majors.

These studies are presented in chronological order and are referred to as Studies 1, 2, 3 and 4. The three objectives of this research outlined in Chapter 1 flow through the four studies. This research occurs in naturalistic settings and uses a combination of qualitative and quantitative methods. It occurred concurrently with the teaching and learning, without interfering in those processes and endured any limitations that occurred as a result of the teaching and learning. The students and staff in Studies 1, 3 and 4 with whom I had contact were positive and optimistic about the value of the research.

The styles of research were largely determined by the opportunities that were available. Study 1 took advantage of a cooperative secondary school chemistry teacher who was willing to modify his teaching approach in consideration of my research agenda and allow me into his classroom. This was an action-research study, according to the definition by Cohen and Manion (1994) described as "a small scale intervention in the functioning of the real world and a close examination of the effects of such an intervention" (p. 186). Study 2 obtained a snapshot of secondary school students' understanding of models and modelling. This research style was a form of descriptive research using surveys. Study 3 and Study 4 were both longitudinal descriptive studies using case studies, and Study 4 had an action-research component with the introduction and assessment of pre-laboratory exercises.

There was a range of sample sizes, ages and abilities across the four studies. Year 8, 9 and 10 students were involved in Study 2, Year 11 chemistry students in Study 1 and first-year university chemistry students in Studies 3 and 4. In Studies 3 and 4 large samples are used alongside individual case studies in an attempt to build an accurate picture of the learning situation. The use of case studies provides rich data but the ability to make generalisations from the case study data is limited. However, ideas obtained from the case studies could be applied to larger samples – in a more quantitative manner.

In order to gain a holistic view of the learning situation, multiple sources of both quantitative and qualitative data were collected from a variety of the student population. The quantitative data were quick and convenient to collect even from large sample sizes. The qualitative data took more time and effort to collect but provided greater insight into the students' understanding through the expressions of their opinions, experiences and expressed models of chemical phenomena.

Direct and indirect data sources were collected throughout the research. The direct sources asked students for their experiences, opinions and their understanding of how their personal learning was proceeding using both qualitative and quantitative methods. The indirect sources looked for examples of how the students were learning in activities, dialogue, worksheets and questions, making inferences and implications from their responses. Both sources of data are valuable and both are needed for validation. As the researcher, I was alert to examples of students saying one thing and actually doing another.

The three objectives outlined in chapter 1 led the research. Each of the four studies has particular and unique contributions to make. Besides addressing the primary objectives outlined in chapter 1, the research describes other complementary and relevant data available due to the nature, location and sample of the four studies. These include reporting on the differences in students' understanding of the role and use of scientific models across year levels from Year 8 to first year university; comparing the learning environment, learning strategies, learning opportunities, pedagogical differences and the way students learn chemistry, in a Year 11 chemistry class with first year university chemistry classes; examining the learning situation for non-major chemistry students; and looking at the impact of the introduction of an online component of assessment.

4.2 Quantitative Data

The quantitative data primarily consisting of surveys and questionnaire results provided broad general indicators.

4.2.1 Surveys and Questionnaires

There are a number of quantitative instruments administered in this research. They are described in detail in the data sources section of each study in this chapter. Quantitative instruments are easy, quick and convenient to administer but their value depends on the quality of the items. The reliability of the items can be determined through statistical analysis. For example with the *Students' Understanding of Models in Science* (SUMS)[1] instrument, three questions were omitted after its initial use because they did not fit into the five scales of the instrument. Similarly, with the *My Views of Models and Modelling in Science*, (VOMMS)[2] instrument, students were required to justify their choice by providing a written answer. This justification provided a way of verifying that the students had interpreted the question correctly as well as providing an understanding of the students' reasoning. All questionnaires were tested and modified to deliver more accurate and unambiguous items. Throughout the research process, all the instruments were constantly re-evaluated and modified or omitted as part of the ongoing process of ensuring that the questionnaires were addressing the research questions.

4.2.2 Statistical Analysis

Surveys and questionnaires were administered to students; some were pen and paper, others were completed online. The *Statistical Package for Social Scientists* (SPSS) (SPSS Inc., 2001) was used to analyse the quantitative data. Descriptive statistics showing frequencies, means, standard deviations, ranges are commonly presented. T-tests are used for comparison of gender and analysis of variance (ANOVA) for age comparisons (Coakes & Steed, 1996).

The underlying assumptions in statistical analyses were taken into consideration: randomness and normality of data and homogeneity of variance. Some instruments were administered to two or more studies so comparisons could be made. The reliability of instruments was ascertained through the Cronbach alpha reliability score where possible.

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[1] SUMS is an abbreviation for Students' Understanding of Models in Science.
[2] VOMMS is an abbreviation for My Views of Models and Modelling in Science.

4.3 Qualitative Data

The qualitative data consisted of the participant researcher's observations, students' written comments, dialogue between students and interview data.

4.3.1 Participant Researcher

I was an observer in the high school chemistry classroom in Study 1 and a demonstrator (teaching assistant) in the laboratory in Studies 3 and 4, acting as a participant-researcher (Merriam, 1988) and kept a reflective journal. My presence as a researcher in the classroom in Study 1, nor the knowledge that research was being conducted in the laboratory classes in Studies 3 and 4, appeared to affect the students' behaviour or learning. Many students were keen and interested in the research.

4.3.2 Written Comments

There are numerous sources of written comments – including answers to questions in instruments, worksheets and surveys, and discussion and e-mail communication. The written comments were transcribed and the many online comments from the Online Survey, e-mail and discussion messages were corrected for syntax and spelling errors.

4.3.3 Dialogue

Routinely, during Study 1, students were required to discuss particular tasks and challenges set by the teacher. Pairs of students were selected randomly throughout the lessons to have their conversations recorded. During any typical lesson, the recorder was placed on a pair of students' desks for a period of time and then the researcher moved the recorder to another pair of students. It was not obtrusive and after one or two lessons, students did not appear to take any notice of the recorders presence.

4.3.4 Interviews

The purpose of the interviews was to gather data about the volunteers opinions and experiences with learning chemistry and assess their level of understanding of chemical concepts. Interviews occurred in Studies 1, 3 and 4 in which the dialogue was recorded on an audio recorder and written notes were taken as needed. In Study 1, the interviews were informal, with the researcher interrupting pairs of students, working together, to ask questions about the task at hand. In Studies 3 and 4, the interviews were more formal, with set questions to be asked. Approximately one hour was needed for each interview and the volunteers gave up their free time to participate.

The interview format for Studies 3 and 4 were standardised open–ended interviews (L. Cohen, Manion, & Morrison, 2000). A colleague acted as an independent researcher and examined the relevance of the interview questions to the research questions. In response to his comments, changes were made with the aim of making the questions more focused. Printed copies of the interview questions were made available to students at each interview, so students could read the question as well as hear it spoken. All students were asked the same basic questions in the same order. This method allows for comparison of students' responses, kept me as the interviewer on track and reduced bias (L. Cohen et al., 2000). Where warranted, I added questions to explore some issues in more detail or skipped questions if they seemed redundant.

There was consistency with all interviews being conducted by me. I knew the students interviewed during Study 3 because I was their demonstrator. At the time of the first interview, we had had only one or two classes together and by the second interview had been through a semester of laboratory sessions together. In Study 4 there was a mixture of students – some of them had me as their demonstrator, so had known me for up to eight months, while other students who were in other laboratory sessions knew me through my involvement with WebCT, the online facility that I supervised. The number of students being interviewed at any one time varied from one to four. This was due to the availability of students and some students preferring to be interviewed in groups with friends. In Studies 3 and 4 some students were interviewed twice about chemical representations and learning chemistry. The experience of participating in the first interview could have influenced their responses to the second interview.

In Study 1, the dialogue between pairs of students working together was recorded. Individual students were not identified and the labels of S1 and S2 used for any pair of students talking at that time. In Studies 3 and 4, pseudonyms were used in place of the names of the volunteers to protect their anonymity. An associate and I transcribed the interview tapes. I reviewed the transcripts for authenticity; in addition, the teacher in Study 1 and the students in Studies 3 and 4 were given the opportunity to check the transcribed tapes.

4.3.5 Coding

The transcripts were read through several times, looking for commonalities, anomalies and trends in students' responses. Care was taken to identify students who repeated the key words from the researcher's questions. When students languished, it was observed that they repeated part of the question in their response, not an intentional deception by the students more a saving-face strategy with the students not wanting to appear ignorant. The qualitative data were coded in terms of relevant aspects of students' understanding and activity (Silverman, 2000). Categories were created to correspond to the analysis of the data in light of the research questions. As categories were created and coding continued, the robustness of each category was assessed, resulting in continual adjustment and refinement of the categories. This process continued throughout the coding process. After the coding of all documents was complete for a particular question or concept, the coded data for each category was inspected and the frequency and accuracy of the coding assessed. The software package N-Vivo was utilised in the coding process. My supervisor acted as an independent researcher (Merriam, 1998) crosschecking the coded categories and the coded text to verify the accuracy of my coding practice.

4.3.6 Interpretive Analysis

The foundation of the interpretive analysis throughout all four studies is Johnstone's (1982) three levels of chemical representation of matter – symbolic, macroscopic and sub-microscopic (section 2.2). However, to further analyse the students' learning it is advantageous to identify meaningful learning as described in terms of conceptual change or relational learning. Conceptual change considers epistemological, ontological and social/affective perspectives of the individual's learning and the plausibility, intelligibility and fruitfulness of particular concepts to the individual. The depth of understanding and the application of knowledge that learners exhibit can be used to determine their level of understanding – instrumental or relational understanding (Skemp, 1976) (section 3.6). The impact of meaningful learning or conceptual change is manifested in changes to the students' mental models.

The analysis also considers both internal and external factors influencing the students understanding. At the internal level, Johnstone's three levels of chemical representation are used for interpreting students' comprehension of diagrams, a symbolic level of representation and their relationships to their laboratory experience, a macroscopic level of representation and the sub-microscopic level of representation are considered. At the external level, the learning opportunities, such as the learning environment, unit requirements, opportunities for communication are examined with respect to students' understanding of chemical concepts. The perspective of the learning situation can also provide a framework for analysis, for example, a social constructivist perspective or an individual perspective (Figure 3.1).

In summary, it is fruitful to consider multiple levels of analysis including: three levels of chemical representations; meaningful learning - considering the aspects contributing to conceptual change or relational learning; the students' mental models; internal factors and external factors contributing to learning; and the perspective of the learning situation. The interpretive analyses of the multiple sources of data led to the generation of findings in response to the relevant research questions. Each finding is based on multiple data sources of both quantitative and qualitative variety. In attempts to present a true representation of the learning experience, disconfirming evidence and confirming evidence was sought. (Erickson, 1986)

In Study 1, I had discussions about the findings and the analysis to establish the reliability of the findings. The results also were discussed with independent researchers for confirmation of the deductive reasoning that had occurred. In Studies 2, 3 and 4 discussions occurred with my supervisor. In Studies 3 and 4 conceptual learning profiles were developed for each of the volunteers. The quantitative and qualitative data were used to construct a conceptual profile for each participant in an attempt to understand how they thought about chemistry, how they learnt chemistry, and their level of understanding of the chemical concepts being taught.

For the generation of findings and conceptual profiles, the contributing data were crosschecked to ensure accurate interpretation and to corroborate the finding being proposed or the conceptual profile being produced for each volunteer. The expressed model made through written and verbal responses provided insight into the mental model of the participant. Since the research makes use of a constructivist perspective, assuming that each individual constructs his or her own understanding, the conceptions of interpretive validity according to Altheide and Johnson (1994) and Gall, Borg and Gall (1996) were used. Interpretive validity is referred to as a "judgement about the credibility of a researcher's knowledge claims" (Gall et al., 1996, p. 572). Credibility of my findings and conclusions is directly proportional to the degree of comprehensiveness of the research. Consequently, the multiple data sources are integral in ensuring the validity of this analysis.

4.4 Validity and Reliability of the Research

4.4.1 Validity of the Research

The validity of the interpretive analysis of the data is dependent on the rigour adopted by the researcher. Only the researcher knows all the data and has all the experiences to draw on. The large volume of data must be considered, but the job of the researcher is to identify the important findings. The researcher relies on the rigour and robustness of the research methods to have confidence in the data and the analysis.

Quantitative and qualitative data collected in the studies served as a form of methodological triangulation (L. Cohen & Manion, 1994, p. 236) in order to improve the validity and quality of data (Anderson, 1997; Burns, 1997; Mathison, 1988). The validity of particular quantitative instruments was secure in their administration in a serious and significant manner encouraging respondents to provide honest and accurate responses. The combination of multiple data sources described as triangulation helps to provide validity to the data by providing corroborating results for a holistic view of learning chemistry. In Study 2, some questionnaires (8) were completed in an invalid manner with identical choices made for all items and they were deleted from the results. Overall, I evaluated the students' responses to questionnaires and interviews to be honest and accurate.

With Study 1, all students in the two classes except for one were willing to be involved in the research. With Studies 3 and 4 volunteers were sought. Volunteers are more likely to be confident, mature-aged students or school leavers experienced in chemistry and may not be representative of the whole population. Students new to university and new to chemistry may feel vulnerable and nervous and may be unlikely to volunteer to be involved in research. To overcome this problem, I approached students who were in my laboratory class in Studies 3 and 4 and encouraged them to participate, with some success. These students commonly were interviewed in groups. My efforts to maintain that the volunteer group was representative of the whole population were to ensure the validity of the research sample (L. Cohen et al., 2000).

It is often difficult to ascertain the validity of quantitative data such as interview transcripts and their analysis. The transcripts are the words but the delivery and intonation, the way it is said can differ and the interpretation can differ. I conducted all the interviews and was present at all classes involved in this research, so can only rely on my own interpretation and understanding of the participants responses. The interviews and analysis required vigilant attention to my personal biases, for example guarding against pre-conceived ideas or leading the participant, in order to minimise the amount of personal bias (L. Cohen & Manion, 1994).

4.4.2 Reliability of Data

There are an infinite number of variables in an educational setting which are often very difficult to identify, isolate or test, whereas with chemistry the number of variables is finite and most may be identified as dependent or independent and consequently controlled. However, with chemistry as well as educational research, there is not always an obviously correct answer, and in both areas, supporting evidence is needed to build up new ideas. Ideas are built on other ideas consistent with a constructivist scenario.

In physical science, experiments are performed and repeated, with controls undertaken and results confirmed to be reliable; however, in the social sciences it is much harder to repeat research situations, so alternative measures are taken to ensure the reliability of the data. Cohen et al. (2000) suggest that qualitative data can be treated like quantitative data by considering: the stability of observations, parallel forms and inter-rater reliability of the data. In this research, with all four studies the sample size is adequate to provide a range of responses. In Studies 3 and 4, this meant extended time interviewing students outside their normal class-time. As a researcher, I was keen to have an adequate sample size so went out of my way to encourage students and tried at all times to fit in with their schedules.

4.4.3 Objectivity/Subjectivity/Bias

My background as a science and chemistry teacher and researcher has impacted on my interpretation of the data. Hopefully my background knowledge is an advantage to the research, but with this background knowledge it is sometimes difficult to fully realise the level of understanding of students who are just beginning to learn chemistry. It is too easy to make assumptions using pre-learned knowledge without realising it. This is why it is important to recognise that my personal opinions and beliefs may introduce a bias into the research. This interpretive research cannot be totally objective and there is subjectivity due to my personal interpretation of the data. Measures are in place to avoid any bias such as my supervisor rechecking my coding of data. Being aware of possible bias necessitates the checking of data analysis with associates.

4.4.4 The Evolution of the Data Collection

Over the period of the research, there has been a development and evolution of the data sources. The research literature was used as a basis to develop the first quantitative instruments used in Study 1. These instruments were modified and used in Study 2 and modified again and used in Studies 3 and 4. The trialling and evaluation of the instruments has been a dynamic part of the research process involving responding to the results, acting on feedback, eliminating unnecessary or repetitive items. In this iterative process, the number of instruments has reduced and the instruments have become more valid in achieving the desired objective.

Over the period of the research, the emphasis on the quantitative data declined and the emphasis on qualitative data increased. Studies 1 and 2 have substantial quantitative data sources, while in Study 3 and 4 the quantitative data sources are used to support and complement the qualitative data sources. This evolution is typical and expected because the qualitative data provided a good overview of the research topic highlighting some misconceptions or weaknesses and then the quantitative data sources provided opportunities to examine these areas in more detail. These aspects add to the rigour and robustness of the research.

4.5 Ethical issues

As the researcher, I have given full consideration to the participants and their learning environments. The methodology has had to fit in with the learning situation of each study, without interfering with or intruding on the students' learning in any of the four studies included in this research. While endeavouring to achieve the objectives of this research, I attempted to do so in a manner that did not interfere or conflict with any individual. The students were mostly positive and interested in the research, keen to see improvements to their learning situation.

4.5.1 Consent

Except for the anonymous surveys, all research was dependent on students volunteering to participate in the research. With Study 1, the class teacher asked students for their cooperation on my behalf and only one student from the two classes objected to being included in the research. With Study 2, permission was obtained from the teachers and principals of the participating schools for the students to complete the anonymous questionnaires. With Studies 3 and 4 students were informed of the research during the first laboratory session of each semester and volunteers were sought through verbal requests and written online requests. I was gratified with the positive and willing response by students. Permission slips were read and signed before the research began. For Study 1, the classroom teacher obtained written permission from the parents of the high school students before I was able to enter the classroom, and for Study 3 and Study 4 permission was obtained from the students. A copy of the information and permission slips for Studies 2, 3 and 4 are available in Appendix B. Permission was obtained to undertake the research at the particular high schools as well as at the university. In addition the Curtin Human Research Ethics committee approved the research. The identity of the institutions and the students' involved in this research was kept confidential.

Table 4.1 List of Data Sources and the Corresponding Identification Numbers

Study	Data Source	Anonymous /Volunteer	The Number of the Data Source
1	Models	V	1
1	Molecular Chemical Representations (MCR)	V	2
1	My Views of Models and Modelling in Science (VOMMS)	V	3
1	Group work dialogue	A	4
1	Participant researcher's observations		5
2	Scientific Models (SM)	V	1
2	Students' Understanding of Models in Science (SUMS)	V	2
2	My Views of Models and Modelling in Science (VOMMS)	V	3
3	Students' Understanding of Models in Science (SUMS)	V	1
3	My Views of Models and Modelling in Science (VOMMS)	V	2
3	Molecular Chemical Representations (MCR)	V	3
3	What do you think this atom looks like?	V	4
3	Student Unit Experience (SUE)	A	5
3	Worksheets 1-4	V	6
3	Participant researcher's observations		7
3	1st Interview	V	8
3	2nd Interview	V	9
4	Students' Understanding of Models in Science (SUMS)	V	1
4	My Views of Models and Modelling in Science (VOMMS)	V	2
4	Students' Evaluation of Educational Quality (SEEQ)	A	3
4	Online survey	A	4
4	1st Interview	V	5
4	2nd Interview	V	6
4	My observations	*NA	7

*NA Not applicable

4.5.2 Identification

The identification of any participants was protected. Where any name is used, it is a pseudonym. Each data source is allocated a number as shown in Table 4.1. All data are identified with a series of digits: the first digit refers to the number of the study – 1, 2, 3 or 4 in which the data source was used, followed by a period. The second digit refers to the number of the data source according to Table 4.1; and this is followed by a period. The third digit is the identification number of the student, followed by a period; the remaining digits refer to the data source such as a line number of the transcript, or question number in a worksheet. For example:

(4.5.17.9) Study 4, 1st interview, Identification number 17, line 9.
(4.4.90.26) Study 4, online survey, Anonymous student reference 90, item 26,
(3.8.12.43-46) Study 3, 1st interview, Identification number 12, lines 43-46
(1.4.272) Study 1, Group work dialogue, line 272 of transcript.

4.6 The Four Studies

The four studies of this research address the objectives of investigating students' understanding of models and chemical representations and the influence they have on students' learning of chemistry. My interest in models and modelling was initiated and fostered through my employment as a research associate during which I investigated the role of models and modelling in students' learning of science, resulting in Studies 1 and 2. Combining my interest in models and chemistry, I was fortunate to have the opportunity to work with first year non-major chemistry students at the university. Subsequently, I investigated the role of models and modelling in students' learning of chemistry, which resulted in Studies 3 and 4. Through this, my attention was drawn to the unique problems facing non-major students in the university learning environment and as a result new teaching and learning strategies were implemented. The monitoring and implementation of these changes was incorporated into Study 4. The ideas of models, representations and learning developed throughout the research. The linking of these three concepts arose as a result of the diversity that the four studies provided and can be considered the strength of the research. While the direction of the research was influenced by the opportunities that were available, the diversity of students and learning environments involved has provided valuable contrast and has also highlighted similarities among the diverse groups.

Study 1 took place in a senior high school, observing Year 11 chemistry students working with chemical models; Study 2 involved collecting survey data about high school students' perceptions of scientific models; Study 3 and Study 4 involved investigating how first year university students with little or no chemical background learnt chemistry. The three objectives of this research flow through the four studies. Table 4.2 provides an overview of each of the studies including details of the institution, the level of the students, and the sample size. It also shows how each study is related to the research objectives and the data sources. Table 4.3 shows where the research questions are addressed in each of the four studies. The remainder of this chapter examines the research methodology for each study in turn, providing a detailed description of the design and procedures, data sources and data analysis for each of the four studies.

The analysis of the data for all four studies is conducted independently of each other, but in light of the research questions. The interpretation of the analysis for each study is used to respond to the relevant research question in the form of findings. The results for all four studies are presented together in the following chapters in accordance with the research objectives; chapter 5 addresses objective 1, chapter 6 addresses objective 2 and chapter 7 addresses objective 3. In chapters 5, 6 and 7, data are presented to answer each research question in turn. A summary and response to each research question concludes each sub-section.

Table 4.2 Outline of the Four Studies

Study	Institution	Student Level	Period of Study	Research Questions for Objective: 1	2	3	Type of Study	Data Sources* and Sample Sizes
1	High school	Year 11	3-4 weeks	1.1 1.2 1.3 1.4	2.1 2.3 2.4	3.2 3.3	Interpretive research - descriptive and explanatory case studies	Questionnaires – Models n=36 MR n=36 VOMMS n=36 Class group activity – audiotapes and videotapes, observations
2	High school	Years 8, 9, 10	1 week	1.1 1.2 1.4	2.1		Quantitative analysis	Questionnaires – SM n=228 SUMS n=228 VOMMS n=228
3	University	First year	2 semesters	1.1 1.2 1.3 1.4	2.1 2.2 2.3 2.4	3.1 3.2 3.3	Interpretive research – descriptive and explanatory case studies	Initial Questionnaire (containing SUMS, VOMMS and MR) n=18 SUE n=61 Worksheet 1 n=9 Worksheet 2 n=8 Worksheet 3 n=9 Worksheet 4 n=10 1st interviews n=7 2nd interview n=12 Observations
4	University	First year	2 semesters	1.1 1.2 1.3 1.4	2.1 2.3 2.4	3.1 3.2 3.4	Interpretive research – descriptive and explanatory case studies	Introductory Questionnaire (containing SUMS and VOMMS) n=49, SEEQ n=98 Online Survey n=115 1st interview n=17 2nd interview n=5 Observations

*abbreviations include: MR – Molecular Representations; SM – Scientific Models; SUMS – Students' Understanding of Models in Science; VOMMS – My Views of Models and Modelling in Science; SUE – Student Unit Experience; SEEQ – Students' Evaluation of Educational Quality.

Table 4.3 The Studies Investigating the Research Questions

Objective 1	Study	Sub-section
1.1 What are students' perceptions of the role and purpose of generic models and scientific models?	1, 2, 3, 4	5.2
1.2 What are the criteria which students identify as being significant when classifying scientific models?	1, 2, 3, 4	5.3
1.3 How does students' modelling ability affect their use of models and their ability to understand chemical concepts?	1, 3, 4	5.4
1.4 How and why do models help students learn?	1, 2, 3, 4	5.5
Objective 2		
2.1 What are students' perceptions of the role and purpose of chemical representations, including chemical models, teaching models, chemical equations, diagrams, and pictures in learning chemistry?	1, 3, (2 & 4 indirectly)*	6.2
2.2 What are students' understandings of each level of chemical representation in relation to the chemical phenomena they experience?	3, (1 & 4 indirectly)**	6.3
2.3 How does this understanding enable students to effectively transfer from one representational level to another?	1, 3, 4	6.4, 6.5 & 6.6
2.4 How do the variety of representational forms, which students encounter in chemistry, impact on the epistemology, ontology and social factors that have been shown to contribute to conceptual change?	1, 3, 4	6.7
Objective 3		
3.1 What are the factors that influence how and why students learn chemistry?	3, 4	7.2
3.2 What learning strategies do students use in learning chemistry?	1, 3, 4	7.3
3.3 How do learning strategies contribute to the development of students' personal mental models of chemical phenomena?	1, 3	7.4
3.4 How does students' metacognitive awareness influence their learning of chemistry?	4	7.5

*Data from Study 1 and 3 are used to address Research Question 2.1, however data from Studies 2 and 4 that are reported in other parts of the thesis also address this research question.

**Data from Study 3 is used to address Research Question 2.2, however data from Studies 1 and 4 that are reported in other parts of the thesis also address this research question.

4.7 Study 1 – Learning Introductory Organic Chemistry in Secondary School

Study 1 examined how high school students used chemical models to enhance the learning of introductory organic chemistry.

4.7.1 The Purpose of Study 1

The purpose of Study 1 was to investigate secondary students' perceptions of teaching models that are used in representing compounds in introductory organic chemistry as well as to examine the role that the teaching models play in the learning process. The teaching models are symbolic representations of chemical compounds. In Study 1 students made use of teaching models to gain an understanding of the nomenclature, structure and properties of organic molecules. A model-based approach to learning is an opportunity for students to develop modelling skills, develop an understanding of the role and purpose of models in the process of science and to provide insight into the sub-microscopic level of chemical phenomena.

4.7.2 Design and Procedures

Study 1 was conducted with two classes of Year 11 students (15–17 years of age, n=36 males=20 females=16) from a private co-educational high school in Perth, Western Australia. The classes were of mixed academic ability. The same teacher, who had recently participated in a professional development program, taught both classes. The professional development program on integrating the use of teaching models and analogies into science lessons introduced the concept of a target and analog and recommended Focus-Action-Reflection as a suitable teaching strategy (Treagust, Harrison, & Venville, 1998). The purpose of this teaching approach was to make overt the relationship of features between the target (an organic molecule) and the analog (one of the four types of teaching models described below).

The research took place in the teacher’s two chemistry classes over a period of three weeks, during the introductory organic chemistry unit that included topics on the structures and properties of alkanes, alkenes, alkynes, cyclo-alkanes, nomenclature, isomerism, and substitution, addition and combustion reactions. The details of the syllabus are presented in Appendix C. The four types of teaching models used to depict the organic molecules were structural formula, ball-and-stick models, a computer-modelling program – *The Chemistry Set* (1995), and space-filling models. Primarily, the students used the ball-and-stick models while working in pairs and they routinely drew structural formula of the ball-and-stick models, in addition they had access to *The Chemistry Set* in the library and also saw, but did not use, some space-filling models.

The teacher modified his teaching style to include the four teaching models. He introduced the ball-and-stick models before any structural formula had been used, and continued with this sequence throughout the organic chemistry unit. The class usually experienced a more teacher-centred and textbook-oriented class, so the group-work and deductive activities were new to the students. The general pattern of each lesson observed was for the teacher to provide some background information on the topic, after which the students were given a task to build models of particular compounds. Each task was presented as a challenge with the students keen to draw the structural formula representation of the chemical model on the whiteboard prior to their responses being discussed by the class as a whole.

The computer software, *The Chemistry Set,* allowed students to look at a variety of compounds in a ball-and-stick animated image and it was possible to remove the balls and just look at the sticks and then remove the sticks and just observe the balls moving. This feature was beneficial in giving an image of the region of influence of the electrons and to emphasise that the ball-and-stick models are just tools to help visualise the atom. However, only translational movement was possible, either by the computer program moving the compound in a random motion around the screen or manually by the user directing and controlling the motion with the computer mouse.

4.7.3 Quantitative Data Sources

Three quantitative, pen and paper instruments, *Models, Molecular Chemical*

Representations[3] (MCR) and My Views of Models and Modelling in Science (VOMMS), were administered to the students at the end of the teaching unit. Student responses provided data on students' understanding of teaching models and modelling in science. Copies of the instruments are provided in Appendix D.

4.7.3a Models

The first instrument, Models, required students to decide if an item was a model or not and then to select the best way to describe the particular model – choosing from a list of model types. The list of models included: a toy car; a model of the ear; a living animal – e.g., a wombat; an experiment of a metal in acid; a photograph of a cell taken with an electron microscope; a chemical equation; a diagram of the inside of an atom; a computer image of a rat dissection; and a graph showing the energy changes in a reaction. The alternative ways to describe the model included: a static model; a 3D model; looks the same – but different size; works the same as the real thing; diagram or map or plan; a description in symbols/numbers; a description with words; a description using pictures/diagrams; and a simulation.

Because the design of the instrument Models allowed the selection of more than one way to describe a particular model, it was not fair to compare the results statistically – it was only possible to get an overview of students' opinions. This weakness was considered in the formulation of items for the instrument, Scientific Models (SM)[4], used in Study 2. Identifying weaknesses and making modifications was an important part of the research process.

4.7.3b Molecular Chemical Representations (MCR)

The second instrument, Molecular Chemical Representations (MCR), required students to respond on a 5-point Likert scale from strongly disagree to strongly agree to questions on the purpose of each of the four teaching models they had encountered during the past three weeks. Such questions were to consider the purpose of the ball-and-stick model, for example, as showing what the molecule looked like, or showing how the molecule behaved, or showing the shape and

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[3] MCR is an abbreviation for Molecular Chemical Representations.
[4] SM is an abbreviation for Scientific Models.

structure of the molecule or making and testing predictions. Items one to eight asked about the descriptive nature of the models and items nine to eleven about the predictive nature of models. The instrument compared four scales on molecular representations, namely, structural formula, ball-and-stick, computer and spatial models. Each scale contained 11 items. The items were developed with consideration of previous studies (Barnea, 2000; Copolo & Hounshell, 1995; Gabel & Sherwood, 1980; S. W. Gilbert, 1991; Grosslight et al., 1991), incorporating model typologies and attributes of models (J. K. Gilbert & Boulter, 1998; Harrison & Treagust, 2000; Van Driel & Verloop, 1999). The validity of the items was based on my scrutiny of the results in addition to the overseeing by my supervisor – with both of us attending to the purpose of the model and trialling with a small sample of students. In response to this scrutiny and trial, vocabulary and layout were improved and the use of diagrams was included. The consistency of the results across the sample of 36 responses is indicated by the Cronbach alpha measure shown in Table 4.4. The Cronbach alpha values showing internal consistency of the scales of the instrument given to this group of students ranged from 0.68 to 0.85 indicating that the reliability of each scale was acceptable. Although normally reliability measures above 0.8 are preferred, in this study interviews, student conversations and video data have contributed to clarify the students' understanding of items in the instrument, MCR and in this way have supported the reliability values and the validity of the instrument (Gall et al., 1996).

Table 4.4 Descriptive Statistics and Cronbach Alpha Reliability of Scales of the Molecular Chemical Representations Instrument for Study 1 (n=36)

Scale	No of Items	Mean*	Standard Deviation	Cronbach Alpha
Structural Formula	11	39.40	6.28	0.68
Ball-and-stick	11	41.90	5.74	0.73
Spatial	11	34.60	8.14	0.85
Computer	11	40.78	6.85	0.84

*Note: The mean score is calculated from the responses being assigned the values: Strongly Disagree = 1; Disagree = 2; Don't Know = 3; Agree = 4; Strongly Agree = 5.

4.7.3c My Views of Models and Modelling in Science (VOMMS)

The third instrument, My Views of Models and Modelling in Science abbreviated by the letters VOMMS, required students to choose between two alternative statements about scientific models and then explain their choice. These items evolved from Aikenhead and Ryan's (1992) item bank of questions on Views of Science–Technology–Society (VOSTS) and were designed to investigate students' general understanding of scientific models, with the items focussing on the role of models in science. For example, given the statement, "Models and modelling in science are important in understanding science", students were asked to choose whether models are representations of ideas of how things work, or accurate duplicates of reality. In addition, an open response sought evidence to justify the students' choices. The validity of the evolved items was established through peer review. The naturalistic methodology used by Aikenhead and Ryan (1992) in the original instruments was based on students' perspectives, not on how "science educators supposed students might reasonably respond" (p. 488). The Cronbach alpha of 0.87 for this instrument with this group of students indicated a high reliability within the scale of items dealing with students' views of models and modelling in science. The reasons students wrote to support their choice for each item in the VOMMS instrument were collated, analysed using N-Vivo and coded in terms of the epistemological, social, and ontological factors.

4.7.4 Qualitative Data Sources

I took on the role of participant observer in the classroom during the lessons (Merriam, 1998) in order to document the interaction between the students and observe how they made use of models in understanding the naming and identification of structures and properties of organic compounds. During all student activities, pairs of students working together were randomly selected and audiotaped. In addition, interview questions were asked during the lesson, to pairs of students, usually in response to a set task. For example: So what if we decide to change this one (methyl group) and connect it here. Does it change anything? Which carbon does it come off? How do you name it? Why do you say the right one (carbon atom) is the same as the middle one? If you break that bond then what will you form? The student dialogue and interview data were transcribed and analysed.

The practical examination was videotaped and observed learning strategies coded with an identifying number corresponding to the time elapsed on the video. The examination results were obtained, however, without pre-testing and without the results of a control class they were of little value for inferring how much the model-based learning had been responsible for student achievement. Despite this, the video provided insight into the way that students used the ball-and-stick models to answer the test questions.

4.8 Study 2 – Secondary School Students' Views on Models

In Study 2 high schools students were surveyed regarding their perceptions of models.

4.8.1 Purpose of Study 2

The objective of Study 2 was to gain some insight into high school students' understanding of the role of scientific models in learning science and to understand why models are perceived to be valuable tools in learning science.

Scientific models and teaching models are used regularly in science classrooms, often without explanation or instruction as to their role, purpose and limitations. Students have their own personal and unique understanding of the role of models in science built up through their life experiences. These understandings may not always be scientifically correct and may lead to alternative conceptions; teachers' assumptions about the degree of students' understandings of scientific models also may not always be correct. Consequently, a more accurate picture may be obtained through the administration of a pen and paper instrument so that science teachers and students can become more aware of the range and variety of understandings of the role of models in learning science.

4.8.2 Design and Procedures

This study surveyed 228 students from two government, non-selective, co-educational high schools in Perth, Western Australia, where they learn general science. There were 69 (30.3%) Year 8 students (age 13 years), 44 (19.3%) Year 9 students (age 14 years), and 115 (50.4%) Year 10 students (age 15 years). The sample consisted of 49% male students and 51% female students. The students were required to complete three pen and paper questionnaires about scientific models. They had received no special teaching about scientific models in science, so their responses reflect their understanding based on the general science curriculum they have experienced. The data were anonymous.

4.8.3 Quantitative Data Sources

The three quantitative instruments about scientific models completed by students in Study 2 were *Scientific Models* (SM), Students' Understanding of Models in Science (SUMS), and My Views of Models and Modelling in Science, (VOMMS) (Appendix E). The content of each instrument is described below and in the next section, the analysis of each instrument is described.

4.8.3a Scientific Models (SM)

Part 1 of the instrument, Scientific Models (SM), was developed from the instrument Models used in Study 1. In Part 1, students were asked for their opinion about what ideas they associated with the term model. There were seven items that required a response on a five-point Likert scale from strongly disagree to don't know through to strongly agree for statements such as, "The word model is associated with a visual representation of how something works" (item 4) or, "The word model is associated with anything that gives a clearer picture of a scientific idea" (item 7).

Part 2 of the instrument, Scientific Models (SM), included diagrams and pictures of particular models and the students were required to choose the best descriptor for the particular model from the list provided. The objective of this question was to gain some insight into the students' understanding of the purpose of a particular model. Visual representations of the models were used intentionally to remind students of the two and three dimensionality of the model that they were considering.

4.8.3b Students' Understanding of Models in Science (SUMS)

The items in the instrument, Students' Understanding of Models in Science (SUMS), were based on data from Study 1 regarding the use of chemical models in teaching organic chemistry (Treagust, Chittleborough, & Mamiala, 2004) as well as Grosslight et al.'s (1991) research into students' understanding of models and their use in science. The instrument, SUMS, was designed to gain some insight into students' understanding of what a model is, the role of models in science, including how and why models are used and what causes models to be changed. The SUMS instrument is a 27 item pencil and paper questionnaire that required students to respond on a 5-point Likert-type scale, with a choice of responses from strongly disagree (1), disagree (2), not sure (3), agree (4) and strongly agree (5). The Statistical Package for Social Scientists (SPSS Inc., 2001) was used to analyse the quantitative data (Coakes & Steed, 1996).

4.8.3c My Views of Models and Modelling in Science (VOMMS)

The third instrument used in Study 2 is the VOMMS instrument that was described in section 4.7.3c. In Study 2, students responded to the 6-items; however, they were not required to provide written responses to justify their choice as they were in Study 1. The student response for VOMMS is lower than that for SUMS, which is most likely due to VOMMS being the last page of the survey and students lacking attention to respond.

4.8.4 Quantitative Data Analysis

4.8.4a Scientific Models

The Cronbach alpha reliability of the seven items in Part 1 of the instrument, Scientific Models, is 0.59 (n=229); for the items in Part 2, several descriptions are suitable and appropriate for the one model, so a reliability score is unsuitable. Although 230 questionnaires were administered, not all students answered all the questions on all the instruments, so the sample size does vary.

4.8.4b Students' Understanding of Models in Science (SUMS)

Factor analysis using a varimax rotation identified five distinct factors in the items of the SUMS instrument which are described as five scales in the instrument: the *Models as multiple representations* (MR) scale (factor 1)[5]; the *Models as exact replicas* (ER) scale (factor 2)[6]; the *Models as explanatory tools* (ET) scale (factor 3)[7]; *The uses of scientific models* (USM) scale (factor 4)[8]; and *The changing nature*

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[5] MR is an abbreviation for Models as multiple representations.
[6] ER is an abbreviation for Models as exact replicas.
[7] ET is an abbreviation for Models as explanatory tools.
[8] USM is an abbreviation for Uses of scientific models.

of models (CNM) scale (factor 5)[9] (see Table 4.5).

Table 4.5 Factor Analysis of the 27-item Instrument Students' Understanding of Models in Science (SUMS) (n=228).

	Factor Loadings				
Item Number	Factor 1 Models as Multiple Representations (MR)	Factor 2 Models as Exact Replicas (ER)	Factor 3 Models as Explanatory Tools (ET)	Factor 4 The uses of Scientific Models (USM)	Factor 5 The changing Nature of Models (CNM)
1	0.75				
2	0.62				
3	0.61				
4	0.60				
5	0.59		0.48		
6	0.57				
7	0.52				
8	0.50				
9		0.80			
10		0.67			
11		0.65			
12		0.64			
13		0.60			
14		0.55	0.51		
15		0.50	0.45		
16		0.47			
17			0.66		
18			0.66		
19			0.61		
20			0.45		
21			0.41		
22				0.83	
23				0.70	
24				0.69	
25					0.70
26					0.67
27					0.47
Variance%	33.2	8.6	5.2	4.8	4.1
Eigenvalue	8.97	2.32	1.40	1.28	1.11

Factor loadings less than 0.4 omitted.

The scale *Models as multiple representations (MR)* explores students' acceptance of using a variety of representations simultaneously, and their understanding of the need for this variety. Examples of items from this scale are:

[9] CNM is an abbreviation for The changing nature of models.

“Many models may be used to express features of a science phenomenon by showing different perspectives to view an object” (item 1) and “Many models represent different versions of the phenomenon” (item 2).

The scale *Models as exact replicas (ER)* refers to students’ perceptions of how close a model is to the real thing. Examples of items in this scale are: “A model needs to be close to the real thing by being very exact in every way except for size” (item 13) and “A model should be an exact replica” (item 9).

The scale *Models as explanatory tools (ET)* refers to what a model does to help the students understand an idea. This scale includes providing visual enhancement, generating a mental model or providing a concrete representation. Examples of items in this scale include: “Models help create a picture in your mind of the scientific happening” (item 18) and “Models are used to physically or visually represent something” (item 17).

The scale dealing with *The uses of scientific models* (USM) explores students’ understanding of how models can be used in science, beyond their descriptive and explanatory purposes. Examples of items in this scale are: “Models are used to help formulate ideas and theories about scientific events” (item 22) and “Models are used to make and test predictions about a scientific event” (item 24).

The final scale *The changing nature of models (CNM)* addresses the permanency of models. Examples of items include: “A model can change if new theories or evidence prove otherwise” (item 25) and “A model can change if there are new findings” (item 26).

The reliability of each scale for the SUMS instrument ranged from 0.71 to 0.84 (see Table 4.6) showing that the instrument has high internal consistency for each scale; item-to-total correlations were above 0.45 except for item 16. A bi-variate correlation of the five scales (see Table 4.7) shows a high level of correlation indicating that students’ responses to each scale are related and consistent.

The range of items in the SUMS instrument attempts to identify the breadth of students’ understanding of particular aspects of models. Each item attempts to identify the details of students’ understanding by asking about particular aspects of models that are categorised as scales of the SUMS instrument. A number of items for each scale help ensure consistency of results. Three items load into two factors: Item 5 – “Many models may be used to show different sides or shapes of an object” loaded into the MR and the ET categories. This is not surprising given that the models take on these complementary roles simultaneously. Item 14 – “A model needs to be close to the real thing by giving the correct information and showing what the object/thing looks like” and item 15 – “A model shows what the real thing does and what it looks like”, loaded into the ER and ET scales. Each of these items reflects both of these aspects of models. These three items are discussed for each of the two scales that they represent.

The distribution of scores for each scale of the SUMS instrument is concentrated closest to the “agree” elective. The CNM scale has the most highly agreed upon response while the USM scale has an even distribution between the “not sure” and “agree” responses. The use of the word “phenomenon” in three items of the SUMS instrument corresponded to a high “not sure” response indicating that students were not familiar with the word; consequently, results involving items using this word are considered guardedly. A one-way ANOVA (Coakes & Steed, 1996) showed no statistically significant differences for any of the scales between year levels. An independent t-test identified a significant difference in gender for the ET scale only, with the results indicating that females responded more positively than males to the items in this scale.

Table 4.6 Descriptive Statistics and Reliability of the Five Scales in the SUMS Instrument (n= 228)

Scale	Number of Items	Mean	Standard Deviation	Cronbach Alpha Reliability*
Models as multiple representations (MR)	8	3.52	0.63	0.81
Models as exact replicas (MR)	8	3.58	0.71	0.84
Models as explanatory tools (ET)	5	3.58	0.71	0.71
The uses of scientific models (USM)	3	3.41	0.73	0.72
The changing nature of models (CNM)	3	3.73	0.74	0.73

*A measure of the internal consistency of each scale

Table 4.7 Bi-variate Correlation of the Five Scales in the SUMS Instrument (n=228)

Scale	ER	ET	USM	CNM
Models as multiple representations (MR)	0.61**	0.63**	0.47**	0.58**
Models as exact replicas (ER)		0.49**	0.30**	0.52**
Models as explanatory tools (ET)			0.46**	0.52**
The uses of scientific models (USM)				0.30**
The changing nature of models (CNM)				

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

4.8.4c My Views of Models and Modelling in Science (VOMMS)

Statistical differences were investigated with respect to gender, age and school. ANOVA tests were performed on all items in the survey to identify any differences between different Year levels; t-tests were used to identify any gender differences. The VOMMS instrument for Study 2 has a Cronbach alpha reliability of 0.58, which is low compared to the results in Study 1, but provides some degree of consistency throughout the instrument.

An independent t-test performed on the six items found that only item 5 was statistically significantly different ($p < 0.05$) with respect to gender. In that item, the female students responded more positively, demonstrating a more scientifically sophisticated view of models. An ANOVA analysis on the results for each item with respect to Year level showed statistically significant differences ($p < 0.05$) between the Year levels for items 1 and 2. For both items there was an increase in the number of students choosing the more scientifically valid response with age.

4.9 Study 3 – Learning Introductory Chemistry for Non-majors

This study investigated first-year university, non-major chemistry students' understanding of chemical representations and their personal learning strategies.

4.9.1 Purpose of Study 3

The purpose of Study 3 was to investigate the way that first year university students with little or no chemistry knowledge perceived the role and use of models in chemistry, interpreted diagrams of chemical phenomena at the macroscopic and sub-microscopic levels, made links between the three levels of chemical representation, developed their mental model of chemical phenomena, and the learning strategies they adopted.

4.9.2 Design and Procedure

Study 3 took place at a university in Perth, Western Australia, where approximately 160 students were undertaking a first year introductory chemistry unit. The study focused on 30 students who were observed weekly during laboratory sessions. This class of 30 was selected on the basis of the laboratory schedule being convenient for the researcher and was generally representative of the overall population of students undertaking the unit. In Study 3 students were encouraged to volunteer to participate in the research, however, it eventuated there were more confident and mature-aged students volunteering, so efforts were made to encourage the younger and less confident students to participate to make the sample more representative of the normal population. The less experienced students were more willing to participate in groups rather than individually. Of the 30 students in the laboratory session, 19 volunteered to participate in interviews and complete worksheets and questionnaires. The age, range, and gender of the volunteers are compared with that of the laboratory class and the whole unit and are presented in Table 4.8. While there were more males in the volunteer sample than representative of the normal population, the age of the volunteers was generally representative of the laboratory class sample. Of the 19 volunteers at the beginning of the study who completed the initial questionnaire, some students did not continue as a volunteer because they did not continue in the unit, others changed their laboratory session making it difficult for me to maintain contact with them and those volunteers remaining, at times, had other commitments. Consequently, the number of responses to worksheets and interviews varies.

This research was conducted with first year Environmental Biology students. As part of their Environmental Biology degree, students are required to pass an introductory chemistry unit, called Chemistry 117, in first semester, and a follow-on unit, called Chemistry 118, in second semester. There is no pre-requisite required to undertake Chemistry 117, although some students have studied high school chemistry. The description from the university handbook states:

> Chemistry 117 - designed for students with no previous study of chemistry. Fundamental concepts of chemistry and a treatment of stoichiometry, the structure of atoms and bonding in chemical compounds. Introduction to organic chemistry - nomenclature, alkanes, alkenes, alkynes, and benzene (Curtin University of Technology, 2003b).

The teaching unit Chemistry 117 extends over one semester of 14 teaching weeks. The tuition consists of a one-hour lecture and a three-hour laboratory session per week. The unit is a self-paced, mastery-learning program designed to provide flexibility and caters for students with a wide range of backgrounds and services students destined for a variety of professions. Students generally do not continue with chemistry after first year and it is not their major area of study. Thus the title non-major chemistry students apply. The learning program is referred to as the PSI method referring to the Personalised Student Instruction[10] that it entails. Details of the program are provided in Appendix F (Curtin University of Technology, 2003c).

Table 4.8 Comparison of Age and Gender for the Students in Study 3

	Size of Sample	Gender %		Age Profiles % *			
		Male	Female	1	2	3	4
Chemistry 117	160	35	65	Not available			
Lab class	30	37	62	58	12	15	15
Volunteers**	19	47	53	53	5	26	16

* Age Profiles
1- attended high school last year
2- within 2 years of leaving school
3- between 2- 5 years of leaving school
4- more than 5 years since leaving school
** Not all volunteers completed all volunteer tasks as availability varied.

The laboratory manual provides detailed instructions on the weekly laboratory work. The Personalised Student Instruction (PSI) study notes provide detailed chemical content corresponding to the lectures, with examples of worked problems, and exercises with answers for checking and trial tests. The university prints the laboratory notes and course notebook in an economical format – black and white print with very few diagrams. The recommended textbook called *Introductory Chemistry* by S.S Zumdahl (2000) is not purchased by many students for three reasons. Firstly, the course is closely aligned to the PSI study notes and students can pass the unit using only those notes; secondly, it is expensive; and thirdly, students cannot see the value in purchasing a textbook in a subject in which they are not going

[10] PSI is an abbreviation for Personalised Student Instruction.

to continue after first year.

The unit has a formative assessment style of continuous assessment throughout the semester. This assessment regime comprises 11 weekly laboratory tasks (10%), 11 compulsory mastery tests (45%), three optional topic tests, and an optional final review examination. The unit outline is provided in Appendix G. By completing only the compulsory topic tests and passing the laboratory component, a student will obtain a Pass grade. To achieve a higher grade, students must attempt the optional tests and the optional examination. The Personalised Student Instruction scheme (PSI) requires students to gain a mark of at least 80% to pass a topic. This formative assessment style provides students with feedback from a tutor on their test results and they may re-sit the test any number of times. The tests require students to complete mainly algorithmic type problems. The style of questions in each test is similar; however, the number values and unknowns can vary, so students are not resitting exactly the same test. The lectures follow the PSI study notes very closely, with the instructor providing detailed verbal description and written notes on the board. Similarly, the PSI mastery tests follow the PSI study notes very closely. Through the laboratory sessions, students are expected to develop skills in common laboratory techniques, learn how to use particular chemical apparatus, process data and, report laboratory results in a scientific manner. Despite efforts to run the laboratory sessions in line with the lecture sessions, the chemistry being used in the laboratory session does not necessarily correspond to the chemistry being taught in the lecture. Chemistry 117 is a pre-requisite for the follow on chemistry unit, Chemistry 118, which has an identical teaching and learning arrangement to Chemistry 117. The syllabus for Chemistry 118 is described in the university handbook:

> Chemistry 118 – Colligative properties of solutions. Thermodynamics and equilibrium. Chemical kinetics. Acids and bases. Salts and buffers. Principles and practice of chromatography. Optical isomerism and alkyl halides. Alcohols, phenols and ethers. Aldehydes, ketones and Grignard reagents. Carboxylic acids, derivatives of acids and amines (Curtin University of Technology, 2003b)

4.9.3 Quantitative Data Sources

There are three quantitative data sources that were used in Study 3: the initial questionnaire, the students' unit experience (SUE) questionnaire and four worksheets.

4.9.3a Initial questionnaire

This initial questionnaire was administered in week 2 of semester 1 to the volunteer students in the laboratory class in which I was working as a demonstrator. Some of the instruments that were used in Studies 1 and 2 have been refined and included here in this initial questionnaire. It contained four sections comprising: abridged versions of the instruments – SUMS (described in section 4.8.3b – five items were deleted, but all five scales are still present); and VOMMS (described in section 4.7.3c – item 3 was omitted as it is similar to item 2); MCR (described in section 4.7.3b – items 1, 10 and 11 were omitted); in addition, three written questions were included: "What do you think the atom looks like?" and two questions in which students were asked to build concept maps using the list of chemical terms provided. The Cronbach alpha values for the four types of models considered in the MCR instrument range from 0.70 to 0.85 and show a good consistency within each scale (Table 4.9). Copies of the instruments are in Appendix H.

Table 4.9 Descriptive Statistics and Cronbach Alpha Reliability of Scales of the Molecular Chemical Representations Instrument for Study 3 (n=18)

Scale	No of Items	Mean*	Standard Deviation	Cronbach Alpha
Structural Formula	8	27.28	4.08	0.70
Ball-and-stick	8	30.53	4.02	0.75
Spatial	8	25.53	5.36	0.85
Computer	8	29.24	3.67	0.81

*Note: The mean score is calculated from the responses being assigned the values: Strongly Disagree = 1; Disagree = 2; Don't Know = 3; Agree = 4; Strongly Agree = 5.

4.9.3b Student Unit Experience questionnaire

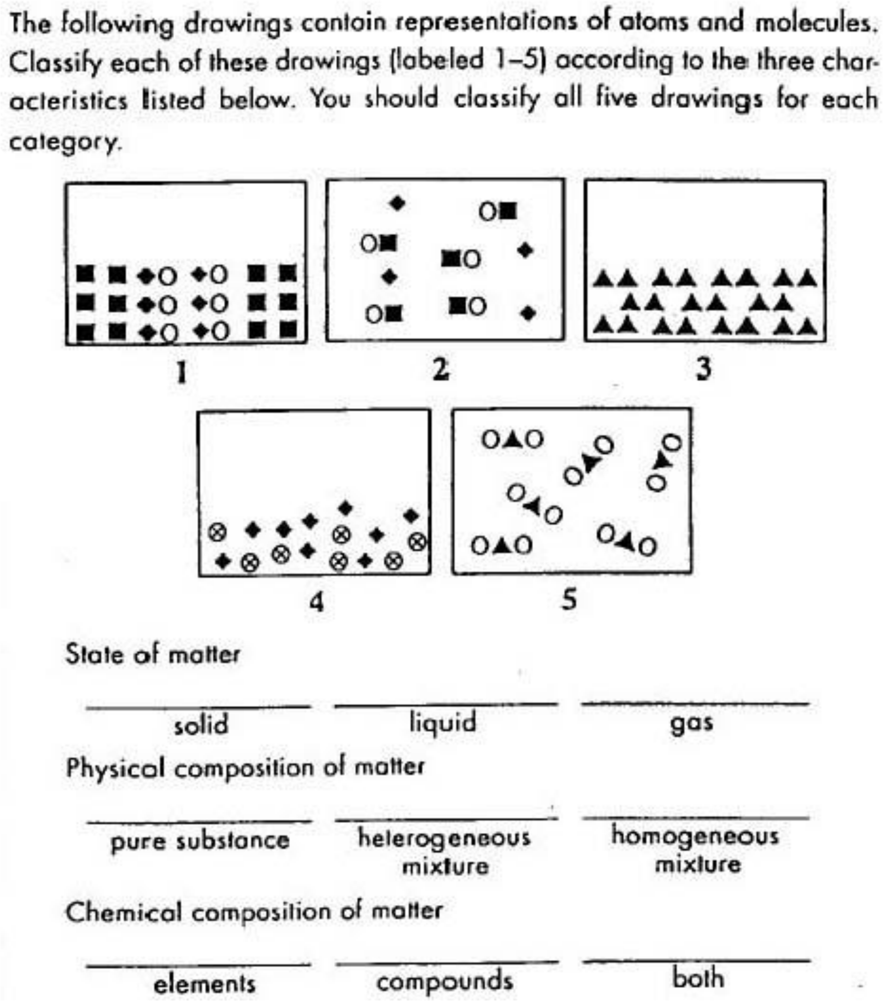
All students in the Chemistry 117 were asked to complete a course evaluation instrument, called the Student Unit Experience (SUE) questionnaire provided by the university, at the end of the first semester. It was an anonymous survey containing 22 items on issues such as unit content, unit organisation, teaching and learning, laboratory classes, and overall evaluation of the unit. The response rate to this instrument (n=61) was lower than anticipated primarily because it was not compulsory and it was given at the end of semester when students either had little time available or were not present. A copy of the instrument is in Appendix H.

4.9.3c Worksheets

The volunteer students completed up to four worksheets progressively throughout the semester after the particular concepts such as solutions and ions, moles, chemical symbols and equilibrium had been taught. The worksheets were completed and submitted to me by the volunteer students. They were for research purposes only and were not assessed in any way. I designed the worksheets in light of the students' laboratory and lecture experiences, to target the students' understanding of the particular topic in terms of the relationship between the sub-microscopic and symbolic representations. The worksheets are described here in words with some pictures; however, complete copies of each of the four worksheets are available in Appendix I.

Worksheet 1, focussed on ions and asked students to express how confident they were that a statement was correct, on a scale of one to five, for 15 statements concerning ions, such as "the dissolved ions cannot be seen with the eye". The students had covered theory about ions in lectures and had performed two laboratory experiments about ions. The first experiment required students to observe the colour of various solutions, identifying the ions present in the a solutions from the formula, and drawing conclusions about the colour of hydrated cations of the alkali (Group 1), alkaline (Group 2), and transition elements. The second experiment required students to observe the solubility of a range of compounds including nitrates, chlorides, sulphates, phosphates silver salts, and hydroxides.

Worksheet 2 explored the mole concept and the classification of matter. Question 1 asked students to show how confident they were about 22 statements concerning moles, such as, "1 mole of Na_2CO_3 contains the same number of particles as there are in exactly 12 grams of carbon-12" and "a mole of any element contains the same number of atoms but its mass will vary". Eight of the 11 laboratory experiments involved quantitative inorganic analyses, so students had plenty of experience performing titrations as well as completing the necessary calculations. I created the statements about the mole concept based on the students' laboratory and theoretical experience. The second question of Worksheet 2 concerned the classification of matter physically and chemically from a diagrammatic representation shown in Figure 4.1. This question was designed by Sanger (2000) and shows five different representations of atoms and molecules that students were required to classify according to their physical state, physical composition and chemical composition.


The following drawings contain representations of atoms and molecules. Classify each of these drawings (labeled 1–5) according to the three characteristics listed below. You should classify all five drawings for each category.

1 2 3

4 5

State of matter

solid liquid gas

Physical composition of matter

pure substance heterogeneous mixture homogeneous mixture

Chemical composition of matter

elements compounds both

Figure 4.1 Worksheet 2 Question 2

Worksheet 3 investigated students' understanding of simple symbolism in chemistry and contained six multiple-choice questions about common chemical symbols used in chemical equations. For example: what does the notation $2NO_2$ represent? And what does the arrow in the centre of an equation mean? The inspiration to examine symbolism came from a presentation by John Oversby (2001) reporting on students' understanding of chemical symbols. Questions 1, 4, 5 and 6 in Worksheet 3 are originally from a study by Marais and Jordaan (2000) into university students' understanding of chemical symbols and words. I created questions 2 and 3 in Worksheet 3 to supplement the other questions.

Worksheet 4 on chemical equilibrium asked students to make predictions and describe what would occur to two different equilibrium situations when a change is initiated. I generated the questions using diagrams from the textbook by Zumdahl (2000) that are shown in Figures 4.2 and 4.3. The diagrams included both sub-microscopic level and macroscopic level depictions.

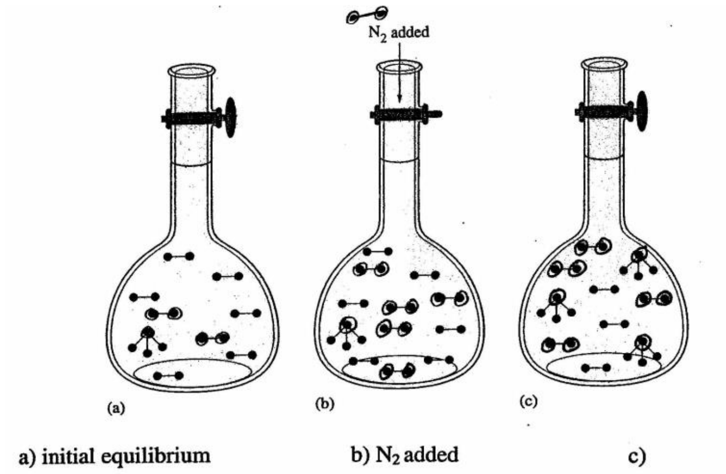


Figure 4.2 Worksheet 4, Question 1

4.9.4 Qualitative Data Sources

The primary qualitative data source is the interviews that were conducted at the beginning of semester 1 and at the beginning of semester 2. In addition, there are my observations as a participant researcher and the reflective journal of my experiences throughout the study and the students' laboratory reports.

4.9.4a First interview

Interviews with seven volunteer students, in the first four weeks of the course, were designed to gain some insight into the students' level of chemical understanding about basic chemical ideas and their preference for a variety of chemical representations. Three focus cards were used in the first interviews. Focus Card 1 contained eight diagrams representing possible arrangements of atoms (Figure 4.4a). Students were asked to categorise each diagram as representing either an element or a compound. Focus Card 2 had eight representations of a single atom (Figure 4.4b). Students were asked to describe what information they gained from each representation and which they preferred. Focus Card 3 showed nine representations of water (Figure 4.5). Students were asked which they preferred and why they preferred it.

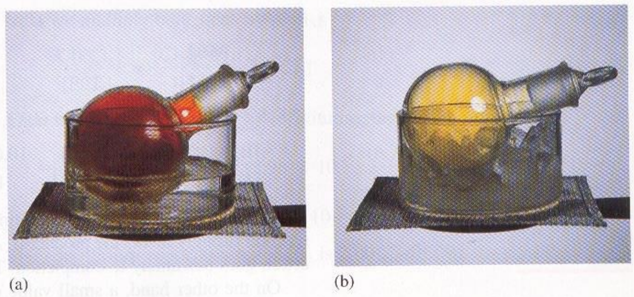


TABLE 16.2

Shifts in the Equilibrium Position for the Reaction Energy + $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

Change	Shift
addition of $N_2O_4(g)$	
addition of $NO_2(g)$	
removal of $N_2O_4(g)$	
removal of $NO_2(g)$	
decrease in container volume	
increase in container volume	
increase in temperature	
decrease in temperature	

Figure 4.3 Worksheet 4 Question 2

4.9.4b Second interview

Twelve students were interviewed at the beginning of semester 2. Five of these volunteers had participated in the first interview. This interview focused on the students' learning strategies, their mental models of chemical compounds, and their understanding of the three levels of chemical representations. Questions included, "What you already know affects what and how you learn. Has this applied to you? Explain" and "In laboratory work, we perform experiments and use equations to do calculations. Can you relate the equations to the experiment?" The first and second interview questions are in Appendix J.

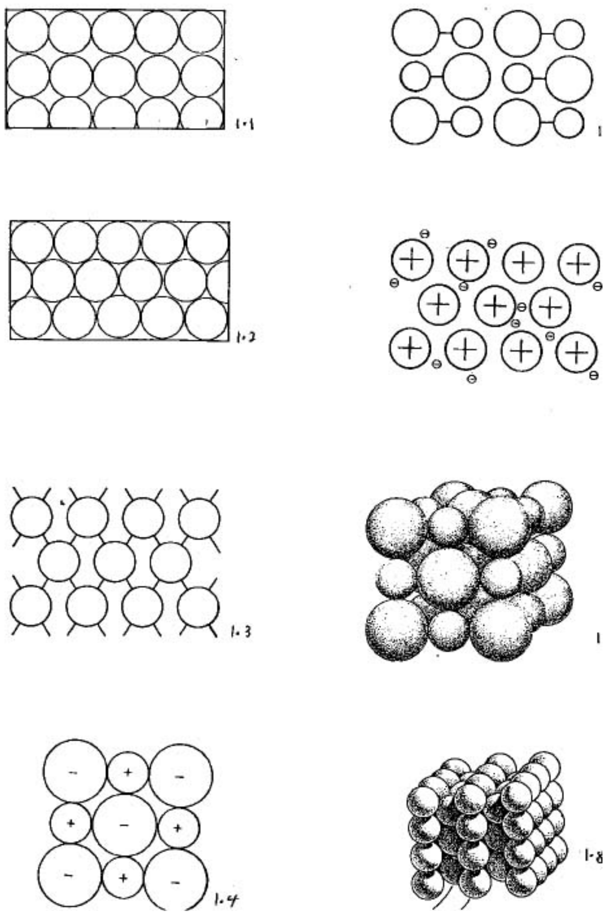


Figure 4.4a Focus Card 1

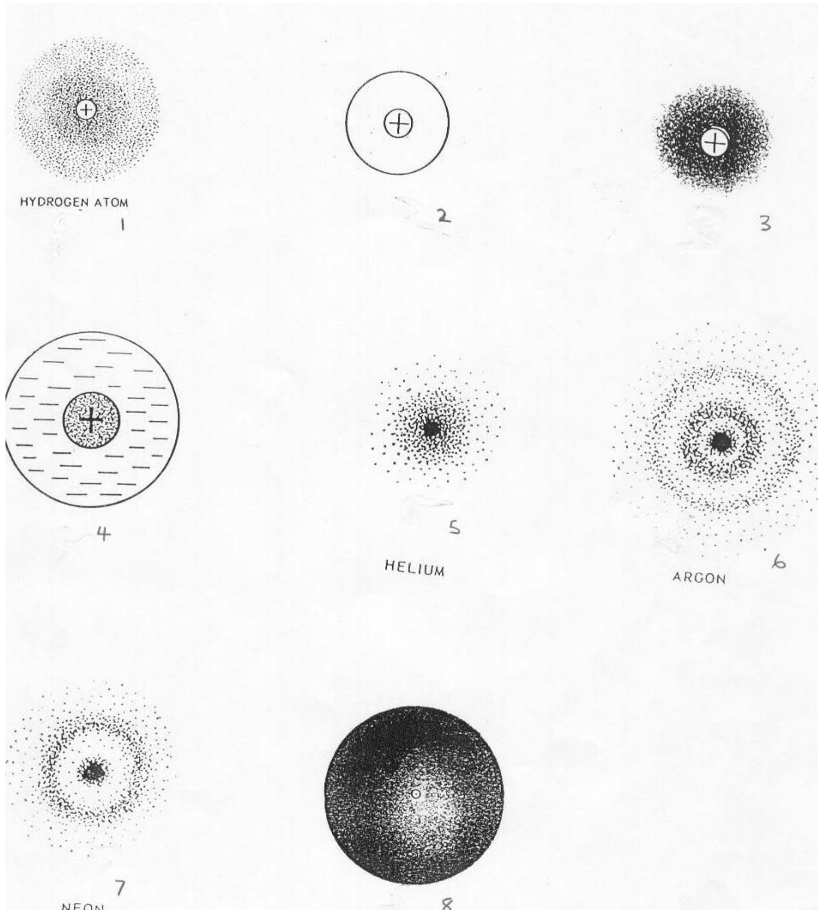


Figure 4.4b- Focus Card 2

Figure 4.4 Focus Cards 1 and 2

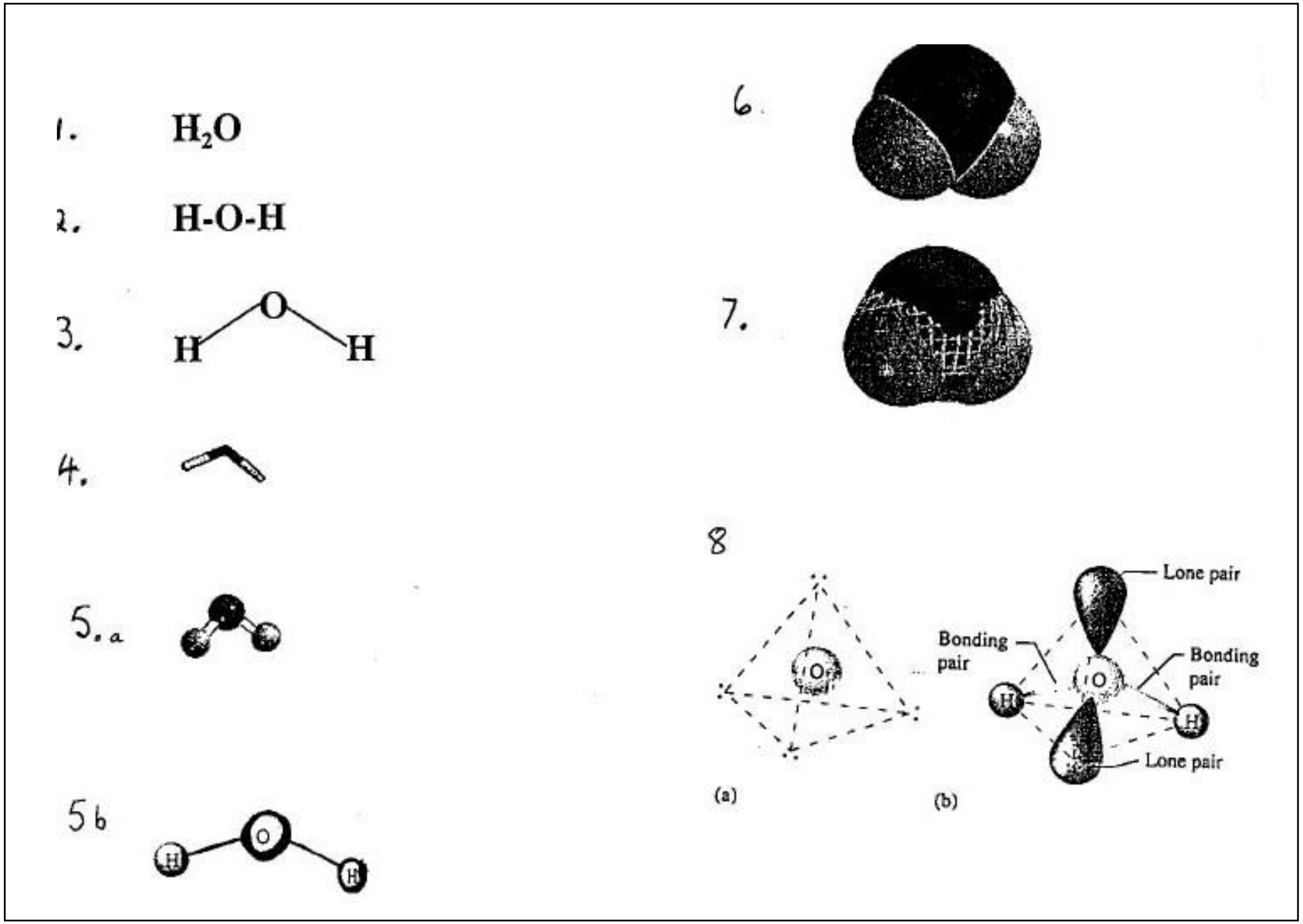


Diagram #8 copied from Zumdahl (2000 p.358)

Figure 4.5 Focus Card 3

4.9.5 Data Analysis Procedures

Except for the Student Unit Evaluation (SUE) results that were anonymous, all other data concerned the student volunteers who were identified with a single identification number that was used in both the quantitative and qualitative data. The sample size of the volunteer group for Study 3 was small (n=18) and it did fluctuate as the demands on students prevailed. This limitation has been taken into consideration throughout the analysis. The number of students being interviewed varied because of student commitments and availability.

The quantitative data for the student volunteers, including the initial questionnaire and the worksheets, were tabulated, collated and analysed using SPSS where appropriate. The small sample size (n=18) for the initial questionnaire limits the reliability of these quantitative data; however, the validity of the instruments used in the initial questionnaire is based on their use in Studies 1 and 2. Because of time constraints, not all students completed all the worksheets: Worksheet 1 – eight responses; Worksheet 2 – eight responses; Worksheet 3 – nine responses; and Worksheet 4 – ten responses. The results of the worksheets were analysed according to the type of data collected.

The larger sample size (n=61) of anonymous responses to the Student Unit Evaluation (SUE) instrument was also tabulated, collated, and analysed using SPSS.

4.10 Study 4 – Learning Introductory Chemistry and the Implementation of Online Pre-laboratory Exercises for Non-majors

4.10.1 Introduction

Study 4 investigated the use of chemical representations in learning chemistry by first-year university, non-major chemistry students. Study 4 took place in the same setting as Study 3 but in the following year and involved first year university students at a Western Australian university undertaking introductory chemistry as a non-major compulsory unit. The results of Study 3 highlighted the importance of chemical representations that are used in chemical explanations to students' understanding of the sub-microscopic level of chemistry. Consequently, this study continued to focus on chemical representations and students' developing mental models.

In response to the findings of Study 3, I gained funding through a competitive university grants application to implement a small change to the introductory chemistry unit by means of introducing compulsory online pre-laboratory exercises, which were designed to better prepare students for the laboratory work by asking questions about the objectives of the experimental procedure, equipment and calculations (R. T. White, 1996). The grant application and evaluations are in Appendix K. The pre-laboratory exercises provided an opportunity to make use of more diagrammatic explanations of laboratory tasks than had previously been available and provided immediate feedback to students on their understanding. The evaluation of students' understanding of the diagrams used in the pre-laboratory exercises provided further data about students' understanding of chemical representations.

4.10.2 Purpose of Study 4

The purpose of Study 4 is identical to the purpose of Study 3 – to investigate how first year university students, who have little or no chemistry knowledge, perceive the role and use of models in science, interpret diagrams of chemical phenomena at the macroscopic and sub-microscopic level, make links between the three levels of chemical representation, develop mental models of chemical phenomena, and choose learning strategies.

4.10.3 Design and Procedures

As with Study 3, I worked as a demonstrator (teaching assistant) with the introductory chemistry unit, Chemistry 117, in first semester and Chemistry 118 in second semester. Volunteers to participate in the study were sought from the students in the laboratory class for Chemistry 117. These volunteers completed the introductory questionnaire and were observed in the laboratory during the first semester. During second semester, volunteer students were sought from the whole unit to be interviewed about the diagrams that were being used in the pre-laboratory exercises. The profile of these volunteers is presented in Table 4.10. In addition to these volunteer groups, all students undertaking the unit were asked to complete a survey towards the end of each semester providing anonymous information about their learning experience.

The profile of the students in Study 4 is very similar to that described for students in Study 3. The students were undertaking degree courses such as Environmental Biology, Health Sciences, Human Biology Pre-clinical, and Environmental Health for which Chemistry 117 and 118 are compulsory units. Chemistry 117 is designed for students with no previous chemistry knowledge and is a prerequisite for Chemistry 118. The unit structure is very similar to that described in section 4.9.2 for Study 3, with the only change being the introduction of the online pre-laboratory exercises. The online management system is called WebCT and is available to all students. The university handbook describes the online learning facility:

> WebCT is Curtin's online teaching and learning management system. It is used to deliver course material, conduct assessments and to facilitate communication and collaboration among staff and students, in the form of email, discussion lists, chat and whiteboard tools (Curtin University of Technology, 2003d).

The university encourages the use of this online facility. A website was designed for both chemistry units containing unit information, communication through e-mail and a discussion page, tools that included a glossary and grades from the pre-laboratory exercises and grades for their laboratory reports, links to useful websites, solutions to the typical tests, and the pre-laboratory exercises. Appendix L shows the web pages comprising the website.

Table 4.10 Comparison of Age and Gender for the Students in Study 4

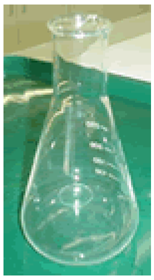
	Size of Sample	Gender % Male	Female	Age Profiles % * 1	2	3	4
Chemistry 117	98	48	52	NA**			
Chemistry 118	115	46	54	NA			
Volunteers from Lab class for Chemistry 117 semester 1	49	43	57	NA			
Volunteers for Interviews from Chemistry 118 semester 2	19	32	68	42	10	21	27

* Age Profiles
1– attended high school last year
2– within 2 years of leaving school
3– between 2– 5 years of leaving school
4– more than 5 years since leaving school

**NA Not available

The pre-laboratory exercises were designed to be straightforward and simple, taking approximately 10-20 minutes per week to complete and were worth 2% of the students' total marks. Even though the value of the task was very small, they were compulsory and designed to be a learning opportunity rather than an assessable task. There were 11 practical classes each semester and students were required to complete the pre-laboratory exercises before each practical class to help them be better prepared for the class. There was on average about eight questions each week, of varying formats including multiple-choice, short-answer or matching. An example of a pre-laboratory question from the Week 1 of first semester is shown in Figure 4.6. An example of a set of questions, showing the WebCT format is provided in Appendix M. Students were given three opportunities to do the pre-laboratory exercises, receiving feedback on their responses and thereby learning from their mistakes, with the highest score being recorded.

Choose the name of the equipment pictured



1. conical flask
2. pipette
3. burette
4. funnel

Figure 4.6 Pre-laboratory Exercise – Semester 1, Week 3, Question 1

When taking the pre-laboratory exercises online, answers are selected for all questions and then the exercise is submitted for marking. Within a few seconds, the marked exercise provides specific feedback on the student's choice – reinforcing a correct choice or correcting an incorrect choice. General feedback is provided to assist students if they are re-attempting the question. Table 4.11 shows two such questions and the feedback for each alternative. The desired outcomes of this project were to improve links between theory and practical work and provide immediate feedback to students, suggesting reasons for their incorrect choice as well as reinforcing correct answers and instilling confidence in their ability. This instructional strategy was designed to encourage a positive learning environment without the pressures of assessment and to provide an avenue of communication with other students and staff.

4.10.4 Quantitative Data Sources

Four quantitative data sources that were used in Study 4 are the Introductory Questionnaire, Students' Evaluation of Educational Quality (SEEQ) and the Online Survey and data recording students utilisation of the WebCT chemistry site.

4.10.4a Introductory questionnaire

Two quantitative instruments that had been used previously in this research – *SUMS* (described in section 4.8.3b, with five items deleted, but all five scales still present); and *VOMMS* instrument (described in section 4.7.3c, with item 3 omitted as it was similar to item 2) – comprised the introductory questionnaire administered to the students in the researcher's laboratory class at the beginning of the semester (n=48) (Appendix N)

Table 4.11 Example of Two Pre-laboratory Exercises Showing Feedback (in italics)

Semester 1, Week 4, Question 5 Why should a constant, minimum amount of indicator be used in titrations?	
Alternative	Reason
Indicators are expensive and should be used sparingly.	*Incorrect. Many indicators come from common plants and other natural sources. The success of the titration is dependent on having the right indicator. Indicators provide evidence that the equivalence point has been reached.*
A lot of indicator must be used to ensure the change is observed.	*No, it is better to have enough indicator to see the colour. Use white paper for contrast. Indicators provide evidence that the equivalence point has been reached.*
To ensure constant colour intensity	*Correct. Indicators provide evidence that the equivalence point has been reached. It is best practice to use the same amount of indicator for each titration.*
The amount of indicator used doesn't matter.	*No, it is better to use the same amount of indicator in each titration so that the results can be compared. Indicators provide evidence that the equivalence point has been reached.*
General feedback – Indicators provide evidence that the equivalence point has been reached. It is best practice to use the same amount of indicator for each titration.	

Semester 1, Week 4, Question 2 When using a burette, to how many decimal places should the reading be quoted?	
Alternative	Reason
One decimal place	*No, the limit of reading is half the smallest division on the scale. The scale on a burette shows every 0.1mL, so it can be read to 0.05 of a mL.*
Two decimal places	*Yes, that's correct.*
Three decimal places	*That would be beyond the instrument. The limit of reading is half the smallest division on the scale. The scale on a burette shows every 0.1mL, so it can be read to 0.05 of a mL..*
Correct to the nearest mL	*No, the limit of reading is half the smallest division on the scale. The scale on a burette shows every 0.1mL, so it can be read to 0.05 of a mL.*
General feedback – The limit of reading is half the smallest division on the scale.	

4.10.4b Students' Evaluation of Educational Quality (SEEQ)

The SEEQ questionnaire was an anonymous pen and paper survey provided by the university. The items concerning the online pre-laboratory exercises were written by the researcher – drawing on previous research by Donovan and Nakhleh (2001). The students were requested only to respond to the 17 items written asking for their opinion about the online pre-laboratory exercises. The students responded on a 9-point Likert scale from strongly disagree to neutral to strongly agree for items such as "The online pre-laboratory exercises provided feedback on my understanding" (item 6) and **"**The pictures in the online pre-laboratory exercises were valuable" (item 15) (see Appendix N). The questionnaire was administered towards the end of the first semester to all students in Chemistry 117. Of the 107 responses, 98 were considered valid responses, while nine responses that had the same response for all items of the questionnaire were omitted for being false records.

4.10.4c Online survey

Towards the end of the second semester, the students were surveyed again for their opinions about the online pre-laboratory exercises as well as their learning strategies and aspects that were perceived to influence their learning. The survey was administered online through the WebCT site for the Chemistry 118 unit to students. The survey contained Likert-style items, requiring a response on a five-point scale to items similar to those in the SEEQ instrument such as "I understood the experiments, having done the pre-laboratory exercises" (item 12), as well as items requiring short answers such as "What aspects of the pre-laboratory exercises are helpful to your learning of chemistry?" (item 23) (see Appendix N).

4.10.4d Utilisation of the WebCT chemistry site

The WebCT management system provides data on the students' frequency of access to the chemistry site, the number of attempts, responses and the time spent on each item of the pre-laboratory exercises, the number of times they access the discussion page, and the number of messages they post. These data are used to support conclusions from the more direct sources.

4.10.5 Qualitative Data Sources

There are numerous qualitative data sources obtained throughout Study 4. A primary source is from two series of interviews conducted with student volunteers who were sought through the WebCT site. Volunteers (n=19) were interviewed after week 5 and week 12 of second semester. Students were asked about their understanding of particular diagrams encountered in the pre-laboratory exercises that were associated with the laboratory experiences. In the interview, students were asked to relate these diagrams to the questions and to their laboratory experience. The interview questions (Appendix O) focused on the three levels of chemical representation as well as the plausibility, intelligibility, and fruitfulness of each diagram to the individual learner. The interviews were conducted individually and in groups, depending on students' availability. Each interview took approximately one hour. There was an excellent participation rate for the first interview (n=17), however, student availability became tested towards the end of the semester, as students prepared for examinations and the number of students participating in the second interview was reduced (n=5). Also for all interviews, the number of students completing the interviews fluctuated with pressures of time and other commitments so the number of students responding to particular questions varied.

In addition, as a demonstrator and a participant researcher I had personal experiences with students, conversations, e-discussion, e-mail communications, the marking of laboratory reports and tutoring episodes that contributed to my evaluation and assessment of the learning that was occurring.

4.10.6 Data Analysis Procedures

As with the previous studies, the research questions form the foundation for the analysis. The analysis considered both internal and external aspects of the students' learning. The internal aspects included students' comprehension of diagrams and their comprehension of the laboratory experiences at the macroscopic and sub-microscopic levels, their time management and motivation. The external level included the available learning opportunities such as receiving feedback on responses, opportunities for communication using WebCT and assessment schemes. Quantitative data collected from a large number of students undertaking the two introductory chemistry units was analysed in conjunction with qualitative data collected from volunteer students. The written responses to quantitative instruments and the interview data were analysed using N-Vivo as described in section 4.35. Contradictory evidence was also sought in the researcher's attempts to present a true representation of the learning experience (Erickson, 1986).

4.11 Conclusion

This chapter has described the general methodological approach taken in this research to address the research questions and has sought to discuss and justify the choices that have been made. The research methodology has described the collection of quantitative and qualitative data sources and the interpretive analysis of the data. The validity and reliability of the data has been demonstrated, the methods of analyses have been justified and critically assessed so that any findings can be considered to be valid and reliable. The rigour and robustness of the research is dependent on these processes of validation and review being in place. The ethical aspects of the research have given full consideration to the participants and their learning environments. The application of this general methodological approach is manifested in the detailed description of the specific methodology of each of the four studies that have been provided. The methodology is complicated having four different studies that make use of different data sources and involve students of different ages and backgrounds. However, this diversity is an asset, allowing for comparison across age groups and backgrounds – adding to the richness of the data. The results of the research are presented in the following three chapters along with interpretative analysis in addressing the research questions.

CHAPTER 5

MODELS AND MODELLING ABILITY

Chapter Outline

This chapter addresses objective 1 of this research by examining students' perceptions of models and modelling in addition to their modelling ability. Section one shows how data are drawn from the four studies to address the four research questions included in objective 1. In section two, students' perceptions of scientific and general models are examined. These data are used to support five characteristics of scientific models, which in turn are used to develop a typology of models in section three. In considering how and why models are useful in learning, section four provides examples from the research that display students' modelling ability and changes to their modelling ability through instruction. In section five, the position of scientific and teaching models in the process of learning is discussed. Lastly, section six is the conclusion, summarising the main points of the chapter.

5.1 Objective 1

Modelling is a core process of the scientific method and as such it is worthwhile attempting to understand what students think about models. The term model has a wide range of meanings that can lead to misunderstandings by teachers and students. This chapter reports on students' perceptions of models and modelling in addition to students' modelling ability as outlined by objective 1 of this research:

> *To investigate students' understanding of models and their modelling ability.*

Data from all four studies are utilised to respond to the four research questions that underpin objective 1. The sections in which each research question is addressed is shown:

> *1.1 What are students' perceptions of the role and purpose of generic models and scientific models? (Section 5.2)*

1.2 What are the criteria that students identify as being significant when classifying scientific models? (Section 5.3)

1.3 How does students' modelling ability affect their use of models and their ability to understand chemical concepts? (Section 5.4)

1.4 How and why do models help students learn? (Section 5.5)

Modelling at a rudimentary level requires the user to relate the target to the analogue (Duit, 1991). There are three frameworks discussed in chapter 2 that have been drawn on in the analysis of models, modelling and modelling ability. Firstly, Stephens et al. (1999) (section 2.4.1) explain the need for students to understand the connections between the model and the target in order to construct explanations. They distinguish lower order and higher order relational mapping between the model and the target. Secondly, there are numerous typologies that categorise models, such as Gilbert and Boutler's (1995) typology of models based on the way a model is used (section 2.4.2). The value in a typology is in its value to the learner in understanding the role and characteristics of a model. Thirdly, to describe students' modelling ability, Grosslight et al. (1991) developed a scale consisting of three levels (section 2.5.3) which was administered to the volunteer students in Studies 3 and 4. The three frameworks about models are closely aligned and are used here in addressing the research questions.

5.2 Students' Perceptions of Models

Multiple data sources concerning models in general and models in science are presented to address Research Question 1.1, "What are students' perceptions of the role and purpose of generic models and scientific models?" The studies in which each data source was administered are shown:

Models (Study 1)

Scientific Models (SM) (Study 2)

My Views on Models and Modelling in Science (VOMMS) (Studies 1, 2, 3, and 4)

Students' Understanding of Models (SUMS) (Studies 2, 3, and 4)

5.2.1 Models

The results of the instrument, Models, administered to the Year 11 chemistry students in Study 1, provide some insight into students' perceptions about models in general. The results (Table 5.1) indicated that most students could readily identify concrete models and distinguish real items as not being models, but had mixed ideas about symbolic representations and images. The majority of students considered the toy car (78%, item 1) and the model ear (89%, item 2) to be models. The high response to the questions on the toy car and the model ear reflects the commonplace definition of a model – it looks the same but is a different size – and is supported by the reasons that students gave for their choices; however, this traditional definition is not always true or appropriate for scientific models. The images – the photograph of a cell (53% agree, item 5) and the computer dissection (58% agree, item 8) and the symbolic representations – the diagram of atom (67% agree, item 7), the chemical equation (50% agree, item 6), and the graph (47% agree, item 9) were not decisively categorised by students as models. These mixed results could suggest that for many students these items did not fit their traditional definition of a model.

The results presented in Table 5.1 show that nearly all of the students surveyed had a good understanding of the traditional definition of a general model as a copy of something, and were able to distinguish them from real situations. However, approximately half of the students did not consider symbolic representations or images to be models. These results are similar to those reported by Grosslight et al. (1991), upholding their conclusions that students of this age have naïve conceptions of models. Only 14% of students in Grosslight's study referred to abstract models (e.g., mathematical or theoretical models). In this study, approximately half of the Year 11 students surveyed identified with the concept of abstract models.

5.2.2 Scientific Models (SM)

The results of the SM instrument administered to high school students participating in Study 2 are presented in Tables 5.2 and 5.3. The results from Part 1 confirm that the majority of students see the scientific model as a scale replica – with 71% agreeing that "a model is a smaller version of the real thing" (item 1) and 83%

agreeing that "a model can show an example of the real thing" (item 2). Most students also agreed that models are tools that help us to see something – with 62% of students confirming that models are associated with "providing a visual representation" (item 4), 60% agreed "that models can give a clearer picture of a scientific idea" (item 7) and 58% agreed that "a model can provide a visual way to show how ideas are connected" (item 6). For Part 1 of the SM instrument, there are no statistically significant differences in the year groups; however, the Year 8 results tended to have a larger "Don't Know" count than the other year groups.

Table 5.1 Percentage Results for the Instrument Models with Year 11 Students in Study 1 (n=36)

	Is it a Model?		Best Way to Describe the Model (% of total responses)							
Item	% Yes	% No	A static model	Works the same as the real thing	Looks the same but different size	Diagram or map or plan	Description in numbers	Description with words	Description using pictures	Simulation
A toy car	78	18	27	8	51	1	0	2	4	7
A model of the ear	89	11	37	8	40	3	2	2	7	2
A living animal	17	83	6	41	19	3	0	6	9	16
An experiment of a metal in acid	19	81	7	24	0	11	9	11	11	27
A photograph of a cell	53	47	18	5	16	22	2	11	22	5
A chemical equation	50	50	6	4	3	3	46	30	7	1
A diagram of the inside of an atom	67	33	13	3	13	27	7	4	33	1
A computer image of a rat dissection	58	42	10	6	5	19	5	5	28	23
A graph showing energy changes	47	53	7	2	7	31	21	9	22	0

Part 2 of the SM instrument asked students to choose the best description for particular models. The results confirm that models can fit well into several descriptors. Most students appreciated the diversity of models and were able to identify the attributes of each particular model being considered and their uses. The frequencies of the Year 8 responses for most popular choices were generally lower than that of the Year 9 and 10 responses. The ability levels of the general science students in Study 2 were not recorded; however, the Year 9 responses tended to reflect a more scientifically accurate choice than the Year 10 responses.

Table 5.2 Percentage Responses to the Instrument Scientific Models Part 1 in Study 2 Showing Each Year Group (n=229)

The word model is associated with:	SD*	D	DK	A	SA
1. A smaller version of the real thing	5	11	13	54	17
Year 8 (n=69)	6	4	22	49	19
Year 9 (n=44)	0	26	9	58	7
Year 10 (n=116)	7	8	9	56	20
2. Something you can use to show an example of something.	1	5	11	58	25
Year 8	1	4	18	57	20
Year 9	0	5	5	67	23
Year 10	1	6	10	54	29
3. A 3-D picture of an object.	7	17	32	35	9
Year 8	10	12	37	34	7
Year 9	4	16	32	43	5
Year 10	7	20	30	31	12
4. A visual representation of how something works.	2	12	24	45	17
Year 8	3	15	32	35	15
Year 9	2	16	27	32	23
Year 10	1	10	18	54	17
5. A duplicate of reality.	3	17	38	33	9
Year 8	2	20	42	27	9
Year 9	2	16	43	30	9
Year 10	4	16	33	37	10
6. A visual way to show how ideas are connected.	2	12	28	47	11
Year 8	3	13	45	28	10
Year 9	0	20	14	55	11
Year 10	3	8	24	55	10
7. Anything that gives a clearer picture of a scientific idea.	4	10	26	46	14
Year 8	3	13	25	46	13
Year 9	5	14	25	43	13
Year 10	3	7	28	47	15

[1] First line of each item shows the responses from the total sample
*SD Strongly Disagree, D Disagree, DK Don't Know, A Agree & SA Strongly Agree

Table 5.3 Percentage Student Responses to the Instrument Scientific Models Part 2 in Study 2 Showing Each Year Group (n=216)

Scientific Models	Helps visualise how the real thing works	Looks the same, but different size	Description using numbers or symbol	Description using pictures or diagrams	Simulation
A. A diagram of the inside of an atom (n= 216)[1]	42	27	6	21	5
Year 8 (n=67)	39	21	13	15	12
Year 9 (n=43)	28	24	2	44	2
Year 10 (n=106)	49	32	3	15	1
B. A plastic model of the heart	51	28	7	11	3
Year 8	48	20	9	18	5
Year 9	72	16	5	7	0
Year 10	45	37	8	7	3
C. An electric circuit	26	8	20	29	17
Year 8	18	17	25	28	12
Year 9	33	5	19	24	19
Year 10	28	5	17	32	18
D. A chemical equation	8	10	57	16	9
Year 8	12	18	38	21	11
Year 9	12	8	56	18	6
Year 10	5	6	69	11	9
E. A computer image of a rat dissection	26	12	14	19	29
Year 8	22	17	20	25	16
Year 9	26	9	6	11	48
Year 10	28	10	13	18	31
F. A graph showing the energy changes in a chemical reaction	10	8	25	49	8
Year 8	13	13	27	41	6
Year 9	12	10	12	64	2
Year 10	7	5	28	48	11
G. A model car	13	58	5	12	12
Year 8	21	48	8	13	10
Year 9	12	72	2	7	7
Year 10	8	58	5	13	16
H. A ball-and-stick model of a chemical compound	21	26	18	21	14
Year 8	23	32	17	17	12
Year 9	19	23	12	19	28
Year 10	20	23	22	25	10

[1] First line of each item shows the responses from the total sample

5.2.3 My Views on Models and Modelling in Science (VOMMS) Studies 1, 2, 3 and 4

The quantitative results of the VOMMS instrument, (Table 5.4 and Table 5.5) showed that many students (>70%) concluded that a model used in science is "a representation of ideas or how things work" (item 1); that there could be "many other models to explain ideas" (item 2); that "many models may be used to explain scientific phenomena"(item 3); that "a model is based on the facts that support the theory" (item 4); that a model is accepted "when it can be used successfully to explain results" (item 5); and that "a model may change in future years" (item 6).

The results of this research are encouraging with the majority of students having a scientifically acceptable understanding of the model concept and the level of understanding improving with increasing year levels. These data are displayed in Figure 5.1 where the result for each item in the VOMMS instrument is graphically presented for each year group from Year 8 through to first year university level. The graph (Figure 5.1) indicates that students appreciation of models in science improves with age and experience with a higher percentage of university students providing more scientifically acceptable responses than the younger and less experienced students.

The discrepant results with item 5 is discussed in more detail in section 5.2.3c; however, it should be noted that from the students' written responses it can be concluded that the interpretation of the item varied – with the older students appreciating that success in the scientific world requires support by other scientists regardless of the merit of a new model. Consequently, more university students than younger students selected response a) that the acceptance of a new scientific model requires support by a large majority of scientists, rather than the more scientifically acceptable response b) that the acceptance of a new scientific model occurs when it can be used successfully to explain results. Facing a dilemma in choosing between the two alternatives, some students at the university level selected both responses seeing them as interdependent (Table 5.4).

The VOMMS instrument also identified some students' weaknesses and alternative conceptions that have been used as a basis for identifying what students need to know about models. Alternative conceptions include: a model being an exact copy; that there is only one possible model for a particular phenomenon which is unchangeable; and the value of a model is determined by scientists' opinions.

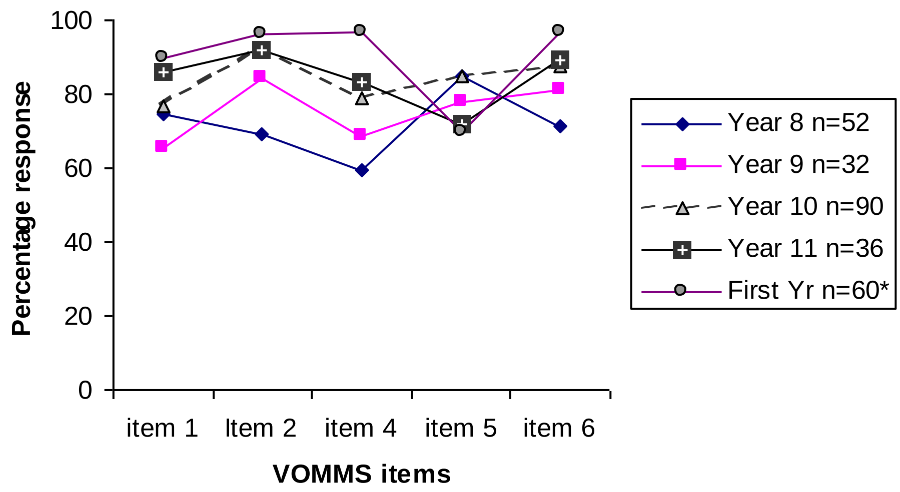
Table 5.4. Comparison of Results for VOMMS Instrument for Studies 1, 2, 3, and 4 (n=275)

Statement	Total	% Responses for Each Study			
		1	2	3	4
	n=275	n=36	n=174	n=17	n=48
1) Models and modelling in science are important in understanding science. Models are:					
a) Representations of ideas or how things work.	85	86	74	88	92
b) Accurate duplicates of reality.	11	8	26	12	8
2) Scientific ideas can be explained by:					
a) One model only, – any other model would simply be wrong.	7	3	16	0	8
b) One model, – but there could be many other models to explain the ideas.	92	92	84	100	92
3) When scientists use models and modelling in science to investigate a phenomenon, they may:					
a) Use only one model to explain scientific phenomena.	15	17	12	*NA	*NA
b) Use many models to explain scientific phenomena.	85	81	89	*NA	*NA
4) When a new model is proposed for a new scientific theory, scientists must decide whether or not to accept it. Their decision is:					
a) Based on the facts that support the model and the theory.	88	83	71	100	96
b) Influenced by their personal feelings or motives.	11	11	29	0	2
**Both a and b					2
5) The acceptance of a new scientific model:					
a) Requires support by a large majority of scientists	23	19	17	24	30
b) Occurs when it can be used successfully to explain results	70	72	83	59	66
**Both a and b	20	-	-	18	4
6) Scientific models are built up over a long period of time through the work of many scientists, in their attempts to understand scientific phenomenon. Because of this scientific models:					
a) Will not change in future years.	7	3	18	6	0
b) May change in future years.	91	89	82	94	100

Note the percentages provided do not total 100% because several students did not respond, For example, for item 1, 5.5% of students did not respond.
*NA Not Available – this item was not included in the instrument for this study.
** Students chose both a) and b) simultaneously – contradictory to the instructions.

Table 5.5 Percentage Results of the VOMMS *Instrument for Study 2, Showing Each Year Group (n= 174)*

Statement	Total n=174	Yr 10 n=90	Yr 9 n=32	Yr 8 n=52
1) Models and modelling in science are important in understanding science. Models are:				
a) Representations of ideas or how things work.	74.1	76.9	65.6	74.5
b) Accurate duplicates of reality.	25.9	23.1	34.4	25.5
2) Scientific ideas can be explained by:				
a) One model only, – any other model would simply be wrong.	16.0	7.7	15.6	30.8
b) One model, – but there could be many other models to explain the ideas.	84.0	92.3	84.4	69.2
3) When scientists use models and modelling in science to investigate a phenomenon, they may:				
a) Use only one model to explain scientific phenomena.	11.5	12.2	6.3	13.5
b) Use many models to explain scientific phenomena.	88.5	87.8	93.8	86.5
4) When a new model is proposed for a new scientific theory, scientists must decide whether or not to accept it. Their decision is:				
a) Based on the facts that support the model and the theory.	71.3	78.9	68.8	59.6
b) Influenced by their personal feelings or motives.	28.7	21.1	31.3	40.4
5) The acceptance of a new scientific model:				
a) Requires support by a large majority of scientists.	16.6	15.4	21.9	15.4
b) Occurs when it can be used successfully to explain results.	83.4	84.6	78.1	84.6
6) Scientific models are built up over a long period of time through the work of many scientists, in their attempts to understand scientific phenomenon. Because of this scientific models				
a) Will not change in future years.	18.4	12.2	18.8	28.8
b) May change in future years.	81.6	87.8	81.3	71.2



*Invalid responses- where both a) and b) where chosen have been omitted.

Figure 5.1 Percentage Responses to the Preferred Alternative for Each Item in the VOMMS Instrument for the Available Year Groups

The VOMMS instrument has been used in all four studies. There are three characteristics of scientific models identified by the VOMMS instrument, with item 1 examining the idea of *models as representations*, items 2 and 3 looking at the *multiplicity of models*, and items 4, 5 and 6 probing the *dynamic nature of models*. The written reasons students provided to justify or support their choice in Studies 1, 3 and 4 provided qualitative data about their perceptions of scientific models. The written responses further confirm that the majority of students surveyed generally do appreciate these three characteristics of scientific models.

Nearly all the university students from Studies 3 and 4 provided written responses to support their choice for all the items, whereas only approximately half the school students from Study 1 provided reasons. Therefore, the written responses from the school students represent only about 20% of all the written responses.

The reasons were scrutinised and coded into categories that were determined from the range of written responses using N-Vivo (Qualitative Solutions and Research Pty Ltd, 1999). A reason could be coded for one or more categories, for example, a written reason provided for item 1, “Generally only help to explain what’s going on. Not needed to be completely exact” (4.2.29) is coded for *learning* because the explanations promote learning and is also coded for *characteristics of* *models* – identifying that models are not accurate or precise. The frequencies of each of the main categories are presented in Tables 5.6, 5.7 and 5.8 corresponding to the main three characteristics identified by the VOMMS instrument – *models as representations, the multiplicity of models and the dynamic nature of models*. The categories developed from the written reasons provided by students for each of these three characteristics are presented and analysed in sections 5.2.3a to 5.2.3c.

5.2.3a Models as representations

For this characteristic based on the responses to item 1 of the VOMMS instrument, five categories of reasons were distinguished from the students' written responses: *scale, representation, characteristics of scientific models, theory and learning*. The frequencies of response for each category are shown in Table 5.6 and are also included in brackets in the text after the name of the category.

Students responded that the *scale* (7) of reality is too small to be seen, so models provide a representation. Students described a model as a *representation* (28) that presents ideas and is not the same as reality, often using alternative modes to reality – for example "they do not have to be the same as reality (i.e. size shape etc), like a mathematical model represents something in numbers and equations" (4.2.27). The category, *characteristics of scientific models* (42), that is shown in Table 5.6 included subcategories that are not shown. The sub-categories are: a model is not accurate (26), a model provides a way to visualise the concept/idea (10), a model can be used to test ideas (2), a model describes a idea/concept (2), a model simplifies a idea/concept (2) and a model may change (1). These three categories, *scale, representation and characteristics of scientific mode*ls describe the criteria that students use to define a scientific model and in this way their answers provide some insight into their ontological understanding of models.

The last two categories – *theory and learning* – show the way students think about the role of models in the process of science and in the learning of scientific ideas. The responses for these two categories provided evidence of students positioning the model in the construction of ideas and knowledge. This epistemological perspective reveals a greater depth in students' understanding of the role of models in science and in learning. Many students (25) commented that models were significant in explaining and understanding ideas/concepts to help with learning. Seven students referred to the role of models in the scientific process, for example, “Models do not duplicate reality they are used to represent a scientific ‘theory’, which may or may not be true” (3.2.4).

Table 5.6 Frequencies of each Category for Item 1 of the VOMMS Instrument

Item 1
Models and modelling in science are important in understanding science. Models are:
a) Representations of ideas or how things work.
b) Accurate duplicates of reality.

Category	Frequency	Study 1	Study 3	Study 4
Scale	7	3	2	2
Representation	28	5	9	14
Characteristics of models	42	9	11	22
Theory	7	3	1	3
Learning	25	6	2	17

5.2.3b The multiplicity of models

The second characteristic of the VOMMS instrument, determined from the student response to items 2 and 3, is the multiplicity of models. The reasons provided for items 2 and 3 were coded into eight categories and are presented in Table 5.7. The written responses for items 2 and 3 indicated that students regarded multiple models to be useful in explaining ideas in different ways with 11 responses such as, “different models can explain the same concept in a different way” (3.2.12) and “by having many ways of describing how things work (i.e. a model) it is easier to learn” (4.2.22). Catering for individual learning styles was identified as an important reason for using alternative models with comments such as, “different people have different interpretations, understandings and learning styles. Different models may be needed” (3.2.15). Similarly, seven students made comments about the way that an individual interprets information, for example, “different people (scientists) may interpret information differently or view things in different visual ways” (3.2.4) and “a model is usually one person’s interpretation of an idea, other people might view the idea differently” (4.2.37). The most common reason provided for item 2 was in the ability of a model to provide an alternative perspective, often through alternative modes of representation (frequency=31). In this way, the two categories of different perspectives and alternative modes of representation do overlap. Students appreciated these aspects, for example, “Models are used to aid in learning and to give a different or easier perspective on how things work" (4.2.11) and "The more models the greater probability of learning everything. Same models of the same thing may represent or display that thing differently – may be easier to understand" (4.2.18). The limitations of models were recognised by 11 students with comments such as, "one model can limit the way people understand scientific concepts" (4.2.10) and "too many exceptions; one model can't cover everything" (1.2.29). The written responses corroborate the quantitative results. Overall, multiple models were seen by students as valuable to the learning process.

Table 5.7 Frequencies of each Category for Items 2 and 3 of the VOMMS Instrument

Item 2
Scientific ideas can be explained by:
- a) One model only – any other model would simply be wrong.
- b) One model – but there could be many other models to explain the ideas.

Item 3
When scientists use models and modelling in science to investigate a phenomenon, they may:
- a) Use only one model to explain scientific phenomena.
- b) Use many models to explain scientific phenomena.

Category	Frequency	Study 1	Study 3	Study 4
Theory	1			1
Learning – explanations	11	1	3	7
Learning – different learning styles	3		1	2
Learning – different interpretation	7		4	3
Representations – different perspectives	14	5	1	8
Representation – alternative modes of representation	15	1	2	12
Characteristics of models – Inaccurate not precise	2	1	1	
Characteristics of models – simplifies	2	1		1
Characteristics of models – limitations of model	11	1	2	8

5.2.3c The dynamic nature of models

The student responses to items 4, 5 and 6 in the VOMMS instrument, which deals with the dynamic nature of models, were coded into eight main categories as displayed in Table 5.8. In response to item 4, many students (21) explained their understanding of the relationship between *fact, theory and model*. Examples of such responses include, "having an accurate model will emphasise change of future models having to adapt to new theories" (4.2.38) and "the model needs to clearly support and help explain a theory – that's what they're designed to do" (4.2.11).

Six students commented on the importance of explanations in learning, categorised as *Learning – explanations*, stating, for example, "If it can't be used to explain something - what's the point?" (3.2.15) and "A model is made for the explanation of ideas and results" (4.2.19). Similar reasons were used for the category, *Characteristics of model – it works!* with 16 responses referring to models being valuable and functional.

Table 5.8 Frequencies of each Category for Items 4, 5 and 6 of the VOMMS Instrument

Item 4
When a new model is proposed for a new scientific theory, scientists must decide whether or not to accept it. Their decision is:
a) Based on the facts that support the model and the theory.
b) Influenced by their personal feelings or motives.

Item 5
The acceptance of a new scientific model:
a) Requires support by a large majority of scientists.
b) Occurs when it can be used successfully to explain results.

Item 6
Scientific models are built up over a long period of time through the work of many scientists, in their attempts to understand scientific phenomenon. Because of this scientific models:
a) Will not change in future years.
b) May change in future years.

Category	Frequency	Study 1	Study 3	Study 4
Fact, theory and model	21	1	3	17
Learning – explanations	6		3	3
Science – based on fact	55	4	18	33
Science – new ideas	40	4	6	32
Scientists – professionalism	41	8	6	27
Characteristics of models – will change	14	3		8
Characteristics of model – it works!	16	5	5	6
Characteristics of model – majority of support	5		5	

The category, *Science - based on fact*, had a high frequency of response (55) with students confirming the importance of the factual basis of science – with comments such as, "Science is based on facts as we know them and accepted until proven otherwise" (4.2.13) and "Science is not a negotiable subject and should not be based on opinionative information but on fact" (4.2.31). The fixed and constant nature of facts is tempered with the realisation that facts can change, and many comments by students revealed that they were aware of this. The category, *Science - new ideas*, consisted of 40 comments recognising the impact of new technology, new discoveries and new knowledge on current models and is complemented by the category, *characteristics of models – will change*, where 14 students mentioned models changing.

Items 4 and 5 explore students' ideas about the professionalism of scientists. Younger students (40% of Year 8 responses) considered a scientist's personal motives to influence his or her decision-making (item 4), compared with less than

2% of the university students who were surveyed. Item 5 questions the professionalism of scientists, with 41 students' responses confirming that scientists follow the evidence and facts through the scientific process. The results for item 5 show that up to 30% of university students consider that the acceptance of a new model depends more on peer support than on its ability to explain results. This response, along with the increased number choosing both responses indicated that the university students were aware that having the "correct" answer may not always be enough for scientific success.

5.2.3d Summary of the VOMMS instrument

The VOMMS instrument has proven to be a powerful tool in forcing students to make a choice between two alternatives and also, through the written reason, provides some insight into the students' understanding. When the categories of the responses displayed in Tables 5.6, 5.7 and 5.8 are examined, it is evident that many students have an appreciation of the models as representations; they also appreciate the characteristics of models; many students consider models an important tool in the process of science; and many students are aware of the role models play in the process of learning. These ideas are pertinent to the overall research and the data are encouraging and contribute to answering Research Question 1.1 "What are students' perceptions of the role and purpose of generic models and scientific models?"

5.2.4 Students' Understanding of Models (SUMS)

The results of the SUMS instrument for Studies 2, 3 and 4 are presented in Tables 5.9, 5.10, and 5.11, respectively. Overall, the university students had more positive results than the high school students, suggesting that the older and more experienced students have a better understanding of the nature of models. Despite the obvious age and maturity differences, it should be remembered that the university students were volunteers, willing to participate in educational research in their own time whereas the data collected at the high school was on an anonymous basis during school times. The large sample of high school students involved in Study 2 (n=228) had no contact with the researcher or appreciation of the value of the research, whereas the sample sizes for Study 3 (n=18) and Study 4 (n=49) were much smaller and the students had contact with the researcher. Also, the sample of high school

Table 5.9 Descriptive Statistics and Range of Responses on the Instrument Students' Understanding of Models (SUMS)(n=228) for Study 2

			Percentages %		
Factor[<]	Item	Mean (sd)	Disagree*	Not sure	Agree **
MR/1	Many models may be used to express features of a science phenomenon by showing different perspectives to view an object.	3.6 (1.0)	12	27	61
MR/2	Many models represent different versions of the phenomenon.	3.3 (1.0)	15	41	44
MR/3	Models can show the relationship of ideas clearly.	3.7 (1.0)	11	27	62
MR/4	Many models are used to show how it depends on individual's different ideas on what things look like or how they work.	3.6 (0.9)	10	34	56
MR/5	Many models may be used to show different sides or shapes of an object.	3.6 (0.9)	11	25	64
MR/6	Many models show different parts of an object or show the objects differently.	3.4 (0.9)	14	34	52
MR/7	Many models show how different information is used.	3.5 (0.9)	11	34	55
MR/8	A model has what is needed to show or explain a scientific phenomenon.	3.5 (0.9)	13	30	57
ER/9	A model should be an exact replica.	3.1 (1.2)	36	21	43
ER/10	A model needs to be close to the real thing.	3.7 (1.1)	13	18	69
ER/11	A model needs to be close to the real thing by being very exact, so nobody can disprove it.	3.4 (1.1)	23	28	49
ER/12	Everything about a model should be able to tell what it represents.	3.6 (0.9)	14	23	63
ER/13	A model needs to be close to the real thing by being very exact in every way except for size.	3.6 (1.1)	18	20	62
ER/14	A model needs to be close to the real thing by giving the correct information and showing what the object/thing looks like.	3.8 (1.0)	9	16	75
ER/15	A model shows what the real thing does and what it looks like.	3.7 (0.9)	9	26	65
ER/16	Models show a smaller scale size of something.	3.8 (1.1)	15	15	71
ET/17	Models are used to physically or visually represent something.	3.9 (1.0)	9	17	74
ET/18	Models help create a picture in your mind of the scientific happening.	3.6 (1.1)	16	19	65
ET/19	Models are used to explain scientific phenomena.	3.4 (0.9)	12	43	45
ET/20	Models are used to show an idea.	3.8 (1.0)	12	9	79
ET/21	A model can be a diagram or a picture, a map, graph or a photo.	3.5 (1.1)	20	22	58
USM/22	Models are used to help formulate ideas and theories about scientific events.	3.4 (0.9)	14	37	49
USM/23	Models are used to show how they are used in scientific investigations.	3.5 (1.0)	15	32	53
USM/24	Models are used to make and test predictions about a scientific event.	3.4 (0.9)	14	42	44
CNM/25	A model can change if new theories or evidence prove otherwise.	3.8 (0.9)	6	23	71
CNM/26	A model can change if there are new findings.	3.8 (0.9)	7	22	71
CNM/27	A model can change if there are changes in data or belief.	3.6(0.9)	10	26	64

[<] MR – Models as multiple representations; ER – Models as exact replicas; ET – Models as explanatory tools; USM – The uses of scientific models; and CNM – The changing nature of models. *Disagree = Strongly Disagree and Disagree; **Agree = Strongly Agree and Agree

Table 5.10 Descriptive Statistics and Range of Responses on the Instrument Students' Understanding of Models (SUMS n=18) for Study 3

			Percentages %		
Factor[<]	Item	Mean (sd)	Disagree*	Not sure	Agree **
MR/2	Various models represent different versions of a phenomenon	3.8 (0.5)	0	28	72
MR/3	Models can show the relationship of ideas clearly.	4.2 (0.5)	0	6	94
MR/4	A range of models caters for different learning styles	4.1 (0.5)	0	11	89
MR/6	Numerous models are used to show different parts of an object or show the objects differently	4.1 (0.6)	0	11	89
MR/8	A model has what is needed to show or explain a scientific phenomenon.	3.3 (0.9)	22	28	50
ER/9	A model should be an exact replica.	2.4 (1.0)	67	17	16
ER/11	A model needs to be close to the real thing by being very exact, in every way except for size	3.4 (1.1)	28	11	61
ER/15	A model shows what the real thing does and what it looks like	3.1 (1.1)	35	12	53
ER/16	Models show a smaller scale size of something.	2.8 (1.1)	47	12	41
ER/10	A model is always like the real thing	2.4 (1.1)	68	17	17
ET/17	Models are used to physically or visually represent something.	4.2 (0.4)	0	0	100
ET/18	Models help create a picture in your mind of the scientific happening.	4.1 (0.3)	0	0	100
ET/19	Models are used to explain scientific phenomena.	3.8 (0.5)	0	28	72
ET/20	Models are used to show an idea.	3.9 (0.6)	0	22	78
ET/21	A model can be a diagram or a picture, a map, graph or a photo.	4.1 (0.5)	0	11	89
ET/	Models are used to represent abstract objects or ideas for which the real appearance or behaviour is not certain	3.4 (0.8)	6	44	50
USM/22	Models are used to help formulate ideas and theories about scientific events.	3.9 (0.6)	0	22	78
USM/23	Models are used to show how they are used in scientific investigations.	3.6 (0.6)	5	28	67
USM/24	Models are used to make and test predictions about a scientific event.	3.7 (0.5)	6	22	72
CNM/25	A model can change if new theories or evidence prove otherwise.	3.9 (0.5)	0	17	83
CNM/26	A model can change if there are new findings.	4.1 (0.3)	0	0	100
CNM/27	A model can change if there are changes in data or belief.	4.0 (0.5)	0	11	89

[<] MR – Models as multiple representations; ER – Models as exact replicas; ET – Models as explanatory tools; USM – The uses of scientific models; and CNM – The changing nature of models. *Disagree = Strongly Disagree and Disagree; **Agree = Strongly Agree and Agree
The item numbers refer to the original numbers used in the instrument in Study 2.

Table 5.11 Descriptive Statistics and Range of Responses on the Instrument Students' Understanding of Models (SUMS n=49) for Study 4

Factor[<]	Item	Mean (sd)	Disagree*	Not sure	Agree **
MR/2	Various models represent different versions of a phenomenon	3.6 (0.6)	2	41	57
MR/3	Models can show the relationship of ideas clearly.	4.1 (0.7)	4	8	88
MR/4	A range of models caters for different learning styles	4.1 (0.7)	0	14	86
MR/6	Numerous models are used to show different parts of an object or show the objects differently	4.1 (0.6)	0	13	87
MR/8	A model has what is needed to show or explain a scientific phenomenon.	3.3 (0.9)	22	27	51
ER/9	A model should be an exact replica.	2.2 (0.9)	76	12	12
ER/11	A model needs to be close to the real thing by being very exact, in every way except for size	3.4 (1.1)	33	8	59
ER/15	A model shows what the real thing does and what it looks like	3.4 (1.0)	25	14	61
ER/16	Models show a smaller scale size of something.	3.0 (1.3)	45	6	49
ER/10	A model is always like the real thing	2.3 (1.1)	73	8	19
ET/17	Models are used to physically or visually represent something.	4.1 (0.8)	6	2	92
ET/18	Models help create a picture in your mind of the scientific happening.	4.4 (0.5)	0	2	98
ET/19	Models are used to explain scientific phenomena.	4.0 (0.6)	2	10	88
ET/20	Models are used to show an idea.	4.1 (0.7)	6	2	92
ET/21	A model can be a diagram or a picture, a map, graph or a photo.	3.9 (0.9)	10	13	77
ET/	Models are used to represent abstract objects or ideas for which the real appearance or behaviour is not certain	3.3 (0.9)	22	27	51
USM/22	Models are used to help formulate ideas and theories about scientific events.	3.9 (0.9)	4	16	80
USM/23	Models are used to show how they are used in scientific investigations.	3.4 (0.7)	8	42	50
USM/24	Models are used to make and test predictions about a scientific event.	3.5 (0.9)	16	27	57
CNM/25	A model can change if new theories or evidence prove otherwise.	3.8 (0.9)	6	16	78
CNM/26	A model can change if there are new findings.	4.0 (0.7)	2	12	86
CNM/27	A model can change if there are changes in data or belief.	3.8 (0.8)	6	16	78

[<] MR – Models as multiple representations; ER – Models as exact replicas; ET – Models as explanatory tools; USM – The uses of scientific models; and CNM – The changing nature of models. *Disagree = Strongly Disagree and Disagree; **Agree = Strongly Agree and Agree

The item numbers refer to the original numbers used in the instrument in Study 2.

students in Study 2 included students from a wider cross section of classes including students who may love or hate science whereas with Studies 3 and 4, the university students were undertaking some type of science degree.

The SUMS instrument has five scales, as described in section 4.8.4b. The percentage results of particular items of the SUMS instrument are reported in order with Study 2 first, then Study 3, followed by Study 4.

5.2.4a Models as multiple representations (MR)

This scale indicated that generally over 80% of the university student volunteers agreed with the concept that multiple models can provide a variety of perspectives and appearances (MR items), whereas on average only between 50% and 60% of the high school students supported this concept.

5.2.4b Models as exact replicas (ER)

With this scale 76% and 67% of the university students from Studies 3 and 4, respectively, disagreed with item ER/9, "A model should be an exact replica" whereas only 36% of the high school students disagreed with this item. Similarly with item ER/10, "A model is always like the real thing", 68% and 73% of the university students in Studies 3 and 4 disagreed with this item, whereas only 13 % of the high school students disagreed and 69% agreed with the statement.

5.2.4c Models as explanatory tools (ET)

With this scale, 100% of the university students in Study 3, 92% of the university students from Study 4 and 74% of the high school students from Study 2 agreed that models are used to "physically or visually represent something" (ET/17). This trend is consistent with the other items in the scale.

5.2.4d The uses of scientific models (USM)

The results for this scale are not as overwhelmingly positive as some of the other results, most likely because this characteristic of models is not as well appreciated as the more obvious descriptive characteristics. For example, the percentage of students agreeing with the statement in item USM/24, "Models are used to make and test predictions about a scientific event" is 44% of high school students from Study 2, 72% of university students from Study 3 and 57% of university students from Study 4. There is still a difference in the response for different aged students, but here it is not as acute.

5.2.4e The changing nature of models (CNM)

The results for this scale indicate that nearly all students appreciated that models can change. Very few students disagreed with this idea; however, there were a few high school students (about 25%) who chose the alternative "not sure".

5.2.5 General versus Scientific Models

The differences in students' understanding of general and scientific models may have implications for the use of scientific and teaching models in teaching. This may be significant when students apply the more simplistic characteristics of the general model to scientific models – forgoing the potential of the scientific model.

The diverse forms that a model may take may include an idea, object, event, system or process (J. K. Gilbert & Boulter, 1998). The variety of forms that can be represented were appreciated by the majority of students with 58%, 89% and 77% agreeing that a model can be "a diagram, picture, map, graph or photo" (Tables 5.9, 5.10, 5.11 item ET/21). With respect to scientific models, the implied meaning of the term model is broad and includes many representations compatible with the variety of representations used in explaining science; however, the meaning of the term model in general everyday use is narrower and hence may lead to misunderstandings. The contextually relevant dictionary meaning of the term model is, "1. a standard or example for copying or comparison; 2. a representation, usually on a small scale; 3. an image in clay or wax." (The Macquarie Essential Dictionary, 2000, p. 508). The discrepancy between the everyday meaning – as described by the dictionary and the diverse representational forms encountered in science could explain the high school students' lack of understanding of the concepts of models and model building in science (S. W. Gilbert, 1991).

The contrasting and conflicting data obtained from the four instruments (Models, SM, VOMMS and SUMS) highlights this difference. When students knew they were answering questions about scientific models and were thinking in that vein, they displayed a clear understanding of the meaning of a scientific model: their written reasons to support their choice nearly always had scientific references. However, when students were thinking about models in general, they did not consider the scientific aspects, possibly because they were not perceived to be relevant or appropriate.

The two differing concepts of models can be considered to belong to different ontological categories within each student's mental framework. The value and importance of models in explaining scientific phenomena has been analysed in detail by Gilbert, Boulter, and Rutherford (1998b), who identified that "one of the striking aspects of science, as a mature field of inquiry, is the high status of the mathematical (or symbolic) mode of representation, as compared with that of the visual, verbal or material modes" (p. 188). The desire to improve students' understanding of the scientific model is a significant part of improving their understanding of the scientific process and enhancing their epistemology of science.

The data collected in Study 1 revealed that nearly all the Year 11 chemistry students had a good understanding of the traditional definition of a general model and were able to distinguish them from real situations. However, using their traditional concept of a model, approximately half of the students in Study 1 did not consider symbolic representations or images to be models. The differences in students' understanding of general and scientific models may have implications for their use of scientific models in learning. This may be significant when students apply the more simplistic characteristics of the general model to scientific models.

There is an expectation that the model will be an accurate representation as is common in most scale replica models; however; students frequently treated an abstract representation in the same manner assuming it to be an accurate representation when in fact it is not. Evidence for this conclusion comes from a high percentage of students agreeing that, "A model shows what the real thing does and what it looks like" (item ER/15 – 65%, 53%, 61%, Tables 5.9, 5.10 and 5.11) and that "Models help create a picture in your mind" (item ET/18 – 65%, 100%, 98%, Tables 5.9, 5.10 and 5.11). The conflict between the theoretical aspects of a model, in that it may not be precise or accurate, and the practical use of models, where students rely on the teaching models to build their mental model of phenomenon results in students assuming the teaching model to be precise and accurate. This is understandable because it extends the traditional definition and use of general models to scientific models.

Confusing the attributes of the two types of models – general and scientific could be responsible for some students' misunderstandings. The results presented in Table 5.12 highlight the dilemma facing students: those agreeing with item ER/16 are using the everyday definition of a model whereas those disagreeing are thinking of scientific and more abstract models. This dilemma becomes more apparent in the older aged students, possibly because they have a better understanding of the role of scientific models.

Table 5.12 The Percentage Results to Item ER/16 from the SUMS Instrument for Studies 2, 3 and 4

Item ER/16 Models show a smaller scale size of something

Study	Sample Size (n)	Mean (sd)	Percentages %		
			Disagree*	Not sure	Agree **
2	228	3.8 (1.06)	15	15	71
3	18	2.8 (1.1)	47	12	41
4	49	3.0 (1.3)	45	6	49

*Disagree = Strongly Disagree and Disagree; **Agree = Strongly Agree and Agree

There is no dependence on models of everyday items to build mental models because the real item is available for that purpose. However, for abstract items that are not visible, a model is relied on to build a mental model. Students rely on teaching and scientific models to build mental models even though the model may not be like the real thing. So the teaching model or scientific model needs to be accurate and precise in itself, so that students can rely on it, even if it is not accurate and precise when compared to the real thing.

Contrasting with these data, the results of the VOMMS instrument revealed the majority of students to possess informed and even sophisticated ideas about scientific models. Most students were able to identify the scientific model as a representation that could take on numerous forms and was dynamic in nature. The students' written responses support their understanding of the importance of models in the process of scientific thinking – if only in a theoretical perspective.

5.2.6 Summary and Response to Research Question 1.1

The results of the multiple data sources presented in this section answer Research Question 1.1: "What are students' perceptions of the role and purpose of generic models and scientific models?" Overall the majority of students participating in the research displayed a good understanding of the role and purpose of generic models and scientific models. The students' perceptions of general models differed to that of scientific models in respect of the degree of accuracy and the role of the two model types. Abstract models were less easily recognised by students as models than more general, everyday models. The need to be more specific in referring to model types became evident as differences in the role and purpose of the various model types including generic, scientific, teaching and mental models were discussed (Treagust, Chittleborough, & Mamiala, 2002).

The quantitative and qualitative data indicated that most students recognised the value of models in providing visual and alternative representations, as being explanatory tools, in representing scientific theories and in helping learning. While not all students appreciated the predictive nature of models, nearly all students appreciated the changing nature of models. Some misconceptions, such as some students believing a model is an exact replica of the real thing, were evident and highlight the need for the model concept to be taught overtly. For abstract concepts, for which there is no other visual or concrete anchor, students rely on models to build their personal mental model even though they know the model may not be accurate or precise. The data showed that generally, as students mature, their level of understanding of the nature and role of models improves.

5.3 Criteria That Students Use to Classify Models

In addressing Research Question 1.2: "What are the criteria that students identify as being significant when classifying scientific models?" the identification and analysis of the main characteristics of models is determined from the research data and then these characteristics are used to develop a typology of models.

Five characteristics of scientific models have been determined through the analysis of the data from the four quantitative instruments, Models, SM, VOMMS and SUMS. They are:

- Scientific models as multiple representations.
- Scientific models as exact replicas.
- Scientific models as explanatory tools.
- The use of scientific models.
- The dynamic nature of scientific models.

The five characteristics correspond to the five factors in the factor analysis of the SUMS instrument. Three of the characteristics correspond to items in the VOMMS instrument with items 2 and 3 corresponding to scientific models as multiple representations, item 1 corresponding to scientific models as exact replicas, and items 4, 5 and 6 probing the dynamic nature of scientific models. The data from the SM and Models instruments lend support to the characteristics: models as exact replicas, models as explanatory tools, and the use of scientific models.

Selected data from the four instruments that support each characteristic are analysed, presented, and discussed. The consistent and contradictory examples of the data are examined and implications from the results discussed.

5.3.1 Scientific Models as Multiple Representations

Alternative scientific models can provide a variety of perspectives and appearances and most students showed an appreciation of these (SUMS – MR scale). Consistently, more than 55% of high school students and more than 80% of university students agreed that multiple models are useful to show different perspectives and different views of an object. More than half of the students recognised that a variety of scientific models are useful in catering for individual differences (SUMS item MR/4). These results show that more than half of the respondents recognised the need for multiple scientific models to cater for particular aspects of a concept or object as well as catering for individual needs of the learner.

Items 2 and 3 from the VOMMS instrument examine the coexistence of multiple models, revealing that almost 85% of all students agreed, “many models could be used to explain scientific phenomena” (Table 5.4, item 2). Despite this very high response, there is still a significant difference between the year groups with 31% of Year 8 students agreeing that "one model only" is preferable compared to 7.7% of Year 10 students, 0% for university students in Study 3, and 8% for university students in Study 4 (Tables 5.4, 5.5).

Selected written responses are presented to items 2 and 3 of the VOMMS instrument that asked students to give a reason to support their choice of one model only or multiple models in explaining scientific ideas:

> Different people have different interpretations, understandings and learning styles. Different models may be needed. (3.2.15)
>
> Because there is often more ways to explain things, people might need different explanations. (4.2.4)
>
> Different models can explain the same concept in a different way. (3.2.12)
>
> There are different ways of showing things, i.e., different model shapes (OO, 0-0) and formula etc. (1.3.30)
>
> The make-up of isomers etc show different structures. (1.3.33)
>
> Models [are] not always accurate so there must be a variety of forms and give slightly different ideas. (1.3.22)
>
> By having many ways of describing how things work (i.e. a model) it is easier to learn. (4.2.22)
>
> More different models, more ideas, better explanation. (4.2.23)
>
> Phenomena are things we try to understand and it may take various models to make clear the phenomena and how it works. (1.3.31)
>
> If there is more than one model to explain something, it might be confusing. (4.2.17)
>
> People respond, understand differently, hence the necessity for more than one way to explain something. (4.2.40)
>
> Different people (scientists) may interpret information differently or view things in different visual ways. (3.2.4)
>
> A model is usually one person's interpretation of an idea; other people might view the idea differently. (4.2.37)

Students frequently referred to the role that models play in their learning, mentioning individual differences and the importance of explanations. However, their responses focused on the descriptive rather than the predictive nature of models. By recognising the value of multiple scientific models, we can infer that students have an understanding that a model is just one representation of an entity and that each representation displays a particular perspective or emphasis. These results contrast with those of Grosslight et al.'s (1991) where "very few of the mixed ability 7th and the honors 11th graders even hinted at the sense of multiple modelling" (p. 816). Considering the extensive use of multiple representations in science, the need to recognise multiple representations and be able to transfer from one representation to another is important.

5.3.2 Scientific Models as Exact Replicas

The SM instrument data show that 42% of high school students in Study 2 agreed that a model has something to do with being a duplicate of reality (Table 5.2 item 5), but 38% chose "Don't Know". Yet in the same instrument, 71% of students agreed that a model is a smaller version of the real thing and then only 13% selected "Don't Know". This discrepancy could be due to the description "a smaller version of the real thing" being familiar to students from their common experiences and fitting into their general definition of a model having to be a scale version of the original. More often, in biology and chemistry, a model is a larger version of the real thing rather than a smaller version. The SUMS instrument showed that 43% of high school students agreed that a model is an exact replica (Table 5.9, item 9), but only 16% and 12% of the university students agreed with this statement (Table 5.10, item 9 and Table 5.11 item 9). With the high school students, their responses consistently confirmed that models needed to be "close to the real thing" (Table 5.9, items 14, 10, 11 and 13).

These results indicate that there is a significant group of students with a naïve understanding of the concept of a model as an exact replica. This view corresponds to scale models that are usually representative of more familiar and better-understood objects, for example a model ear or a globe of the earth, for which accuracy and detail are crucial. When scientists model abstract and unknown entities, often the actual appearance is not known or is irrelevant, and the model – which may not have accuracy or detail – can provide insight into why and how something works the way it does.

In considering the need for scientific models to be accurate and closely represent the real thing, the data from the SUMS instrument show that 75% of high school students agreed that a model needs to be "close to the real thing by giving the correct information and showing what the object looks like" (Table 5.9, item 14); 62% of high school students agreed that "a model should be exact in every way except for size", and 49% of high school students and 71% of university students from Study 3 and 59% of university students from Study 4 agreed that the model must be "very exact, so nobody can disprove it" (Tables 5.9, 5.10, 5.11, items 11 and 13).

From the VOMMS instrument, there were significant differences across the year groups with 26%, 34%, and 23% of Year 8, 9 and 10 general science students, respectively, describing a model as an "accurate duplicate of reality" in preference to "a representation" (item 1). This descriptor became less popular with more experienced students, being chosen by 8% of Year 11 chemistry students, 12% of university students from Study 3 and 8% of university students from Study 4. For the SM instrument, 36%, 39%, and 47% of Year 8, Year 9 and Year 10 students, respectively, agreed or strongly agreed that a model is closely associated with a "duplicate of reality". These results compare to those reported by Grosslight et al. (1991) where even higher percentages of students (about 50%) believed that "the model should be exact, smaller or proportional" (p. 810). The difference between the age groups is similar to that reported in the first characteristic – Scientific models as multiple representations and provides further evidence that older and more experienced students have a better understanding of the nature of models.

A selection of the reasons provided by students in Studies 1, 3 and 4 to justify their choice between a model being "a representation" or "an accurate duplicate of reality" (VOMMS, item 1) are reproduced to demonstrate the range and depth of students' understanding of the representation.

> The compounds in real life are not as big as the models used in class so it's just a representation. (1.3.5)
>
> Existence of atoms are a theory, how they look is a theory, no one has actually seen [them]. (1.3.36)
>
> Models do not duplicate reality they are used to represent scientific 'theory', which may or may not be true. (3.2.4)
>
> From the models we can understand about their ideas more accurately. (3.2.16)

> Models are used to aid in learning and to give a different or easier perspective on how things work. (4.2.11)
>
> Models represent what the teacher is trying to describe which helps the learning process. (4.2.22)
>
> They can help you get a better understanding, e.g., how atoms and molecules look. (4.2.23)
>
> Model is not always accurate, but it gives ideas how things work and visualise and create image in the mind. (1.3.22)
>
> Models are only a representation of how we believe something to exist, in order to simplify it. It is not exact. (4.2.41)
>
> We use models to create a visual image that we can work with to test out ideas. (1.3.37)
>
> Because there is no point in recreating reality; models are designed for representation.(3.2.12)
>
> An idea can easily be shown with a model even if in reality the object can't be seen, eg, molecules. (3.2.13)
>
> They do not have to be the same as reality (i.e., size shape etc) – mathematical model represents something in numbers and equations. (4.2.27)
>
> To help create an image of it in your mind. (3.2.17)
>
> Need to see ideas/theories on paper (or as a model) to get a better understanding. (4.2.12)
>
> So you can visualise what is happening. (4.2.35)
>
> Models are not necessarily to scale – they just illustrate a general idea. (4.2.39)
>
> They may or may not be accurate, but give an explanation of how things work or exist. (1.3.26)
>
> They are how we want to think things behave or look like. However they aren't accurate as there are many exceptions. (1.3.34)
>
> Reality is on a much smaller scale, not accurately shown. (1.3.12)
>
> Models do not duplicate reality they are used to represent scientific 'theory' which may or may not be true. (3.2.4)
>
> No model is an exact duplication of something; it is made how it is perceived by the human investigator. (3.2.5)

These reasons show some of the students have a well-developed, even sophisticated, understanding of the role of models in the process of science and the process of learning.

In Part 2 of the SM instrument (Table 5.3), high school students had a diagram of a Bohr-like atom (item A) with 42% choosing that the model helped them "to visualise how the real thing works" and 27% choosing "it looks the same but is a different size". Similarly, with item H, the ball-and-stick model, 26% of students believed the model "looked the same but was a different size" from what it represented. These responses suggest that students may think the model is a duplicate of reality. It is not possible from the data to ascertain if the student is aware of the model's lack of accuracy and its other limitations. For the plastic model of the heart (item B), 51% of students chose the response that the model helped them "to visualise how the real thing works" and for 28% the choice was because "it looks the same but is a different size". This is an example of a model of real objects for which the descriptors fit well in line with the traditional idea of a scale model. However, this is not always the case for models of abstract concepts or entities. The results from SM showed that the more abstract the concept or entity being modelled, the greater variety of descriptors chosen by students. This variability of response could indicate a lack of awareness about the specific role of the models for the more abstract concepts.

The data from all four instruments suggest that some students continue to regard scientific models as exact duplicates of reality. Similar results have been obtained in other studies (Grosslight et al., 1991; Harrison & Treagust, 1996). This stumbling block associated with models has been recognised by Hardwicke (1995a) who emphasised the role of the teacher in "distinguishing the positive and negative analogies as clearly as possible" (p. 64) so that students realise the limitations of the model. Students seem to be faced with a dilemma of trading off the accuracy of the model (exact replica) with the concept of a model providing insight into specific aspects of the entity, even though this could mean that the model is not totally accurate. These results distinguish two types of models – the scale replica, a precise representation – which has accuracy and detail; and the imprecise representation – which does not have the accuracy or detail, and may be nothing like the object, but which can provide insight into why and how something works the way it does. Students' experiences with everyday models of everyday items are usually associated with the first type, whereas scientific models, especially of the more abstract concepts, would more commonly fall into the latter scale. Students' awareness of the type of model being used is a most important issue when considering their understanding of the role of scientific models in learning.

5.3.3 Scientific Models as Explanatory Tools

Models are often used to represent things that are too small or too big to be seen with the naked eye, so, in this way, models are the only visual representation that the learner sees. Gilbert et al. (1998b) describe scientific models as providing a form of visual explanation which helps students link the known and the unknown, familiar and the unfamiliar (Collins & Gentner, 1987). The responses to the SUMS instrument revealed that most students valued this descriptive aspect of models with the majority agreeing to statements such as, “models are used to physically or visually represent something” (Tables 5.9, 5.10, 5.11, item 17, 74%, 100%, 92%) and “a model shows what the real thing does and what it looks like” (Tables 5.9, 5.10, 5.11, item 15, 65%, 53%, 61%). Similarly, in the SM instrument (Table 5.2), 61% of high school students confirmed, “models are associated with providing a visual representation” (item 1.4); 60% agreed that “models can give a clearer picture of a scientific idea” (item 1.7) and 58% agreed that a model “can provide a visual way to show how ideas are connected” (item 1.6).

These results suggest that most students are aware of the value of the visual representation that many scientific models provide. The ability of students to take advantage of the features of a model must be taken into consideration when assessing the value of a particular model; consequently, with visual representations and three-dimensional representations, students’ spatial abilities are a significant factor in the success of using the model. In a study investigating the effects of visually stimulating computer generated representations, Barnea and Dori (1999) have shown that there is a strong correlation between spatial ability and achievement in science; such a finding is not surprising considering the dependence on scientific models in the form of diagrams, graphs, tables and three-dimensional scientific models.

There is a close relationship between models and explanations. Students use models to make a connection between the observed phenomena and the scientific explanation to generate a mental model as explained by Gilbert et al. (1998b). Many topics in science require students to generate their own mental models and students are aware that physical representations can help them to do this. Teachers routinely make use of models and representations to assist students to construct their own mental model (Duit & Glynn, 1996). This mental construction is particularly relevant and useful for abstract ideas. Students have indicated a good understanding of this role of scientific models as explanatory tools in their responses to the SUMS instrument with the majority agreeing that “models are used to show an idea” (Tables 5.9, 5.10, 5.11, item 20, 79%, 78%, 92%), and that “models help create a picture in your mind of the scientific happening” (Tables 5.9, 5.10, 5.11, item 18, 65%, 100%, 98%). It is interesting that students were able to recognise this quality of models that enables them to develop mental models for new concepts (Duit & Glynn, 1996). Many teachers assume that modelling is an instinctive behaviour, but evidence from Study 1 suggests this not to be the case. Nevertheless, Study 1 showed that by practising specific modelling skills, students could enhance their understanding of the specific models and their targets.

5.3.4 How Scientific Models are Used

Students' understanding of the predictive use of models varied. The percentage of students agreeing with the statement, “Models are used to make and test predictions about a scientific event” ranged from 44% in Study 2 to 72% in Study 3 and 57% in Study 4 (Tables 5.9, 5.10, 5.11, item 24). There is evidence that many students, especially the younger ones, did not understand how scientific models are used in the development of scientific ideas and theories. In Grosslight et al.'s (1991) study into students' understanding of the role of models in science, similar results were found with the following recommendation.

> First, it is important to provide students with experiences using models to solve intellectual problems. In this way, students would have an opportunity to learn that a model can be used as a tool of inquiry and that it is not simply a package of facts about the world that needs to be memorized. (Grosslight et al., 1991, p. 820)

The application of models outside a descriptive nature was beyond the understanding of many of these students. If the results reflect students' experiences, then this suggests that students have had experience with scale models and descriptive models but have not used models in a predictive or interpretive fashion. Stephens et al. (1999) reported that model-based reasoning is not practised in school science and consequently students have no experience with models being used in a scientific way. Similarly, Gilbert, Boulter, & Rutherford (1998a) reported on the value of mathematical and symbolic representations which allow predictive, interpretive and causative varieties compared to the more descriptive explanations of visual, verbal and physical models. Obviously, the descriptive models are valuable for teaching and are used extensively; however, there is a need to make more use of interpretive and predictive models in the teaching process.

5.3.5 The Dynamic Nature of Scientific Models

Models play an important role in the process of science. The data are discussed with respect to students' understanding of the changes to models that occur as a result of changes in scientific ideas and knowledge; the appreciation by students as they mature; and how students' understanding of models and theories underpin their understanding of the scientific process.

The SUMS data indicated that over two thirds of students showed an appreciation that models are constructs to support scientific theories and that these theories will change as a result of changes in scientific thinking. These findings are supported by strong agreement for statements in the SUMS instrument such as, "A model can change if there are new findings" (Tables 5.9, 5.10, 5.11, item 26, 71%, 100%, 86%) or "A model can change if new theories or evidence prove otherwise" (Tables 5.9, 5.10, 5.11, item 25, 71%, 83%, 78%). The consistency of these results confirms that more than two thirds of all students surveyed had a clear understanding of the changing nature of scientific models in response to changes in scientific thinking. This aspect of models introduces students to the important feature of the uncertainty of scientific knowledge and the nature of science, which has been shown to be lacking even in Grade 12 chemistry students (Boo, 1998). Students' understanding of the nature of science influences their learning in science (Songer & Linn, 1991), so it is a most important to foster this aspect of their learning.

The data from the VOMMS instrument (Table 5.4) that deals with the changing nature of models indicates that 83%, 71%, 100% and 96% of students for Studies 1 - 4 respectively agreed that a model is "accepted on the facts that support it and the theory" (item 4); 72%, 83%, 76% and 70% agreed that "a model is accepted when it can explain results" (item 5); and 89%, 82%, 94% and 100% believe that "scientific models will change in the future" (item 6). These quantitative data suggest that students have a good theoretical understanding of the changing nature of models.

The older and more experienced students demonstrated a better understanding of the roles of models and the diversity of models than the younger less experienced students. The differences between the year groups for the results of the VOMMS instrument are quite marked (Tables 5.4 and 5.5). A comparison of students' responses to items 4 and 6 is presented in Table 5.13. The percentage number of students agreeing with the statements from item 4, "that scientists are influenced by their personal feelings or motives" and from item 6, "that scientific models will not change in future years" reveal a consistent improvement as the age of the student increases to a more scientifically acceptable response. These results suggest that the students are gaining a better understanding of the role of models as they learn more about science.

When comparing data across the studies in this research, older students consistently displayed a more scientifically acceptable understanding of the role of scientific models (Tables 5.4, 5.5, 5.12). The university students in Studies 3 and 4 generally provided more detailed and meaningful reasons to support their choices in the VOMMS instrument, than the high school students in Study 1.

Table 5.13 Percentage of Students Agreeing with Item 4 and Item 6 of the VOMMS Instrument for All Four Studies

Item	Study 2			Study 1	Study 3	Study 4
	Year 8 n=52	Year 9 n=32	Year 10 n=90	Year 11 n=36	1st Yr n=17	1st Yr n=48
4. Scientists are influenced by their feelings	40	31	21	11	0	2
6. Scientific models will not change in future years	29	19	12	3	6	0

The written responses for items 4, 5 and 6 of the VOMMS instrument from students in Studies 1, 3 and 4 support the theoretical process of science – presented diagrammatically in Figure 5.2. The written responses for the category science-based on fact (Table 5.8) had a very high frequency of response (55), with students confirming the importance of the factual basis of science. The importance is indicated in the following student responses:

> Only fact not fiction can prove a theory to be correct, evidence must support "theory". (3.2.4)
>
> Science is based on what we believe is fact at the time. (3.2.9)
>
> Science is based on facts as we know them and accepted until proven otherwise. (4.2.13)
>
> Scientific theories are based on a fact that's why they're scientific, a faith in something is more fictional. (4.2.30)
>
> A model has to have scientific reasoning behind it to be given credit. (4.2.28)
>
> A model is accepted if it is correct. (4.2.37)
>
> Models have to rely on real facts. (4.2.12)

There were many responses reciting the sanctity of science and the scientific process, describing how it provides explanations of phenomena, helps people to understand how and why things occur, allows ideas to flourish, is responsive to change, and is validated and scrutineered by professional scientists. Many students reverted to the need for true facts and correct models – happy in their belief that there is always one correct and true answer, whereas the process of science is not so prescriptive. The term 'fact' was used in item 4 of the VOMMS instrument and its careless use may have led to students' misconceptions. Hunt and Millar (2000) describe data such as observations and measurements as facts, but the data are not necessarily evidence for scientific discoveries. Rukavina and Daneman (1996) confirmed that students who view scientific knowledge as consisting of facts have a naïve epistemology that can interfere with knowledge acquisition. Scientific explanations are the result of finding patterns in the data, making generalisations and formulating theories often based on models.

The evidence here does suggest that the students exhibited a range of epistemologies from naïve or static through to dynamic. Many students – especially at the university level – had a dynamic epistemology of science as described by Songer and Linn (section 3.4.2). The belief in the process of scientific thinking as rigorous and valid comes through in the students' comments. Many of the students' responses support the relationship of reality, theory and model proposed by Neressian as described by Gilbert, Pietrocola, Zylbersztajn, and Faranco (2000) with models as the starting point for the development of theories, and models taking up an intermediary position between observed reality and theory (J. K. Gilbert & Osborne, 1980). Despite this expression by many students of the exploratory role that models play in the process of science, the majority of students simultaneously, albeit at a different ontological level, regard models as descriptive rather than exploratory tools.

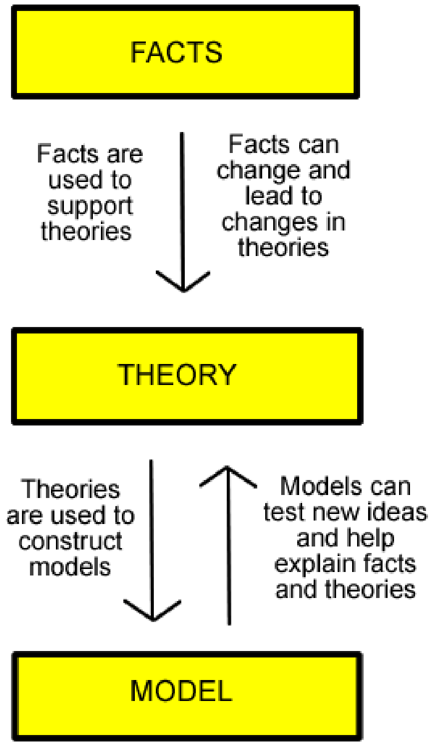


Figure 5.2 The Process of Science – Based on Student Responses to the VOMMS Instrument

5.3.6 A Typology of Models

The five characteristics pertaining to models identified by the SM, SUMS and VOMMS instruments have been used to develop a typology of models. Each characteristic contributes to the new typology: Scientific models as multiple representations – provides alternative perspectives and refers to the mode of representation (M); Models as exact replicas – refers to the accuracy of a model (A); How scientific models are used and Scientific models as explanatory tools – refer to the purpose of the model (P_u); and The dynamic nature of models – refers to the permanency of models (P_e). The typology of models, based on these characteristics, targets the common alternative conceptions that students have shown in this area and highlights the attributes of particular models. The typology is based on four means of recognition – attributes that are considered when classifying models:

- Mode of representation (M) – What is the physical nature of the representation, e.g., visual, concrete, symbolic, verbal, two or three dimensional?
- Accuracy of the model? (A) – Is the representation an exact replica or scale model of the target? Is it imprecise or impressionistic?
- Purpose (P_u) – What is the purpose of the model? Is the model a teaching model, an explanatory model, a predictive model, a mental model, a theoretical model, an analogical model, a scale model, or a simulation? More than one response may be correct.
- Permanency of the model (P_e) – Is this representation based on a theory, which is accepted as fact? Is it just an idea?

These attributes or means of recognition (mode, accuracy, purpose and permanency – abbreviated with the letters MAPP[11]) can be used to classify models and may help students to recognise the limitations of any model and to develop an ontological framework for models. The pedagogical value of this proposed scheme is closely linked to the learning process. It is mostly assumed that students generate their own personal typology based on their own ontological categorisation; however, by targeting particular attributes, students are assisted and directed in this process. The scheme provides a structure for scrutinizing those features of a representation to increase the awareness of learners. Table 5.14 provides an example of how chemical representations can be classified according to this scheme.

5.3.7 Summary and Response to Research Question 1.2

This section has addressed Research Question 1.2: "What are the criteria that students identify as being significant when classifying scientific models?" Students' opinions about models were used to identify five distinct characteristics of models that students recognised as being significant in the role, nature and use of models: Scientific models as multiple representations; Scientific models as exact replicas; Scientific models as explanatory tools; The use of scientific models; and The

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[11] MAPP is an abbreviation for the four attributes of models – mode, accuracy, purpose and permanency.

dynamic nature of scientific models. In response to Research Question 1.2, these characteristics correspond to the criteria that many students identified as being significant when classifying scientific models.

The older and more experienced students demonstrated a better understanding of the roles of models and the diversity of models than the younger less experienced students. The data revealed that generally students had a good appreciation of the descriptive nature of models but had only limited appreciation of the predictive nature of scientific models. The changing nature of models was well accepted by the majority of students, along with an understanding of the role of models in the process of science.

The value of isolating and identifying the five main characteristics was in using them to generate a new typology of models. A typology of models based on the Mode of representation (M), the Accuracy of the model (A), the Purpose of the model (P_u) and the Permanency of the model (P_e) is proposed.

Table 5.14 Comparison of the Characteristics of Chemical Models Using the MAPP *Typology of Chemical Representation*

Example	Mode	Characteristics	Accuracy	Purpose	Permanency
Ball-and-stick	Concrete	Three-dimensional Tangible Static	Not accurate	Teach Predictive Descriptive	Theory accepted as fact
Computer simulations	Visual	Two-dimension - that gives the illusion of three dimension, Dynamic	Varies	Teach Predictive Descriptive	Theory accepted as fact
Chemical equation	Mathematical	Symbolic Quantitative	Accurate quantitative data	Teach Predictive Descriptive	Theory accepted as fact
Dancing partners analogy	Verbal	Symbolic Qualitative	Not accurate	Teach Predictive	Theory accepted as fact

5.4 Modelling Ability

The ability of modelling varies amongst students and is a personal and individual characteristic. Consequently in responding to Research Question 1.3: “How does students’ modelling ability affect their use of models and their ability to understand chemical concepts?" it is necessary to look at individual students, using them as case studies, indicative of the larger population (L. Cohen et al., 2000). For each student, various available data sources are drawn on to provide evidence for examining his or her modelling ability. The scale developed by Grosslight et al. (1991) to describe students' modelling ability (section 2.4.2) is applied to the volunteer students in Studies 1, 3 and 4. Each study is discussed in turn. The basis of the classification is on the available data including observations in the laboratory, responses to quantitative instruments and interview responses.

5.*4.1 Study 1- Learning Introductory Organic Chemistry in Secondary School*

The students in this class used the ball-and-stick models and structural formulas every lesson for three weeks. The lessons always started with building models – before any writing was done. This was an unusual classroom procedure for these students who at first found it alien, because it required them to propose solutions to the teacher's challenges. The tasks were active rather than the more usual passive mode of learning. With encouragement, the students took on the challenges that the teacher gave them and went about trying to build ball-and-stick models of molecules that would conform to the teacher's parameters. In this way, the teacher was scaffolding their learning tasks and the students began to understand the value of the three-dimensional perspective. After several lessons of transferring from the ball-and-stick models to the structural formula representations, students gained confidence and could perform the tasks mentally rather than physically.

This excerpt from an introductory lesson provides some insight into the students' initial lack of confidence with the simple ball-and-stick models and their lack of understanding as to what the model represents:

S1: Look, I think we have a propane?

S3: Yes.

S1: Propane!!

S3: Ohhh!

S1: That looks pretty good. No you didn't; The carbon-carbon bonds are longer [referring to the different lengths of plastic that represent the bonds].

S3: Which ones go with carbon? (1.4.673-678)

The precision of the model became important to the students, needing to have the correct length of plastic tubing for the particular bond. In the second lesson, a pair of students was observed to make methyl-butane three times, indicating that they had not at that time appreciated the three-dimensionality of the physical model nor had they identified the differences in the isomeric structures of C_5H_{10}. However, observations in the classroom, the video of the test and the high marks obtained by students in the practical test (Appendix P), suggest that that the majority of students in the sample were successfully modelling at Level 2 at the end of the third week, and were able to “realise that there is a specific, explicit purpose that mediates the way the model is constructed” (Grosslight et al., 1991, p.815). During the practical test students worked individually building ball-and-stick models, drawing structural formulas and answering questions. A selection of photos in Figure 5.3 illustrates these activities. But the data collected are limited and a definitive modelling level cannot be provided for individual students. Despite this, it is valid to conclude that as a result of the model-based instruction all students’ modelling abilities developed throughout the teaching period. This is confirmed by the high grades obtained by nearly all students in the class on the practical test. So in responding to the first part of Research Question 1.3: “How does students’ modelling ability affect their use of models?”, the results suggest that students modelling ability does affect their use of models. However, without a reference to a control situation it is difficult to draw conclusions.

Despite excellent results in the practical test for all the students, with a narrow range from A to B, the results of the theoretical pen and paper test on introductory organic chemistry produced a wider range of grades from A through to E (Appendix P). The marks are considered cautiously in isolation without a control and the range for the theoretical test does represent a more normal distribution than the results for the practical test. The disparity between the marks for the practical test and the theory test shown in Appendix P suggest that the while some students were able to construct the ball-and-stick models of the chemical compounds and demonstrate a good ability at modelling, they did not understand the theoretical aspects of the organic chemistry. For the students who failed the theoretical test, the use of models did not help them to understand the chemical concepts. These results respond to the second part of Research Question 1.3: “How does students’ modelling ability affect their ability to understand chemical concepts?” While all students appeared to be good modellers and passed the modelling test, this did not guarantee that they understood the chemical concepts that were being taught. These results are incompatible with observations made during the lessons of students seemingly understanding the chemistry and are also incompatible with the results of Studies 3 and 4. These results highlight the importance of students' understanding of the role, representation and nature of models in relation to the particular concept being taught.

5.4.2 Study 3 – Learning Introductory Chemistry for Non-majors

The data collected in Study 3 was used to construct a profile about each of the volunteer students' modelling abilities and their understanding of chemical concepts. All the volunteer students assessed achieved at least a Level 2 by the end of the semester, and some exhibited more skill and application to warrant classification at Level 3. The changes to their modelling abilities through the semester are reported. Three students, Narelle, Alistair and Leanne, were selected to report on in detail because they have different backgrounds and provide different perspectives.

The student volunteers with stronger chemistry backgrounds began with a higher modelling level because of their chemical experience and foundation knowledge. However, the inexperienced students made rapid improvements in their modelling abilities in a short period of time. For example, Gabby and Alistair both had strong chemistry backgrounds and were already working at Level 2 in the initial interviews and maintained that level by the end of the semester, whereas Narelle and Russell both mature aged students with no chemical history were very poor modellers in the first interview but improved to Level 2 modellers by the end of the semester.

In Study 3, the students participated in weekly 3-hourly laboratory sessions that required them to complete pre-reading prior to coming to the laboratory session and write up and submit laboratory reports each week. I assessed the students modelling ability towards the end of the first semester. This assessment was based on my observations of their work in the laboratory, their written laboratory reports, the worksheets they completed for me as part of the research and their interview responses. A summary of the modelling assessment of volunteers from Study 3 is shown in Table 5.15. There is a range of abilities. Not all volunteers were assessed because of insufficient data. Whilst the method of instruction was not intentionally constructivist, the laboratory tasks required students to form links between the theoretical and practical aspects of the unit. There are examples of the students actively modelling as a result of the unit laboratory requirements and others who were not. Students were provided with only minimal guidance and needed to be self-motivated and self-disciplined in order to succeed in the unit.

Figure 5.3 Still Photos from the Video Showing Students Modelling in Study 1

Figure 5.3 cont'd – Still Photos From the Video Showing Students Modelling in Study 1

Table 5.15 Assessment of Modelling Ability and Descriptive Data for the Student Volunteers from Study 3 (n=20)

ID	Pseudonym	Age[1]	Comments and Assessment by Researcher and Supportive Quotes by Students	Gender	Experience[2]	Modelling Level
1	Kathy	1	Kathy: All of it has been difficult to learn – takes time and hard work. I found the language quite difficult. I am slowly building up a some network of knowledge. (3.9.1.75))	F	1	2-3
3	Yolanda	1	Found the experiments difficult and relied on classmates for help.	F	1	2
4	Alistair	1	Strong background.	M	2	3
5	Maureen	1	Maureen: Once I have the equation I can work back and I can see where it comes from Int.: Ok can you relate the symbolic equation to what you are actually doing? Maureen: Yes but I can't do the experiment and find the equation - it doesn't work (3.9.17.29)	F	1	2-3
6	Narelle	4	Persevered to understand the concepts; made vast improvements in the semester.	F	1	2-3
7	Gabby	3	Strong background chemistry knowledge, already confident but also open to new ideas.	F	2	3
8	Russell	4	Very diligent researching all tasks, made vast improvements in the semester. Russell: With the theory side sort of I can get a picture of what's happening but if it comes to the actual reality of it its sort of harder to put into the real world, you can picture it in the book. (3.9.8.32)	M	1	3
9	Simon	3	Good background.	M	2	3
10	Sharon	1	Solid worker, attacked problems methodically.	F	2	2-3
11	Margaret	1	Weak answers to the worksheets, difficulties with understanding and writing up experiments.	F	1	2
12	Leanne	1	Used symbolic representations appropriately in experiments.	F	1	2
13	Stuart	1	Strong background, good modelling skills.	M	2	3
14	Wally	3	Weak background, struggling to get concepts understood.	M	1	2
15	Sally	1	Insufficient detail.	F	1	-
16	Rod	3	Insufficient detail.	M	2	-
17	Michelle	1	Left after about 6 weeks.	F	1	-
18	Phil	2	Good background, worked diligently.	M	2	2-3
19	Andy	3	Quiet - results inconclusive.	M	2	-
20	Abraham	4	A late starter to the study, good chemical background.	M	2	3

*[1]Age Profiles
1- attended high school last year
2- within 2 years of leaving school
3- between 2- 5 years of leaving school
4- more than 5 years since leaving school

[2] Experience
1=no experience or up to Year 10 science
2=Year 11 chemistry onwards

5.4.2a Narelle (ID 6)

Narelle was a mature age student beginning university with no previous chemical knowledge, and was enthusiastic and keen to learn. Her responses to the initial interview provided evidence that she had never even considered the sub-microscopic level of matter and that the concept of a representation was foreign to her. When first asked about the structure of atoms she replied, “I have never thought about it” (3.8.6.2). In answering questions in the first interview, she replied, “I don’t know” six times. Narelle had learnt about the structure of the atom in the first lecture and reproduced these ideas as is shown in the Figure 5.4 when answering a question about the inside of an atom in the initial questionnaire.

In the first interview Narelle was unsure about atoms. In her response she sometimes repeated the questions to me.

Int.:	Matter includes everything around us and everything is made up of atoms. What is the difference between the atoms in ‘everything’ e.g. the table, or the air, and the atoms in an element?
Narelle:	Atoms in matter like everything around us is in compounds whereas atoms in an element are well they’re another way. (3.8.6.4)

Int.:	Can you explain how the copper atoms are arranged?
Narelle:	Don’t know, Yeah, I have thought about it. Yeah I have, I have thought how, sort of, thought how would atoms be and that. Umm Don’t Know.
Int.:	Can you tell me how the atoms are arranged in the sodium chloride? How do you picture them?
Narelle:	I picture them as sodium cations and chlorine anions. I know that there would be some sort of bond between them but I don’t know what sort of bond that would be. (3.8.6.8-18)

Narelle was proud to correctly use her new vocabulary. Even in the first few weeks she was quickly assimilating the new terminology and concepts.

When asked to classify the diagrams on Focus Card 1 (Figure 4.4a) into elements and compounds Narelle’s answers were confused. Her first choice of an element was diagram 1.6 (metal array) and when prompted that the circles represent atoms, she then chose diagrams 1.3 and 1.2. Narelle appeared to have a predisposition with the charges associated with the atom – rather than the type of atom(s) present. This could be due to the charges of atoms being emphasised in lectures.

Int.:	So which one might represent a compound?

Narelle: 7 and 8, maybe 5, I mean 3 and maybe 5. (Referring to the diagrams on Focus Card 1 (Figure 4.4) (3.8.6.40-41)

Diagrams 1.7 and 1.8 were both three-dimensional diagrams, with diagram 1.7 representing a compound and diagram 1.8 representing an element. Narelle appeared to have difficulty transferring from the two-dimensional representation to the three-dimensional as well as understanding the basic difference between elements and compounds - with Narelle choosing diagram 1.3 to be a compound – which she had already chosen as an element. Diagram 1.4 – with positive and negative signs in the centre of adjacent circles – was not selected at all.

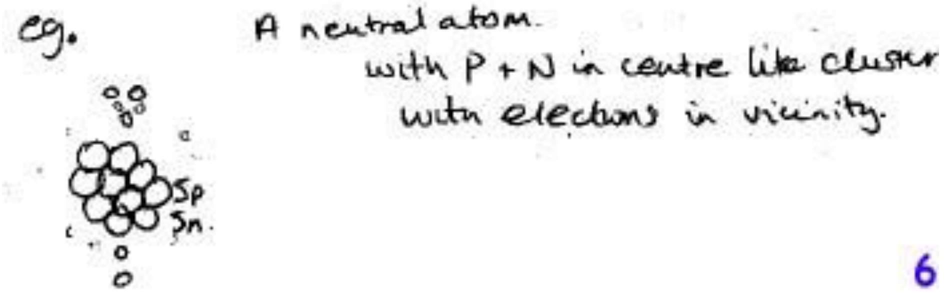


Figure 5.4 Narelle's Drawing of the Structure of an Atom.

The inconsistencies and the apparent confusion with the drawings suggests that Narelle did not have a clear understanding of these representations of elements and compounds and did not know which criteria to use to distinguish them. Her understanding of the subatomic level seemed to be interfering with her understanding at the atomic and molecular level. In addition, the three-dimensional drawings were causing more confusion than clarity for Narelle. These results are consistent with Narelle's responses to Worksheet 2 presented in Table 6.3.

In the initial questionnaire students were asked to draw a concept map Narelle's map (Figure 5.5) indicated that she did not really know what a concept map was, nor did she understand the concepts. The status of Narelle's conceptions of the sub-microscopic level was not fully intelligible, plausible or fruitful – at that stage. Narelle's starting point was rudimentary; however, she worked hard and improved. Her responses to the worksheets during the semester, and the final interview demonstrated this growth.

Narelle's responses to Worksheet 1 on ions and solutions (Table 5.16) indicated a fair understanding of nature of ions with some lack of confidence in the reality of the sub-microscopic level – reflected in her responses to items 3, 6, 9, and 15. Narelle was confident with the macroscopic and familiar qualities of solutions. Narelle's responses to Worksheet 2, question 1 (section 4.9.3c) on the mole concept recorded "Don't Know" to 6 out of 22 questions, and indicated a lack of confidence with four other questions concerning Avogadro's number. Narelle's responses to Worksheet 3 (section 4.9.3c), on symbolism were perfect, except for the meaning of the double arrow used in equilibrium where she chose the alternative C which stated that "the double arrow here means a relatively large amount of product is formed" (3.6.6.3.5).

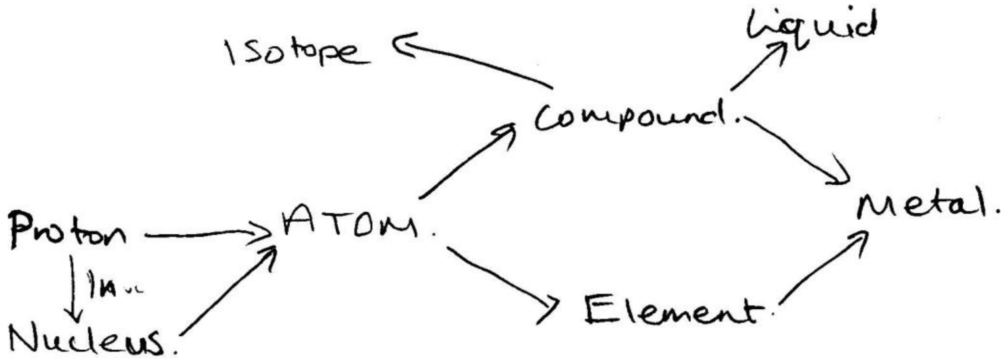


Figure 5.5 Concept Map Drawn by Narelle in the Initial Questionnaire

Lastly in Worksheet 4 (Figure 4.2) on equilibrium, Narelle described the equilibrium arrow to indicate – "the reaction does not reach completion and is reversible" (3.6.8.1a). This interpretation is incorrect and along with the response to Worksheet 3 described above reveals some misconceptions about the state of equilibrium. Despite this, Narelle demonstrated a clear understanding of the sub-microscopic, macroscopic, and symbolic levels in her answer to question 1b in Worksheet 4 by making predictions about the changes to equilibrium situations. Question 1b is presented in symbolic form with an equation and a diagram.

> *Q1b* Predict and explain what happens to the volumes of H_2, N_2 and NH_3 at the new equilibrium position c):
>
> *Narelle:* The volume of NH_3 will be increased. The volume of N_2 and the H_2 will decrease as the added concentration of N_2 drives the reaction in direction to lower the number of moles. (3.6.7.3.1b)

Table 5.16 Narelle's Responses to the Questions on Worksheet 1

[1]Narelle's response on the a five level confidence scale where 1 means not at all confident, 3 means confident and 5 means is very confident, X means Don't Know

Item	Narelle[1]	Pref[2]	Mean[3]	SD[4]	DK[5]
	Study 3 n=9				
1. The white crystals have no net charge.	4	5	3.44	1.33	0
2. Sodium nitrate consists of positively charged parts and negatively charged parts which are attracted to each other.	4	5	4.25	1.17	1
3. When the salt dissolves, it breaks down into very small microscopic particles consisting of one or a few atoms.	2	5	3.67	1.51	2
4. When the salt dissolves the ions in the salt are attracted to each other and stay bonded to each other.	1	1	1.57	1.00	1
5. When the salt dissolves the ions are mixing with the water at a microscopic level.	5	5	4.14	1.21	1
6. Particles held in suspension are not broken down into ions.	X	5	1.67	0.82	1
7. The water molecules help to drag the charged atoms away from the solid crystal thus dissolving it.	4	5	3.57	1.62	2
8. The dissolved ions cannot be seen with the eye.	5	5	4.50	1.07	1
9. The ions are mixing in the water, but they are not reacting.	1	5	2.75	1.49	1
10. When a precipitate forms a chemical reaction has occurred.	4	5	4.13	1.36	0
11. Some ions stay in solution and do not react.	4	5	3.38	1.06	0
12. An insoluble substance can be seen with your eye.	5	5	4.20	1.10	1
13. In a precipitation reaction, one ion gives electrons to another ion to form a chemical bond.	3	5	4.00	1.15	1
14. The dissolved ions cannot be seen but they can react to form an insoluble substance which can be seen.	4	5	4.14	1.22	1
15. The soluble ions can be separated by filtering.	3	1	2.17	0.98	3

[2]Preferred- the "best" answer.
[3]Mean value – mean of students' responses the same five level confidence scale
[4]Standard Deviation.
[5]Number of don't know responses.

Narelle described the effect of the changes on the macroscopic qualities of volume and concentration and refers to the sub-microscopic level by referring to the number of moles of each component.

Responding to question 2 in Worksheet 4 (Figure 4.3), Narelle made incorrect predictions about the equilibrium shift for addition and removal of the substances NO_2 and N_2O_4 and for temperature changes, but predicted correctly the effects of volume changes. Narelle's diagram to represent the equilibrium situation (Figure 5.6) demonstrates that she is more comfortable with the sub-microscopic level than she was at the beginning of the semester; however, her incorrect responses indicate that her interpretation of the sub-microscopic level is still developing. Despite these anomalies, a significant improvement had occurred in Narelle's use of chemical representations throughout the semester.

The data collected about Narelle provided examples of the difficulties some apparent simple concepts can produce for students with little or no chemical background, and the high probability of misconceptions occurring through the misinterpretation of simple representations. The results also demonstrate an inconsistency in understanding – understanding some concepts, and not others. Perhaps this should not be surprising, considering learners are still building up their ideas and their mental models.

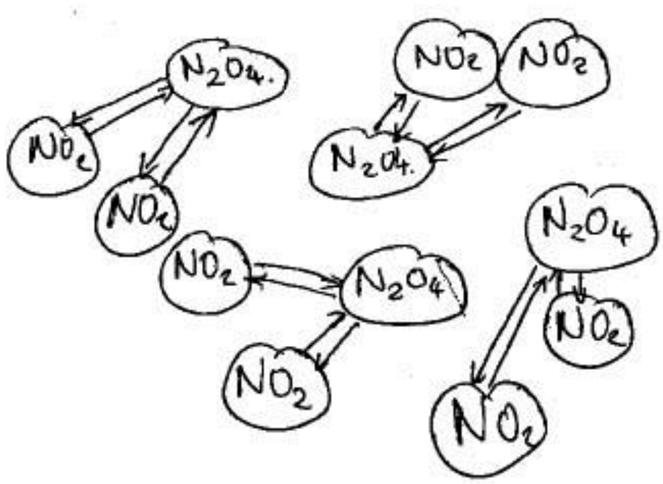


Figure 5.6 Narelle's Answer to Question 2 in Worksheet 4

At the beginning of the semester, Narelle was a Level 1 modeller. Her initial lack of understanding of the various chemical representations corresponded to a lack of understanding of the concepts. As Narelle's modelling ability improved and she became more comfortable with chemical symbols and representations, then her understanding of the chemical concepts also improved. Considering that chemistry language is dependent on symbols and representations this result is not surprising. Narelle's results confirm that a students' modelling ability does affect their use of models and their ability to understand chemical concepts. Narelle repeatedly used equations and performed calculations when completing laboratory reports and preparing for tests, and so was practising her modelling skills. Towards the end of the semester, she conceded that she was developing a mental picture of the sub-microscopic level of matter. Her responses to the equilibrium worksheet –"the model is constructed in the service of developing and testing ideas rather than as serving as a copy of reality itself"– indicated that she was working at Level 3 as described by Grosslight (1991, p. 815); however, because of some inconsistencies in her responses she was assessed as a Level 2-3 modeller.

The research data indicated that the status of Narelle's conception of the representational nature of matter improved significantly over the semester. Initially, Narelle did not have any appreciation of the value of chemical representations. However, repeatedly using the representations to understand chemical concepts, to solve problems, in laboratory write-ups and in calculations and tests, demonstrated the value of the representations in being intelligible and plausible. When Narelle was able to draw her own representations, create her own equations and use them in a fruitful way, the status of the representations in Narelle's opinion also improved. The research data provide evidence of the development of Narelle's knowledge schema of chemical representations and concepts.

5.4.2b Alistair (ID 4)

Alistair's previous chemistry experience included Year 11 and Year 12 chemistry at high school in the previous year, but he had not taken the final examination. Nevertheless, his strong chemistry background had provided him with a better understanding of the sub-microscopic nature of matter. Below is his description of how atoms are arranged in a sample of copper from the first interview.

Alistair: I picture elements the way they show them in layers - rings of 2 and a ring of 8 electrons in orbital.

Int.: And are the atoms close to each other?

Alistair: No atoms are not close to each other, [they are] spaced evenly but far way away from each other. The way I imagine it is that they are in a circular formation-spaced evenly but I've heard that it's not like that so. (3.8.4.3-6)

Similarly with compounds, Alistair had well developed concepts about the bonding of sodium chloride. Nevertheless, the interviews revealed some misconceptions, for example, here Alistair refers to the electrons being 'owned' by particular atoms.

Alistair: In the same kind of way, but in the sharing of electrons in that they will either be set up between two atoms and share the electrons and then it's personal electrons will be evenly spaced around in shell formation around the outside… to make sure. (3.8.4.11)

Alistair was the one of only three students to complete the concept-mapping question in the initial questionnaire. In this way the depth of his background knowledge is revealed (Figure 5.7). His mapping shows that he has a personal structure and hierarchy of chemical knowledge. He grouped common concepts together and tried to relate them with a true statement. There are some misconceptions evident (e.g., metals are compounds), but more importantly he had the confidence to use his own understanding to build up the concept maps.

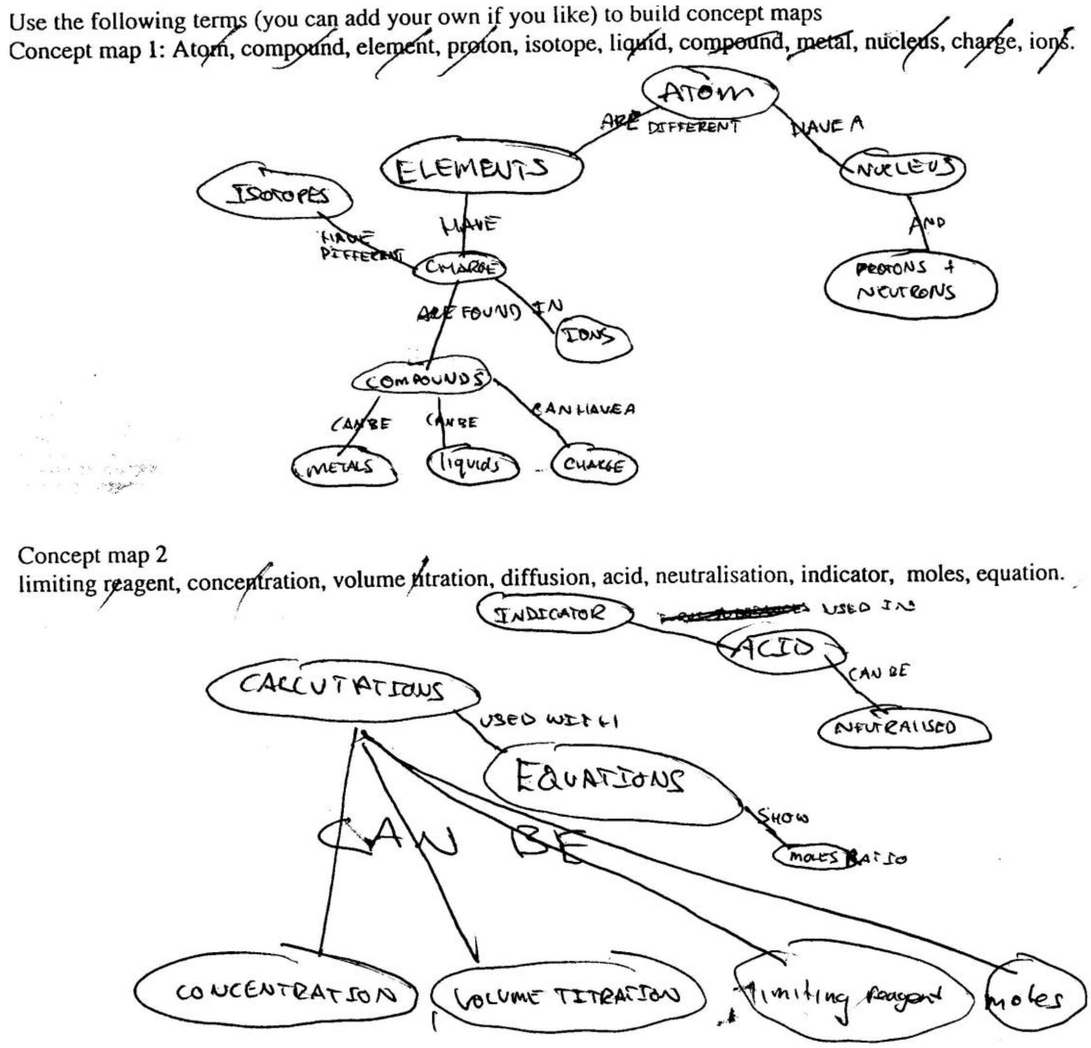


Figure 5.7 Alistair's Responses to the Concept Mapping Question in the Initial Questionnaire.

In addition, the reasons that Alistair provided to support the answers in the VOMMS instrument – shown below – were insightful, indicating that he had a competent understanding of the concepts of model, theory and fact, as well as reality and representation.

1 Models do not duplicate reality - they are used to represent a scientific 'theory', which may or may not be true.

2 Different people (scientists) may interpret information differently or view things in different visual ways.

4 Only FACT NOT FICTION can prove a theory to be correct. Evidence must support "theory".

5 They must all believe the facts and evidence put forth to back up the model. (5.2 may be true but the minority may be wrong).

6 ‘Long period of time‘ changing technology means new technological advances better model theory. (3.2.4)

Alistair was demonstrating a good correlation between understanding chemical content and chemical process.

The classification of matter into elements and compounds seems not to be associated with the students’ mental model of matter, but more with interpreting what the representation portrays. In this regard, Alistair classifies the Focus Card 1 correctly except for diagrams 1.3 and 1.4 (Figure 4.4). The dialogue of the interview indicates how important it is for every part of the representation to be understood.

Alistair Diagram 1.4 is a compound; no it has positive and negative charges like in the nucleus or something. Don’t know if they mean atoms or whether they mean ions? Don’t know what they are trying to get at there, but I’d say that because they have two differing substance – probably means a compound.

Int.: Why did you think this one was a compound (talking about diagram 1.3)?

Alistair: The lines represented a bond.

Int.: Oh OK and you said the bonds mean a compound and then you looked at it twice, and what did you realise?

Alistair: It might not be a compound - you don’t know - you only know what the lines represent.

Int.: Second time you looked at it you said it was an element – why did you say it was an element?

Alistair: Simple because it could be an element or a compound – I’m not too sure.

Int.: What do the circles represent?

Alistair: To me they represent an element. (3.8.4.22-33)

Here Alistair equated lines with bonds, and he associated bonds with compounds, forgetting that elements can also have bonds. He also equated circles with elements not atoms.

Alistair: Diagram 1.5 – a compound.

Alistair: Diagram 1.6 delocalised electrons in between positive charges, aqueous solution, or a metal.

Alistair: Diagram 1.7 a solid compound.

Int.: Why do you say compound?

Alistair: Maybe it could be NH_4 because they have got nice nitrogen and four hydrogen spaced evenly around it. That’s how I imagine it too – like figure 7 with three-dimensional and round shapes and so if there were two more they would be on the front.

Alistair: Diagram 1.8 looks like a solid but an element because all bunch of the same type and the one-size balls. (3.8.4.33-38)

Despite the fact that Alistair has a reasonably good understanding of the concept of elements and compounds, diagrams 1.3 and 1.4 did not fit his criteria and caused him anguish. This observation supports the need for the learner to appreciate the target of all the components of a representation or analogue. Alistair repeatedly categorised the diagrams according to their state as well as their chemical status – "solid compound" or "solid but an element". These comments indicated that he had a well-established network of knowledge that included both attributes, which he was using to classify the diagrams. This provides evidence of the value of an ontological network for processing information. In terms of the status of Alistair's concept of elements and compounds, there is evidence that Alistair found his knowledge schema to be intelligible and plausible and was usually – but not always – fruitful.

Alistair began this unit with well-developed ideas about the process of science and the importance of the role of models in this process as well as an understanding of the role of representations in chemistry and a wide chemical vocabulary. He was familiar with chemical entities and the relationship between them as was exhibited in the concept maps. He performed well on the worksheets as expected. He is an experienced modeller and was comfortable explaining a practical using symbols and equations. Alistair had a preferred representation when asked about the various representations for water (see Focus Card 3, Figure 4.5).

Int.:	Look at the representations of water on focus card 3. Which representation do you prefer? Why?
Alistair:	When I think of water I think of the electron dot formula HOH.
Int.:	Why do you think of that?
Alistair:	It just shows me that there is oxygen, not going to have two hydrogen electrons keep them spaced apart, and all the electrons are accounted for. (3.8.4.53-56)

Alistair preferred the electron-dot representation because to him it was logical, intelligible and plausible and fruitful. He could transfer easily between all three levels of chemical representations of matter: discussing a practical activity in terms of an equation (symbolic), in terms of a macroscopic quality and also at the sub-microscopic level discussing the movement of ions. On the basis of my observations, I assigned Alistair a Level 3 modelling ability.

Alistair's background knowledge and solid foundation gave him a huge advantage in this unit. He had the confidence and ability to visualise, describe, envisage, and make predictions using his mental model. He was confident and easily verbalised his understanding. Alistair demonstrated the importance of having a good understanding and a good mental model.

5.4.2c Leanne (ID 12)

Leanne left high school the previous year and had not studied chemistry before. She had studied science to Year 10 level where she was in the non-chemistry group. In the first interview Leanne applies macroscopic properties to the sub-microscopic nature of matter, displaying a poor modelling ability. There is obvious confusion between the representational nature and the reality of the sub-microscopic level. She was unable to understand the representational nature of the diagrams on the focus cards as is shown in the following excerpts.

Int.: If I gave you a sample of copper for example. Can you explain how the copper atoms are arranged?

Leanne: They would be all together.

Int.: What would they be like?

Leanne: No idea.

Int.: Coppers hard we know that but what about the atoms?

Leanne: Coppers hard, then doesn't mean that they are tightly packed. They would be together. (3.8.12.13-19)

Int.: What would sodium chloride atoms look like?

Leanne: It would look like little white things.

Int.: If you get down from the little white things and go down to the atoms what are the atoms going to look like?

Leanne: White.

Int.: OK. (3.8.12.24-26)

Leanne's comments demonstrate a common assumption by learners in associating the macroscopic qualities to the sub-microscopic level (Andersson, 1990). This misconception arises because the student doesn't understand the differences of the three levels of representation of matter. Initially Leanne had no idea how to classify the diagrams on Focus Card 1 (Figure 4.4a) into elements or compounds, but by asking some questions she worked out the necessary criteria. The lecture and notes informed students what elements and compounds are but they had not had the opportunity to exercise or test their understanding.

Leanne: What do the bonds (in diagram 1.3) represent?

Leanne: Are they waiting to gain electrons (referring to diagram 1.4)?

Int.: It is an atom that needs to gain.

Leanne: And what would be the one with the plus?

Int.: Needs to give one up.

Leanne: OK, So that would be one atom and that would be another atom. Different atoms. Then it must be a compound. A compound because it has different sized atoms. (3.8.12.43-51)

After Leanne had worked through Focus Card 1 she had worked out the criteria for sorting the diagrams of elements from the diagrams of compounds. Leanne's understanding improved as she was questioned about the diagrammatic representations. Although elements and compounds had been covered in lectures she had not been challenged to construct the meaning for herself. Here, categorising the diagrams forced Leanne to apply her understanding to a broader range of diagrams. By using the diagrams or models they have value. The diagrams acted as explanatory tools – extending each student's understanding of the element/compound concept. The student's modelling skill is dependent on how the representations are used.

Leanne's ability to transfer from one level of chemical representation of matter to another was rudimentary at the time of the first interview. Leanne looked at Focus Card 3 (Figure 4.5) – displaying eight different representations of water – and was very clear about distinguishing the reality from the representation, and did not relate the two at all.

Int.:	How do you visualise the beaker with the ions mixing/dissolving in with the water?
Leanne:	I honestly have no idea when it comes to things like that. Like I can't visualise the difference between having H_2O written down on paper and then looking at it. It doesn't look the same, it's nothing.
Int.:	So these things I just showed you? They don't look the same.
Kathy:	Yeah they mean something there (on the paper), but like if I got a glass of water- yeah it looks like water.
Int.:	Yeah, So the real thing is so remote from the symbolic that…
Kathy:	Yeah.
Leanne:	It's unbelievable. (3.8.12.110-120)

By the time of the second interview, Leanne had completed Chemistry 117 and had just started the second semester unit Chemistry 118. With the experience gained in the first semester she had developed a personal understanding of the role of representations in chemistry, however she was still unsure about the sub-microscopic level.

Int.:	In laboratory work, we perform experiments and use equations to do calculations. Can you relate the equation to the experiment?
Leanne:	No, I see the experiment – and I see the equation.
Int.:	Do you fill in the blanks in the calculations?
Leanne:	I do more than just fill in the blanks now but I still couldn't do the calculations without help from Barry (demonstrator); I need help to know where to start.
Int.:	Do you have a mental picture of the reaction occurring?
Leanne:	I do not really have a mental picture of the reaction in my head. I see it in the lab and then I understand the equation represents it, but I do not picture it at the

atomic level. I liked the electron dot formula and I suppose they give me a mental picture to think about. (3.8.12.43-46)

Leanne's modelling skills had improved as a result of the laboratory and theoretical work. Initially, in the first interview, Leanne was confused about the representational nature and the reality of the sub-microscopic level. The distinction between reality and representation is not always obvious in chemical contexts. As discussed in section 2.3.1, teachers often refer to representations as the real thing resulting in this confusion. This is not surprising considering that we want a model to be like the real thing and accurate but we must realise that it is not an exact copy. The disparity between these ideas can lead to misconceptions of the nature of the sub-microscopic level.

During laboratory experiments, Leanne demonstrated a competent use of chemical equations and an understanding of how they relate to the laboratory experiments, so I evaluated her as a Level 2 modeller. Leanne successfully linked the symbolic level with the macroscopic level and the symbolic level with the sub-microscopic level independently of each other. That is, Leanne had not necessarily linked the macroscopic level to the sub-microscopic level although she had mapped the symbolic representation to both (Figure 5.8). Her reticence in using the sub-microscopic level could hinder her understanding since most chemical explanations are at the sub-microscopic level. Leanne's situation supports Johnstone's (1991) warnings of the difficulties students experience in comprehending the sub-microscopic level and handling all three levels of chemical representation of matter simultaneously.

Leanne's reactions to comments provide an insight into her understanding. She demonstrated a clear understanding of the difference between the symbolic and the sub-microscopic levels but demonstrated a persistent lack of conviction as to the reality of the sub-microscopic level with comments like, "It can't be seen with the naked eye". Her logical response is justifiable when considered in her practical, naïve and somewhat simplistic terms: the sub-microscopic level is not visible, no real proof has been provided for its existence, the scale is extremely small, the idea that it is mostly empty space refutes her personal experiences of the macroscopic nature of gases, liquids and solids. Leanne understood that the symbolic chemical representations provide the visual stimulus for how best to envisage the sub-microscopic level – but to her, it was not reality.

Leanne's level of understanding is common. The idea of relating a macroscopic observation to the invisible sub-microscopic level is understandably "unbelievable" (3.8.12.120), impossible, and foreign to some students, and contrary to commonsense. Leanne's non-existent chemistry background meant that she had not been trained to think about matter in a particulate way, while most science students have been taught to think about matter in this way repeatedly every year from a young age. With common macroscopic experiences supporting a continuous nature of matter, it is not surprising that there is a conflict with the particulate nature of matter as reported in the literature (Andersson, 1990; Johnson, 1998; Renstrom et al., 1990). However, the repeated referencing to the sub-microscopic level that provided explanations of macroscopic observations, gives the sub-microscopic level credibility. The sub-microscopic level promoted and required a chemical way of thinking – a chemical epistemology.

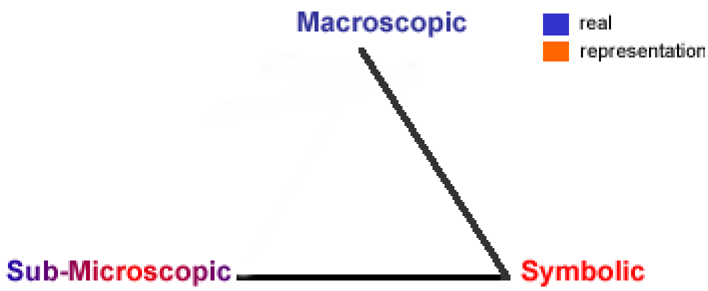


Figure 5.8 The Links that Leanne Demonstrated Between the Three Levels of Chemical Representation of Matter

Presenting the limitations of Leanne's understanding diagrammatically as in Figure 5.8 may help educators to appreciate the difficulties that students have in understanding some chemical concepts. Educators can then modify their teaching approach according to the students' levels of understanding.

5.4.3 Study 4 – Learning Introductory Chemistry and the Implementation of Online Pre-laboratory Exercises for Non-majors

The interview responses of the 19 volunteer students involved in Study 4 were considered in light of their ability to recognise and link the three levels of chemical representation of matter. This appraisal was used to evaluate their modelling abilities that are presented in Table 5.17. To support this evaluation, excerpts from two students are provided to illustrate how the students' comments were evaluated.

Betty talked about the visualisation value of models for organic compounds.

Betty:	Sort of just depends. Like, when we did it, this one had little balls, and this one, with spatial.
Int.:	Did you do that last semester?
Betty:	Yeah, I think that was last prac, last semester. That was good, to study with. Yeah, because I got like some toothpicks and some blue tack.
Int.:	You liked using the models?
Betty:	It's really good for like, doing the optical isomers and then, doing like the proteins and, (like that).
Int.:	Yes. And that's really hard to get your head around. You know the mirror images ones. You know those, the enantiomers.
Betty:	Yeah. (4.5.14.228-235)

Betty was aware of the representational nature of models and their value in helping to visualise complex structures. Caz described how she used the common ball-type model for matter during the interview. She had limited background knowledge, but was applying the model to the change of state remarkably well. Her comments in trying to explain the experiment, referring to the macroscopic level in conjunction with the symbolic representations were commendable. Caz inferred that the symbolic model was helping build her mental model for the change of state but also appreciated their limitations.

Int.:	Do you think these are accurate representations?
Caz:	Yeah, 'cause your solid ones are sort of locked into place. They can't move. The liquid gas are more free, gas just all.
Int.:	Okay. Do you think it's real? Do you think this representation here is real?
Caz:	Yeah, I certainly can, very very easy to relate. I mean, this table here is solid. You don't actually see all the particles but you know, you just know that's the way it is.
Int.:	Okay. Do you think the representation is useful?
Caz:	Um. Yeah, just to jog your memory on the way things are.
Int.:	It gives you a way to picture it.
Caz:	Yeah.
Int.:	What's good about it?
Caz:	Well it's nice and basic diagram and fairly self-explanatory.
Int.:	Anything bad about it?
Caz:	No, no. I don't think so.
Int.:	Do you think of atoms as round balls like are drawn here?
Caz:	Looking at that, yeah I would say that would be the atoms, actually solid, locked in together, atoms moving more free together.
Int.:	When we did this experiment we were using naphthalene and acetanilide. Can you describe what was happening at the molecular level?

Caz:	Um.
Int.:	It's a bit hard.
Caz:	Yeah. I couldn't tell you the differences between the two because I just can't remember, what they physically looked like differently. But it would be as you raise and lower the temperature, the state, like as we melted it they became free, they were able to move around by themselves. And as you dropped the temperature, they became more restricted until they were eventually all solid and stuck together.
Int.:	Okay. So what would it look like if you had a mixture here. So you had naphthalene molecules, say, and you had something else thrown in there as well – the acetanilide.
Caz:	As a solid you'd have your naphthalene molecules, and then, different shape or different colour, jammed into all the little gaps.
Int.:	Okay. Does this representation of solids, liquids and gases as round balls help you understand the change of state?
Caz:	Yep.
Int.:	Is there any other model that you would use to help you understand the change of state?
Caz:	Um. Probably different variances of the same thing. Different shapes locked together and then loosened.
Int.:	Has the representation of solids, liquids and gases as round balls supported what you already knew?
Caz:	Yep.
Int.:	Okay. Has it added to your understanding?
Caz:	Yeah. Especially where we related freezing point, melting point as the same thing. I sort of hadn't really thought about that, but it's just from the opposite direction. (4.5.4.192-227)

Caz successfully related the symbolic representation to her macroscopic observations. Her realisation that the melting point and freezing point were the same thing, just arrived at from different directions revealed her mental model and showed that her understanding of the concept was fruitful.

A range of abilities with the modelling was a reflection of the 19 students' sophistication of understanding. Inspecting the transcripts, some students understanding is simplistic – often due to not having any background knowledge, others have a better understanding, extending the atomic model of matter to macroscopic situations. Some students also are able to think simultaneously about the molecular nature of matter and the macroscopic nature of matter, demonstrating a mental model for the sub-microscopic level.

Table 5.17 Assessment of Modelling Ability and Descriptive Data for the Student Volunteers in Study 4 (n=19)

Pseudonym	Age[1]	Comments and Assessment by Researcher	Gender	Experi-ence[2]	Modelling level
Alice	2	Very basic interpretations – no evidence of transferring between levels thinks of representations as real; She saw models as duplicates of reality; I had to put ideas up for Alice she did not really have a conceptual understanding of the molecular nature of matter except at a descriptive level.	F	1	1-2
Betty	3	Good understanding – good background knowledge.	F	2	2/3
Doug	4	Focussed student, good understanding, analytical approach.	M	2	3
Debra	4	Distinguishes reality from representation.	F	1	2
Karla	2	Aware of the representational nature of models, uses the models to generate a mental picture.	F	2	2
Marc	1	Weak background, doesn't think in terms of sub-microscopic level, manages without it.	M	1	1-2
Rae	4	Weak background, doesn't think in terms of sub-microscopic level, manages without it- but very directed and focused.	F	1	1-2
Gina	4	Weak background, misconceptions and some confusion of symbols.	F	1	1-2
Karen	4	Weak background, deep set misconceptions.	F	1	1
Ned	3	Confident, confusion with fractionating diagram but otherwise good.	M	2	2-3
Bob	4	Good understanding of levels and scale – showed depth and application of knowledge of atomic theory.	M	2	3
Katrina	1	Weak background- doesn't think about molecular level- needs to be prompted.	F	1	1-2
Kel	1	Good background- able to use molecular level appropriately, good vocabulary, able to think about molecular level- mental model.	M	2	2-3
Sueanne	1	Reasonable understanding of representations.	F	2	2
Jenny	1	Had difficulty relating macroscopic level and sub-microscopic level.	F	2	1-2
Julie	1	Had difficulty relating macroscopic level and sub-microscopic level.	F	2	1-2
Lee	1	Had difficulty relating macroscopic level and sub-microscopic level.	F	2	1-2
Caz	3	No previous experience – keen and enthusiastic but had difficulties.	F	1	2
Mat	2	Excellent understanding; had previously completed A-level chemistry, so was misplaced in this unit.	M	2+	3

*[1]Age Profiles
1- attended high school last year
2- within 2 years of leaving school
3- between 2- 5 years of leaving school
4- more than 5 years since leaving school

[2] Experience
1 – no experience or up to Year 10 science
2 – Year 11 chemistry onwards

The results show that some of the volunteer students who had little or no chemical background did not use the sub-microscopic level of chemical representation of matter. They managed to learn the chemistry using the other levels of representation. These students did not have a mental model of the sub-microscopic nature of matter. However, students who had studied chemistry at a senior level at high school did have a mental model of the nature of matter and were able to connect the macroscopic and sub-microscopic representational levels.

5.4.4 Summary and Response to Research Questions 1.3

In responding to Research Question 1.3: "How does students' modelling ability affect their use of models and their ability to understand chemical concepts?" a variety of case studies have been used. The results have shown that students' modelling ability is not necessarily an innate skill and that students need to be taught how to model. Initially, in Study 1 the students did not appreciate why they were using various models in learning chemistry. Indeed, this appreciation requires students to recognize the target and source (J. K. Gilbert, 1997), and for the instruction to provide learning opportunities to build students' confidence with the model as well as show the potential of the model to be applied to solving problems. The model-based approach to learning used in Study 1 promoted this way of thinking. In Studies 3 and 4 dramatic improvements were observed in the modelling ability of students with little or no chemical background through practice and use of the chemical representations.

Modelling has been described in chapter 2 as making the connection between the target and the analogue (Duit, Roth, Komorek, & Wilbers, 2001; Ingham & Gilbert, 1991). With general models there can be a number of analogues (i.e., a number of models) but they link to only one real target. When considering chemical models, links are formed between an analogue and the target where the analogue is a symbolic representation (of which there may be many different types) which links with two real targets – the sub-microscopic level (target 1) and the macroscopic level (target 2). So in terms of Johnstone's triangle, the symbolic representations are analogues of the macro and sub-microscopic levels which are the targets. The duality of models in chemistry is a significant difference to general models. Teachers or textbooks do not always highlight this difference.

Initially, the symbolic representation is used to provide insight into the abstract sub-microscopic level; however, students are expected to also link the symbolic representation to the macroscopic level. So, for example, the ball-and-stick model for methane is obviously a model of the sub-microscopic nature of the molecule providing students with a visual impression of the arrangement of the atoms in the molecule at the nanoscale. But students also are expected to associate the ball-and-stick model of methane with its macroscopic qualities, i.e., it is a gas, an organic compound consisting of one carbon and four hydrogens, which is reactive and flammable. So symbolic chemical representations – or models – have links to both the sub-microscopic level and the macroscopic level of chemical representation of matter. The modelling ability is a measure of the students' ability to make both links simultaneously. Generally, students' modelling ability was observed to improve throughout the period of instruction.

The skill of modelling, which includes making the link between the symbolic, sub-microscopic and macroscopic levels of chemistry can be developed through practice and is essential for understanding chemical explanations. The modelling level is a reflection on the sophistication of the students' understanding. Inspecting the transcripts, some students understanding is simplistic – often due to not having any background knowledge – while others have a better understanding – extending the atomic model of matter to macroscopic situations and being able to think simultaneously about the molecular nature of matter and the macroscopic nature of matter demonstrating a mental model for the sub-microscopic level. A range of modelling abilities was observed in the study groups; some students modelling ability improved dramatically during the teaching period; however, there were several students who had no chemical background and persevered with learning chemistry without using the sub-microscopic level of chemical representation. They managed to learn the chemistry using the other levels of representation. These students did not have a mental model of the sub-microscopic nature of matter. Students who had done chemistry at a senior level at high school often did have a mental model of the nature of matter and were able to connect the macroscopic and sub-microscopic representational levels. The slow, incremental learning of chemistry that is introduced through high school can build up students' ideas about the sub-microscopic level gradually.

The data have emphasised the need for students to: use the models for explaining, predicting, or describing in order to be able to learn from them; build up a foundation through memorisation to improve modelling skills; understand what each component of the model represents; and distinguish different scales of representation and use them appropriately, e.g., subatomic versus molecular. Students cannot use the chemical representations unless they appreciate their modelling characteristics. Obviously, the students' modelling ability is critical to the successful use of the chemical representations and it can be fostered and developed. A student's level of modelling is not fixed or predetermined.

The first part of Research Question 1.3 asks, "How does students' modelling ability affect their use of models?" It is perhaps obvious that students with superior modelling ability make better use of models. This assertion is supported by data presented in this section such as the observations of the inability of some students to understand the role, use and target of models in the first few lessons of each study, compared to their understanding at the end of the study, when many students were able to transfer easily from one representation to another. The generic modelling skills can be applied to the scientific, chemical and teaching models.

The second part of Research Question 1.3 asks, "How students' modelling ability affects their ability to understand chemical concepts?" Again the answer appears obvious with students with superior modelling skills achieving a higher level of understanding of chemical concepts. But it must not be inferred from this answer that modelling ability is equivalent to understanding chemistry. As was seen with Study 1, some students became expert modellers but failed to comprehend the theoretical chemical concepts to the same standard. These results emphasise the importance of integrating the use of models closely with the chemical concepts being learnt. Modelling is a necessary skill for understanding chemistry. Consequently, improving skills in modelling should enhance a students' ability to understand chemistry. Evidence has been presented that indicates students' modelling ability can be developed through instruction and practice and generally, for the majority of students, as modelling skills improved so did their understanding of chemical concepts. This is not surprising since understanding chemical concepts is dependent on appreciating the models and representations of the sub-microscopic level. Students, who had a solid background of chemistry knowledge, were familiar with the modelling nature of chemical explanations and the sub-microscopic level of matter, which enhanced their ability to understand chemical concepts.

Considering the importance of modelling to students' use of models and their understanding of abstract ideas, it is surprising that the skill of modelling is not taught prior to students learning any chemical content that assumes the student has the skills of at least a Level 2 modeller – according to Grosslight's classification scheme. This issue of balancing content and process skills in learning science or, in particularly, chemistry was mentioned in section 1.3. The research has shown how models play a significant and unique role in learning chemistry. However, while models are ever-present as explanatory tools in explaining chemical concepts, the nature of the explanatory tool itself is not often taught directly. The processes or skills such as modelling and critical thinking that are needed to learn and understand chemistry are not taught directly, but rather indirectly within the content of a unit.

5.5 Learning with Models

The literature review has ascertained that models are considered to be valuable tools for learning. In responding to Research Question 1.4: "How and why do models help students learn?", initially the role of teaching and scientific models in learning, in general, is discussed followed by the more specific use of models in learning chemical concepts.

5.5.1 A Theoretical Framework of Models

Justifying the significance of scientific models necessitates looking at how and why models help the students learn. As discussed in section 3.7, a theoretical framework of models in the learning process provides an overview of how and why models are advantageous to learning (Figure 3.2). Through teaching, we are endeavouring to change, develop or modify students' thinking and understanding to a more scientifically acceptable way. The analysis here focuses on the students' understanding of the model concept only, without considering the actual scientific concepts and knowledge for which the models are being used to explain. The classification criteria (MAPP) developed from the results of the SM, SUMS and VOMMS instruments can be used to help identify the attributes of models, in all four types of models considered, and is incorporated into the original theoretical framework of models that was developed from the literature (Figure 3.2), to produce Figure 5.9.

The basic input and output classification explains how the four different model categories (J. K. Gilbert & Boulter, 1995) relate to the learning process. The theoretical framework can be summarised as follows: The internal construction of ideas from students' understanding and interpretation of teaching and scientific models results in the development of a mental model of a phenomena that is communicated through the students' expressed model. The expressed model is the personal expression of each student's understanding of the phenomena - the product of the student's knowledge construction, which can provide some indication of his or her mental model. The simplified framework is not exclusive because there are many factors influencing the learning process. Nevertheless, this analysis has focused on the role of models in learning.

It is indeed useful to consider students' assessment of the intelligibility, plausibility and fruitfulness, i.e., the status of a concept, and this framework can be interwoven into the model framework. Similarly, the ontological, epistemological, social/affective and metacognitive perspectives of students' understanding can also be interwoven into the learning framework.

When considering model types, teaching models play a pivotal role in accessing scientific models, and subsequently help students develop their own mental models of the phenomena being investigated. Teaching models as well as scientific models can serve as descriptive and predictive tools, which are a manifestation of the relevant scientific theory.

In Study 1, the students were at first reluctant to take the models seriously, often laughing and joking about them and treating them trivially; however, when they realised that the models had value and could help explain some attributes of organic compounds then the students performed the model building task more seriously. As previously mentioned, the instructor encouraged students to use the ball-and-stick models to find the answer for the challenges – rather than using pen and paper. The images in Figure 5.3 provide evidence of the students confidently using the models to work out the answers to the questions.

My observations of students physically counting along a model to identify the longest chain and comparing the physical rotation permitted around single bonds and double bonds are examples of how the model was useful in learning. While building isomers of various molecular formulas, students were able to compare and contrast the ball-and-stick model with the structural formula. Students were constantly assessing the plausibility and intelligibility of each structure as well as the concept of isomerism. Here is an excerpt from the conversation between two students trying to build isomers of $C_3H_6Cl_2$

S1: Lets see what we have got, We've got 3C, 1,2,3, and we've got 2, 3 Hydrogens, no they're chlorines.

S2: No its three chlorines, not two chlorines.

S1: No, two chlorines – these are part of it. OK?

S2: Two chlorines they are chlorine and chlorine.

S1: You did it right. ....

S2: This will be called 1,1 dichloro-…(1.4.59-84)

Learning through using the models to predict possible isomers, demonstrated the fruitfulness of the understanding of the concept. So the status of a concept was being raised through the use of models in a constructive and predictive fashion.

In Study 4, interviews revealed how students made use of multiple representations to aid their understanding. So, for example, with the equilibrium experiment, the recollection of the experiment, the diagrammatic representation of the experiment and the diagrammatic representation of the sub-microscopic level contributed towards the students' mental models.

The focus of the framework is indeed the learning process and the development of the learners' mental models. Learning can be described as the construction of mental models. Each individual has to evaluate and integrate new information into his or her existing metacognitive framework. There is extant literature on this process highlighting the difficulties and accounting for the alternative conceptions that arise. The mental model and the scientific model or teaching model can contradict each other when they are grounded in different general frameworks (Duit & Glynn, 1996). Tiberghein (1994) investigated how students are modellers themselves by constructing their own mental models to validate their own knowledge structure. Similarly, Bodner and Domin (2000) investigated the use of representations in problem solving in which knowledge schema are activated and the success of the problem solving was dependent on the student constructing a representation to establish a context for understanding the problem on which other representations could be built. This process demonstrates the relationships between the knowledge framework and representations and the accommodation and assimilation of new information. Meaningful learning via an internal construction process, not via a direct transmission process, requires learning by doing, and by construction and criticism rather than by listening and is reflected in an integrated knowledge schema, as described by Skemp (1979). The framework of learning presented in Figure 3.1 is useful in comparing the students' modelling ability, knowledge schema and types of understanding and is compatible with the models framework presented in Figure 5.9.

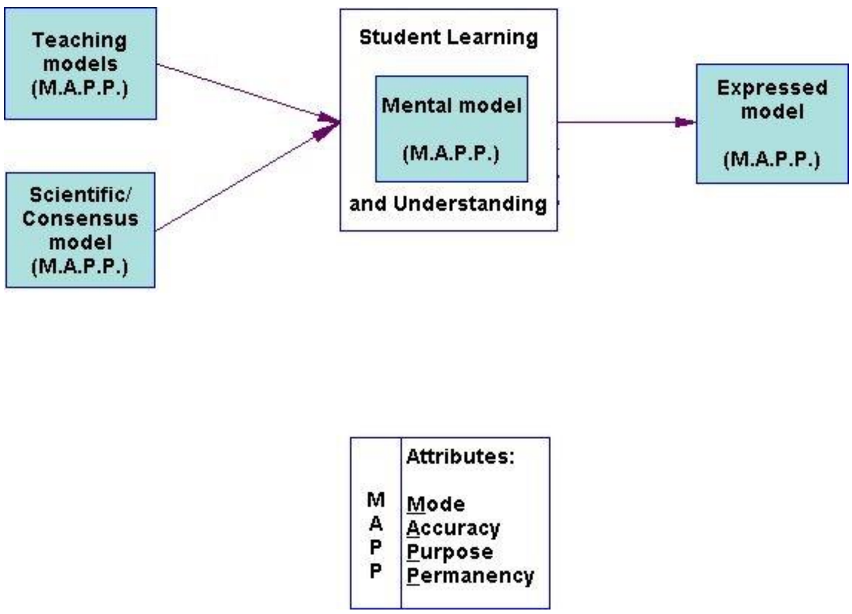


Figure 5.9 A Theoretical Framework Relating the Four Types of Models: Teaching, Scientific, Mental and Expressed, Showing Their Relationship to Learning

The framework of students' modelling ability, knowledge schema and types of understanding (Figure 3.1) is helpful in understanding how the learner makes use of the teaching and scientific models that are displayed in Figure 5.9. So, for example, a learner with Level 1 modelling ability will not be able to link the various levels of chemical representation of matter and his or her level of understanding will be instrumental – knowing how to do something but not knowing why (Skemp, 1976). This behaviour is consistent with a rote learning approach. By comparison, a learner with Level 3 modelling ability will be able to link the various levels of chemical representation of matter and use the model to test ideas or make predictions. His or her level of understanding will be relational – “knowing what to do and why” (Skemp, 1976, p. 20), and the learning behaviour would be consistent with a formal type of learning.

Promoting students development, from a Level 1 to a Level 3 modeller is a key-learning objective that could encourage students’ development from a rote-learner to a formal learner, and from having an instrumental level of understanding to a relational level of understanding. Questions that inform the underlying theoretical frameworks and which can achieve this objective include the following:

- What are the attributes of the model in terms of MAPP?
- Is the model logical?
- Does the model explain the concept that you are trying to learn?
- Is the model useful? – Do I understand the concept better because of the model?
- Are there other models that could be useful?

Inherent in students’ answers to these questions is an assessment of the model as an explanatory tool – separate from the content or concept that is being learnt. The difficulty of separating the model from the concept that is being modelled was identified in section 2.3 concerning representations, with students regarding the representation as part of the concept that is being taught – not as an explanatory tool to help understand the concept itself.

5.5.2 Chemical Epistemology

Johnstone (1991) identified that the sub-microscopic level was the most poorly understood of the three levels of chemical representation of matter and identified that it takes time for students to appreciate the sub-microscopic level. This observation concurs with the indoctrination of students into thinking in a chemical way. The data indicates that students' previous chemical experience is significant in their ability to relate the two levels.

Study 3 highlighted the value of students' previous chemical knowledge. Students like Alistair, who had a strong background in chemistry, demonstrated a good network of chemical knowledge and a personal mental model for the sub-microscopic level, while students like Leanne and Narelle, who had no chemical background knowledge, struggled to understand some chemical concepts. Considering this, it is proposed that the repeated referencing to the sub-microscopic level by way of explanations over years of learning helps students to accept the duality of the nature of matter, that is, the macroscopic and sub-microscopic levels. This emphasis promotes a way of thinking and a way of knowing about matter. This epistemological perspective is significant when teaching and learning are considered. Hence, it is reasonable to suggest that understanding chemical explanations is dependent on students having a clear understanding of the sub-microscopic level and that scientific explanations rely on the way of thinking and knowing about the concept. So, when the student uses the sub-microscopic level to provide explanations the level has value.

In this way, there is a way of knowing required to understand and relate to chemical explanations. This could be referred to as the students' chemical epistemology, that is, the knowledge of how chemical ideas are built and the chemical process is a way of knowing. The students' personal construction of knowledge using the symbolic and sub-microscopic levels seems to be significant to the students' chemical epistemology. And obviously teaching models such as the ball-and-stick models, diagrams, and equations all contribute to the developing the students' chemical epistemology.

Considering the importance of students' understanding of the sub-microscopic level, a teaching curriculum should consider the students' level of appreciation of this level of chemical representation of matter. The constructivist learning theory is equally applicable to more theoretical chemical concepts. With experience, a learner moves from thinking of the sub-microscopic level in terms of his or her favourite representation to having a personal mental model that incorporates information from many representations. Providing opportunities to encourage this to occur and looking for evidence of this shift is significant in the students' personal construction of knowledge. This building of knowledge requires the learner to identify and select the pertinent attributes of the physical representations, to make interpretations of their importance and to relate these ideas to the information from other physical representations. Without the physical representations, it is more difficult for learners to develop their own mental representation. The use of physical models should influence this process of learning, which is diagrammatically presented in Figure 3.1.

5.5.3 Summary and Response to Research Question 1.4

In endeavouring to understand how and why models help students learn, a theoretical framework was developed showing how the learner uses teaching and scientific models. The theoretical framework is used to help explain how the internal construction of ideas from students' understanding and interpretation of teaching and scientific models results in the development of a mental model of a phenomena that is communicated through the students' expressed model.

The reason why models are so important in learning chemistry is because chemistry is unique, in that it is based on the sub-microscopic level of matter – caught between reality and theory. This level cannot easily be seen directly, and while its principles and components are currently accepted as true and real, it is based on the atomic theory of matter. A chemical epistemology requires some understanding of the sub-microscopic level of matter and an understanding of how chemical ideas are built.

5.6 Conclusion

The results have shown that many students in this research have a good understanding of the role of scientific models in learning science. Students' interpretation of the term scientific model depends on their experiences and personal understanding.

Models as multiple representations were recognised as being necessary and useful by the majority of students, and they appreciated the visual value of scientific models in helping to generate their own mental models. Students showed a good appreciation of the dynamic nature of scientific models, which is linked to the changing nature of scientific knowledge. However, with the notion of scientific models as exact replicas there were inconsistencies in the percentage of students' responses, where some students clung to the understanding that a model is an exact replica supporting the scale model definition. The categorisation of a model as a precise representation or an imprecise representation helps to explain some of the conflicting ideas that students have about scientific models. When dealing with more abstract concepts, it is assumed that students would adopt a more abstract nature of scientific models but this is not necessarily true. While this research has specifically focused on scientific models, students' experience with general models is the starting point in their understanding of scientific models. General models more commonly fit into the category of scale replica, whereas scientific models assume many forms and are used more analytically (Hardwicke, 1995a). By highlighting these subtle differences between different types of models, they may be used more effectively in teaching and learning science.

The results showed that the majority of students involved in this research understood that scientific knowledge could change, with new ideas and theories resulting in changes to the accepted scientific models. It is fair to conclude that a large majority of the students understood the descriptive role of models, but there is scope to expand the applicable role of models in scientific ways such as making predictions and testing ideas. The evaluation and use of scientific models in this way could improve students' understanding of the use of scientific models in the development of scientific ideas as well as developing a better understanding of the particular content area.

The data consistently show a general increase in the sophistication of students' perceptions of models in higher year levels. With maturity, more experience and greater exposure to higher-level thinking and approaches, this result is as expected.

The data have been used to identify four attributes in models that are relevant to a model typology: mode, accuracy, purpose, and permanency. These attributes may be of value in a pedagogical context. The theoretical framework for models and learning provides a means of understanding how models are involved in the learning process. Since all learning leads to mental models, it is valuable to understand the relationship between model categories and learning. This improved understanding has the potential to improve learners' epistemological perspective.

The case studies of students' modelling ability provided evidence of the value of a hands-on approach to models and in turn to learning. It is assumed that modelling is easily understood; however, it has been shown in this research that practice and active use does improve students' modelling ability. Explanations in chemistry rely on the sub-microscopic level of chemical representation but grasping the workings of this level is often difficult. The use of models has been shown to assist in explaining this sub-microscopic level.

Under a constructivist philosophy, learning in science requires students to take ownership of an idea or concept, reconstruct it, internalise it and be able to explain or communicate it to others. Models serve as invaluable tools in this process. The theoretical frameworks (Figures 3.1 and 5.9) that show how and why models are useful in learning highlight the importance of students' understanding of the explanatory role of models and representations. The links between models and learning are indisputable; however, there is evidence in these results that many students do not fully appreciate scientific models. The reason for this could be lack of opportunity to use models effectively and applicably, or teachers may fail to emphasise the strengths and limitations of particular models and thereby misunderstandings may arise in students' perceptions. The vast extent to which models are used in the scientific field provides inspiration to further the use of models in the science classroom to enhance learning in a scientific manner.

CHAPTER 6

THE THREE LEVELS OF CHEMICAL REPRESENTATION OF MATTER

Chapter Outline

This chapter addresses the second objective of the research, concerning students' perceptions of chemical representations. Section one outlines the four research questions that address the second objective. The second section examines students' understanding of four teaching models for chemical compounds – namely, structural formula, ball-and-stick models, computer models and spatial models as determined with a pen and paper instrument – and compares these results with students' actual use of models in the classroom. The third section examines the developments of students' perceptions of the three levels of chemical representations of matter throughout a semester of instruction. The fourth, fifth and sixth sections provide a variety of examples of the transference from one level of chemical representation of matter to another. Section seven explores the way in which the three levels of chemical representation of matter are used in chemical explanations and learning. Lastly, section eight concludes the chapter and summarises the main points.

6.1 Objective 2

This chapter presents data to address the second objective of this research:

> *To investigate students' perceptions of chemical representations of matter at the macroscopic, sub-microscopic, and symbolic levels.*

This objective is achieved by examining students' understanding of each of the three levels of chemical representation of matter – macroscopic, sub-microscopic and symbolic – investigating students' use of the three levels in learning chemistry and how students transfer from one level to another. The sections in which each of the four research question are addressed is shown:

2.1 What are students' perceptions of the role and purpose of chemical representations, including chemical models, chemical equations, diagrams, and pictures in learning chemistry? (Section 6.2)

2.2 What are students' understandings of each level of chemical representation in relation to the chemical phenomena they experience? (Section 6.3)

2.3 How does this understanding enable students to effectively transfer from one representational level to another? (Sections 6.4, 6.5 and 6.6)

2.4 How do the variety of representational forms, which students encounter in chemistry, impact on the epistemology, ontology and social factors that have been shown to contribute to conceptual change? (Section 6.7)

Data are drawn from Studies 1, 3 and 4 to achieve objective 2 of the research. A variety of chemical representations are included in this research, with experimental experiences at the macroscopic level and representations such as chemical models, chemical equations, diagrams and pictures at the symbolic level.

6.2 Four Teaching Models of Chemical Compounds

Research Question 2.1 asks, "What are students' understandings of the role and purpose of chemical representations of matter, including chemical models, chemical equations, diagrams, and pictures in learning chemistry?" These symbolic representations of the sub-microscopic level of matter are significant tools in teaching and learning chemistry and so it is important to investigate students' understanding of these tools. While specifically data from Study 1 and 3 are presented to respond to this research question, it should be noted that data from all four studies address this question as the studies involve students encountering a variety of representations.

6.2.1 Molecular Chemical Representations

The Molecular Chemical Representations (MCR) instrument (Appendix D) that was used to survey students about four teaching models of chemical compounds was administered to student volunteers from Studies 1 and 3. The Year 11 students from Study 1 had completed a 3-week model-based instruction unit including experiences with all four chemical teaching models prior to completing the instrument, whereas the first year university volunteers from Study 3 completed the instrument during the first few weeks of their unit, having had no particular instruction. When the results are provided, those from Study 1 are presented first followed by Study 3.

The chemical teaching models under consideration – structural formula, ball-and-stick, computer model and spatial models – are all symbolic representations of the sub-microscopic level of matter. Students' understanding of these chemical teaching models provides some insight into their understanding of the chemical representations and the three levels of chemical representation of matter.

Overall, the analysis of the data from the MCR instrument indicated that the majority of students in both Studies 1 and 3 understood the purpose of each of the chemical teaching models (Tables 6.1 and 6.2) and were able to distinguish the particular features of the four different types of chemical teaching models. Students were generally positive and agreed about the purposes of the ball-and-stick, computer and structural formula models but less confident with the spatial models. This understanding refers to an accurate depiction of the attributes of the model being surveyed, including its limitations and strengths.

For comparison purposes, the items common to both studies (Tables 6.1 and 6.2, items 2–9) are presented graphically in Figure 6.1. The graphs show that for most items, there is little difference between the two study groups. As expected, a high percentage of students strongly agreed or agreed that the structural formula representations "showed the existence of chemical bonds" (Tables 6.1 and 6.2, item 3, 83%, 94%), and similarly more than two thirds of students claimed that the structural formula "helped generate a picture in their mind" (Tables 6.1 and 6.2, item 6, 70% 83%). Responses greater than 80% for the combined agree and strongly agree categories were obtained for the ball-and-stick model's ability to: "show its shape and structure" (Tables 6.1 and 6.2, item 3, 91%, 100%); "show the existence of chemical bonds" (Tables 6.1 and 6.2, item 4, 95%, 87%); and "generate a picture in their mind" (Tables 6.1 and 6.2, item 6, 95%, 100%). The students appreciated the computer-modelling program: 94%, 88% (item 3) confirmed that the computer model "showed the shape and structure of the molecule"; 94%, 82% (item 4)

Table 6.1 Results of the Instrument Molecular Chemical Representations (MCR) for Study 1 (n=36)

The Purpose of the model is to:	Structural Formula					Ball-and-Stick model					Computer model					Space-filling model				
	SD*	D	DK	A	SA	SD	D	DK	A	SA	SD	D	DK	A	SA	SD	D	DK	A	SA
1. Show what the molecule looks like.	11	19	6	45	19	5	3	3	47	42	3	3	5	67	22	5	14	14	42	25
2. Show how the molecule behaves	22	31	5	31	11	0	19	11	39	31	8	3	3	53	33	6	50	25	11	8
3. Show the shape and structure of the molecule.	6	19	3	50	22	3	0	6	44	47	3	3	0	61	33	3	19	14	39	25
4. Show the existence of chemical bonds.	3	3	11	47	36	0	5	0	42	53	0	0	6	61	33	8	47	14	20	11
5. Help understand the idea of chemical bonds	8	8	17	36	31	6	0	19	44	31	3	11	5	53	28	11	31	11	22	25
6. Help generate a picture in your mind.	5	11	14	39	31	5	0	0	42	53	0	0	8	50	42	6	11	11	39	33
7. Touch and manipulate something, which is like the real thing.	36	31	14	14	5	3	8	8	28	53	33	33	11	17	6	8	17	17	41	17
8. Show accurate detail of the molecule.	14	39	11	31	5	3	20	33	33	11	3	8	25	47	17	8	31	19	31	11
9. Make and test predictions.	14	22	28	33	3	0	33	19	42	6	6	19	19	39	17	8	39	31	17	5
10. Solve intellectual problems.	8	28	36	25	3	11	19	39	25	6	11	17	34	19	19	17	22	36	19	6
11. Test ideas.	8	11	50	28	3	6	22	25	36	11	8	14	22	34	22	14	19	36	25	6

*SD Strongly Disagree, D Disagree, DK Don’t Know, A Agree & SA Strongly Agree

Table 6.2 Results of the Instrument Molecular Chemical Representations (MCR) for Study 3 (n=18)

The Purpose of the model is to:	Structural Formula					Ball-and-Stick model					Computer model					Space-filling model				
	SD-*	D	DK	A	SA	SD	D	DK	A	SA	SD	D	DK	A	SA	SD	D	DK	A	SA
2[1]. Show how the molecule behaves	6	17	11	67	0	6	12	17	59	6	0	12	12	65	11	6	29	30	35	0
3. Show the shape and structure of the molecule.	0	39	6	44	11	0	0	0	59	41	0	6	6	76	12	6	6	17	53	18
4. Show the existence of chemical bonds.	0	0	6	72	22	0	6	6	65	23	0	0	18	76	6	6	35	18	41	0
5. Help understand the idea of chemical bonds	0	6	17	79	0	0	6	12	70	12	0	6	12	71	12	6	41	12	41	0
6. Help generate a picture in your mind.	6	11	0	72	11	0	0	0	77	23	0	6	6	82	6	0	6	6	82	6
7. Touch and manipulate something, which is like the real thing.	17	33	33	17	0	6	12	12	59	11	12	41	23	18	6	6	29	6	59	0
8. Show accurate detail of the molecule.	6	33	17	44	0	0	18	23	47	12	0	6	23	71	0	6	29	30	35	0
9. Make and test predictions.	6	0	33	61	0	6	18	18	52	6	0	6	29	65	0	6	18	41	35	0

*SD Strongly Disagree, D Disagree, DK Don't Know, A Agree & SA Strongly Agree

[1] The items are numbered as in the original instrument used in Study 1; Items 1, 10 and 11 from the original instrument has been omitted in this abridged version

confirmed that the computer model "showed the existence of chemical bonds"; and 92%, 88% (Tables 6.1 and 6.2, item 6) agreed that the computer model "helped to generate a picture in your mind". Despite this appreciation, more than half of the students were aware of the computer modelling limitations in that they "couldn't touch and manipulate it" (Tables 6.1 and 6.2, 66%, 53%, item 7). The results for the space-filling model were less conclusive. Students appreciated the value of the space-filling models in "generating a picture of the molecule in their mind" (Tables 6.1 and 6.2, item 6, 72%, 88%); but there were mixed results for many of the other statements and large "Don't Know" frequencies.

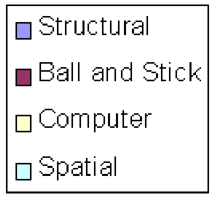
Item 8 of the MCR instrument asked for students' opinions on the statement: "The purpose of the model is to show accurate detail of the molecule". The responses indicated that students were unsure about the need for accuracy for all four types of models, with a large "Don't Know" choice (up to 33% in Study 1 and up to 30% in Study 3). The students involved in Study 1 had used the ball-and-stick models to show particular bond angles and positioning; the computer model was used to provide a visual representation of movement and the spatial model was used to provide a scale representation of the region of space that a molecule occupies; on the other hand, the structural formula was a two-dimensional representation that they did not attempt to align closely with reality. The results here highlight the difficulty of the attribute of accuracy when modelling an abstract concept as discussed in section 5.3.2

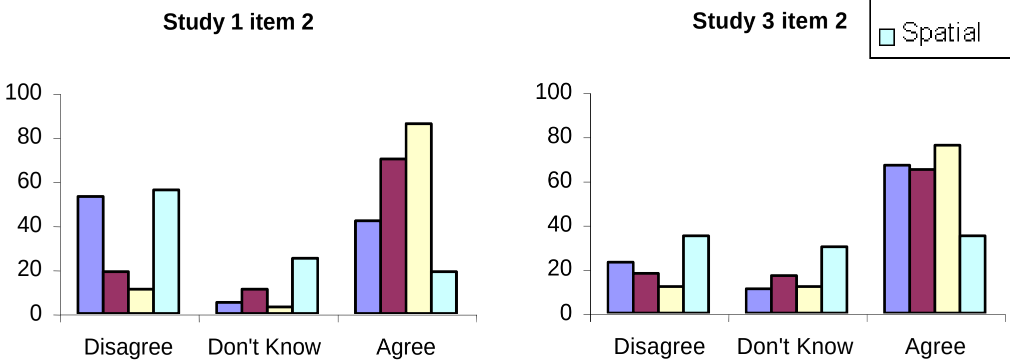
Despite their experiences, the students from Study 1 provided responses to item 8 of the MCR instrument that did not reflect any better understanding of the models than the students from Study 3 who had had no particular modelling experience (Figure 6.1). The maturity of the students in Study 3 may have influenced the results, however, the modelling activities experienced by the students in Study 1 does not appear to have improved their understanding of the significance of the role of models. So from these results it appears that students' modelling experience and abilities are not always related to their understanding of the role of models. The students' understanding of the role of models in the process of science is an indication of the level of sophistication of the students' epistemology of the process of science. While it would normally be assumed that the two go hand-in-hand the results of Study 1 show that this is not always the case.

Figure 6.1 shows the results for item 9 of the MCR instrument, where the number of students identifying the testing and predictive attributes of a chemical teaching model is less than expected. The number of students from Study 1 and Study 3 agreeing with item 9, "the purpose of the model is to make and test predictions" varied from 36% and 61% for the structural formula model, 48% and 58% for the ball-and stick model, 56% and 65% for the computer model and 22% and 35% for the space-filling model respectively. It is surprising that the response from the university students in Study 3 was more positive about the testing and predictive qualities of models than the students from Study 1 who had experienced the testing and predicting themselves as part of their lessons. Consistent with these results is the large "Don't Know" response indicating that from 19–41% of students did not understand the theoretical nature of the question. These results suggest that up to half the students did not have a clear concept of teaching models as tools for testing ideas, solving problems or making predictions. In chapter 5, the SUMS instrument investigated this characteristic of scientific models (sections 5.2.4c and 5.3.4) and similar results were obtained. For example, for item USM/24 of the SUMS instrument, some students agreed that "models are used to make and test predictions about a scientific event" (44% – Study 2, 72% – Study 3, and 57% – Study 4), while for item ET/17 more students agreed that "Models are used to physically or visually represent something" (74% – Study 2, 100% – Study 3, and 92% – Study 4). As with the results of the MCR instrument, more students recognised the descriptive nature of scientific models than the predictive nature of scientific models.

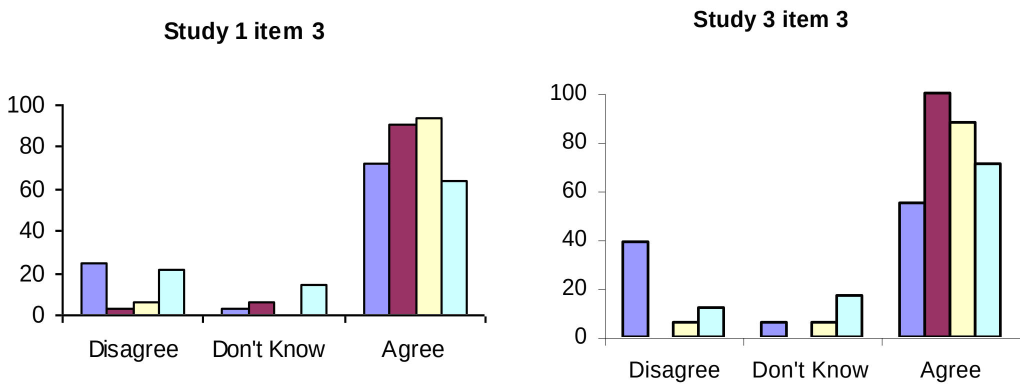
The results of the data from the MCR instrument showed that the first year university students appeared to have a better understanding of the descriptive and predictive roles of the four teaching models than the Year 11 students who had experienced model-based learning. The analysis of the data from the MCR instrument indicated that the majority of students understood the descriptive role of each of the four teaching models, but the predictive role of each of the four teaching models was not as well understood.

2. The purpose of the model is to show how the molecule behaves:





3. The purpose of the model is to show the shape and structure of the molecule:



4. The purpose of the model is to show the existence of chemical bonds.

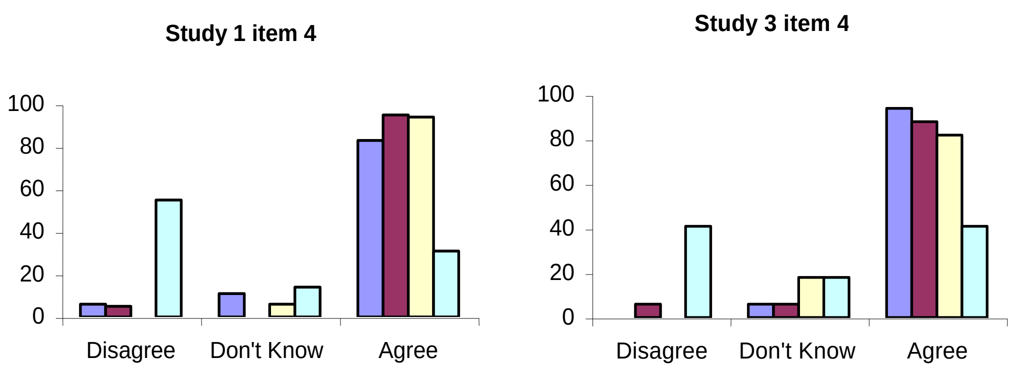
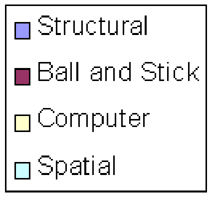
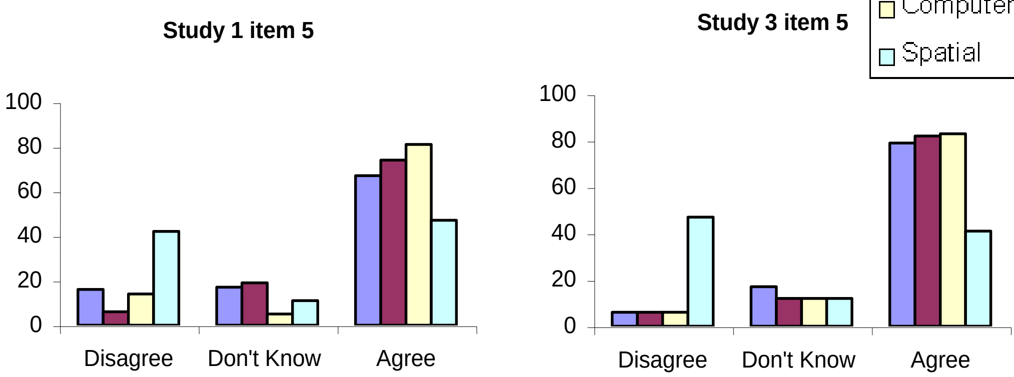


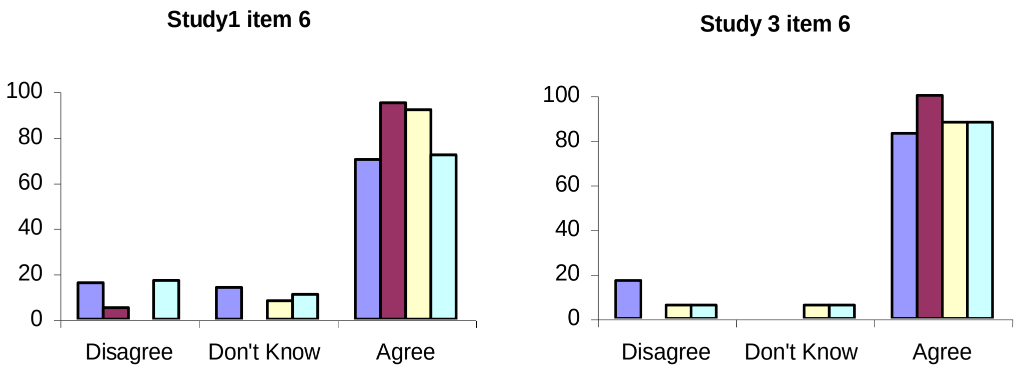
Figure 6.1 Comparisons of the Results for Studies 1 (n=36) and 3 (n=18) for Items 2-9 of the MCR Instrument.

5.The purpose of the model is to help understand the idea of chemical bonds





6.The purpose of the model is to help generate a picture in your mind



7. The purpose of the model is to touch and manipulate something, which is like the real thing.

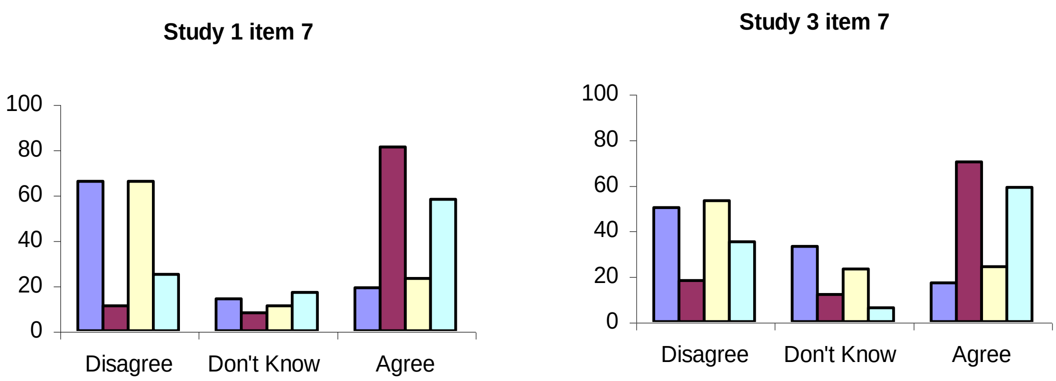
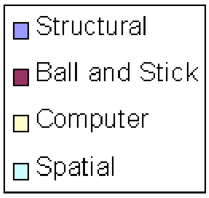
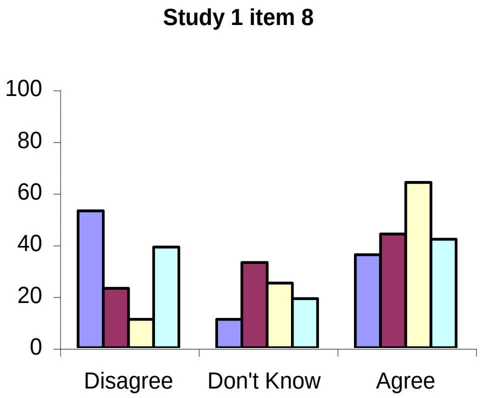
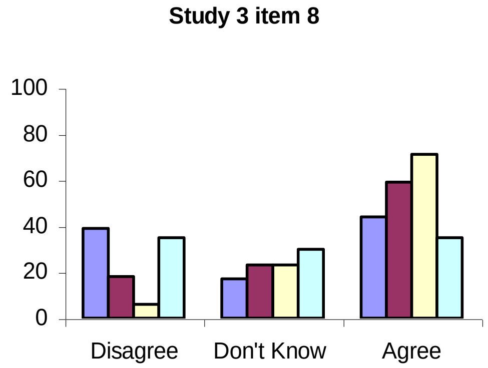


Figure 6.1 cont'd. Comparisons of the Results for Studies 1(n=36) and 3(n=18) for Items 2-9 of the MCR Instrument

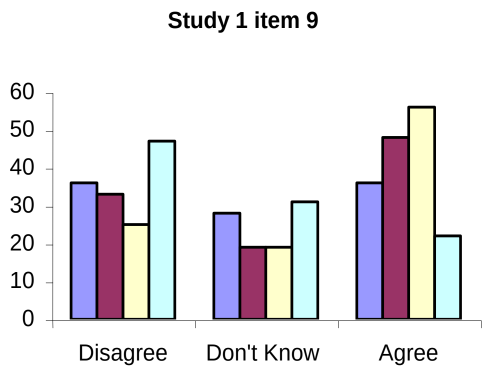
8. The purpose of the model is to show accurate detail of the molecule.







9. The purpose of the model is to make and test predictions.



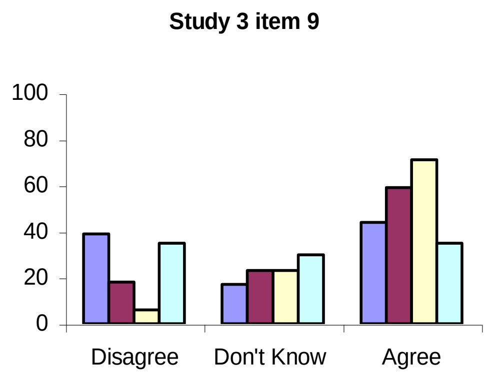


Figure 6.1 cont'd. Comparison of the Results for Studies 1(n=36) and 3(n=18) for Items 2-9 of the MCR Instrument

6.2.2 Using Teaching Models – Study 1

In Study 1, students were observed using the ball-and-stick models to help name molecules, make predictions about a compound's reactivity, for example, by identifying the site of double bonds, and make predictions about a compound's stability by looking at bond angles.

There are examples of students using the ball-and-stick models to predict the molecular arrangements of various isomers and to help name compounds, as is displayed in this dialogue between two students determining the possible isomers for the compound $C_3Cl_2H_6$:

S1: If we stick a CH_3 bond on the same side as the double bond as the chlorine …..

S2: I've already done that.

S1: I say you put them [referring to the chlorine atoms] both on the top - one on the bottom one on the top and both on the same side trans-chloropropene and then we have cis-chloropropene. (1.4.486-489)

Based on the comment "on the same side" and "on the top" these students realised that the there is no rotation allowed around the double bond. In the next example, the students were making possible isomers of C_6H_{14}. Figure 6.2 provides an outline of the two structures that the discussion is about.

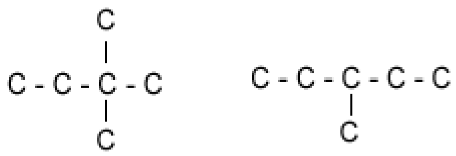


Figure 6.2 An Outline of Two Isomers of C_6H_{14}

S1: They're the same.

S2: No they're not .

S1: Yeh but…

S2: One comes off one [carbon] and one of them comes off the same one. [carbon atom]

S1: It's the same thing.

S2: No they're different.

S2: One of them comes off one [carbon atom] and another comes off two different ones [carbon atoms]. (1.4.926-932)

S2 was explaining the difference of the isomers to S1 using the ball-and-stick model as an explanatory tool. The understanding by S1 of the two structures was challenged; however, the discussion and predictive use of the models helped S1 to understand the isomer concept. Recognising the differences in the two structures was complicated by having to deal with different representations such as the ball-and-stick model and the structural formula and understanding that the structures can move and rotate making them appear different. In these activities, the students used the teaching models to predict possible isomers and develop an understanding of the characteristics of an isomer.

At the conclusion of the unit Introductory Organic Chemistry, the teacher administered a practical test (Appendix P). The students, working under test conditions, were required to make ball-and-stick models of particular compounds. For example:

> *Question 2:* Construct a model for ethane. Try to rotate the end of the molecule about the C-C bond. Record your observations. Draw the structural formula for ethane.

This test was videotaped with both classes and it showed students using the teaching models' physical characteristics to help explain the chemical characteristics of organic compounds. The chemical characteristics to be explained included determining the degree of rotation allowed about single and double bonds, to investigate the angles of the tetrahedral arrangements of bonds coming from a carbon atom and to count the number of carbon atoms in a compound. Students had the ball-and-stick models in front of them while they were drawing the structural formulas on paper and compared both representations. Pictures of the students using models to answer the test questions are displayed in Figure 5.3. The video record and classroom observations provided evidence that the students were using teaching models to make predictions and determine or confirm the answers to the questions in the test.

The teacher used a model-based instructional approach and the data, including the videotaped test and the transcription of student group work' support my observations that students were actively using chemical teaching models to make predictions and test new ideas. However, students' responses to the items in the MCR instrument undertaken at the end of the teaching unit suggest that many students were not aware of the nature of those activities. They did not relate their activities with the teaching models to those of predicting, testing and solving problems. This lack of awareness of the process of the role of the models in their own learning was surprising and in contrast to their awareness of the role of models in learning the chemical content.

It is difficult to generalise about the level of understanding that the students had achieved. Using Skemps' description of instrumental and relational understanding, it could be argued that the students were initially working at an instrumental level – learning nomenclature conventions and structural rules. Indeed, this level is consistent with the descriptive nature of models and the content being learnt. For the students to display a relational level of understanding, they would have to relate one representational form to another or relate a property of the model to a macroscopic property of the compound. This type of understanding requires a more process type of learning. Many students did begin to relate ideas together – as discussed in section 5.4, with the majority of students being evaluated at Level 2 modelling ability. The degree to which the model-based instruction was responsible for this is difficult to assess. The models obviously helped students to develop a mental model of the sub-microscopic level of matter. When a mental model is independent of particular teaching models, then the student can display a true relational level of understanding.

6.2.3 Teaching Models versus Scientific Models

Teaching models are devised to explain the scientific principles of the scientific/consensus model (Giordan, 1991). Since teaching models are designed to be appropriate to the learners' level of understanding, they are often more simplistic than the scientific model but they still play a similar role and have the same characteristics as scientific models. Being able to appreciate numerous models for the same entity supports the characteristic of multiplicity common in scientific models. Using the teaching model to make predictions and test hypotheses is similar to using scientific models. In these ways, the teaching models used here are like scientific models. The data indicate that students perceive both teaching and scientific models as having a descriptive and explanatory role but fewer students appreciate their exploratory and predictive roles.

6.2.4 Summary and Response to Research Question 2.1

Research Question 2.1 asked, "What are students' understandings of the role and purpose of chemical representations of matter, including chemical models, chemical equations, diagrams, and pictures in learning chemistry?" Generally, the majority of students surveyed appreciated the purpose of the four chemical teaching models – structural formula, ball-and-stick, computer model and spatial models – and were able to distinguish their particular features. Consistently, most students recognised the descriptive nature of the chemical teaching models but fewer students had an appreciation of the predictive nature of chemical teaching models.

Despite the fact that some students had used models in a predictive and testing manner, many had failed to recognise this attribute in the model, indicating that students' theoretical understanding of the chemical teaching model was not necessarily related to the practical applications of the chemical teaching model. The model-based instruction experienced by the students in Study 1 does not appear to have made any significant difference to their appreciation of the role and purpose of the chemical teaching models. Chemical teaching models are often simplistic; however, by using them in a predictive and testing manner, they can more closely reflect the true nature of scientific models.

6.3 Identifying Three Levels of Chemical Representation

Research Question 2.2 poses, "What are students' understandings of each level of chemical representation of matter in relation to the chemical phenomena they experience?" In responding to Research Question 2.2, this section provides examples from Study 3 with first year university students; however, data from Studies 1 and 4 are also applicable to this research question are presented in other parts of the thesis. The data from Study 3 include the students' initial ideas about atoms and the development of their understanding about the three levels of chemical representation of matter throughout the semester.

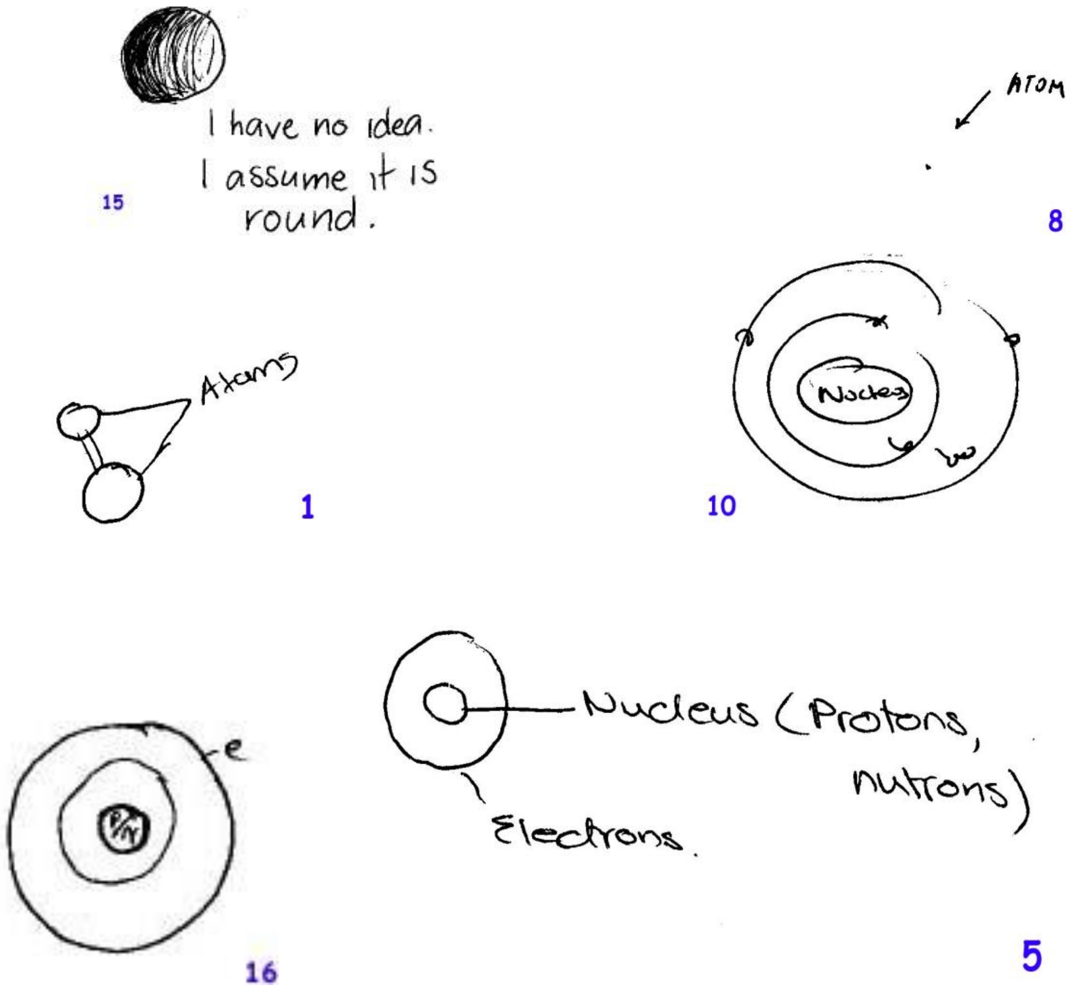
Initially, most of the university students from Study 3 had a limited repertoire of chemical representations, which is not surprising considering their limited experience in chemistry classes. The results reinforce the observation that students' understanding is dependent on what they have learnt – such as the chemical models, symbols, descriptions and experiments they have experienced. The instructor of the introductory chemistry unit introduced topics relatively quickly, expecting students to learn how to use various representations as they were presented. The results indicated that some students had misunderstandings of chemical concepts when attempting to relate a definition to a representation. For example, some students knew the definitions of the terms element and compound but could not classify simple diagrammatic representations of elements and compounds. The unit covered a large amount of content in a short period of time, influencing the depth of understanding that each student could achieve, thereby leading students to a more superficial level of understanding.

6.3.1 Initial Ideas About Atoms

Students' initial ideas about the atom were recorded in response to the question in the Initial Questionnaire (Appendix H), "What do you think the atom looks like? (Use drawing and/or text)". A selection of drawings by the student volunteers is shown in Figures 6.3 and 6.4.

The diagrams show the range of detail students were able to provide. Some drawings show that the sub-microscopic level had not been considered at all. Some drawings in Figure 6.3 showed limited knowledge of the subatomic structure, whereas other students in Figure 6.4 were able to name and position the subatomic particles quite accurately. Out of the 19 volunteers, only 3 students who had Year 12 chemistry experience gave detailed confident drawings. Mostly, students' ideas and conceptions were dependent on what they had been taught previously and what they were able to remember and reproduce. These students had no everyday experiences to contribute to their understanding of the sub-microscopic level of matter, as is demonstrated in the written comment: "I think this 'cause this was what I was taught" (3.4.19). Consequently, the students' previous chemical experiences had a significant bearing on their initial ability to understand chemical representations. Students with no previous chemistry had to quickly build up their background knowledge, including an appreciation of the role and meaning of representations commonly used in chemistry.

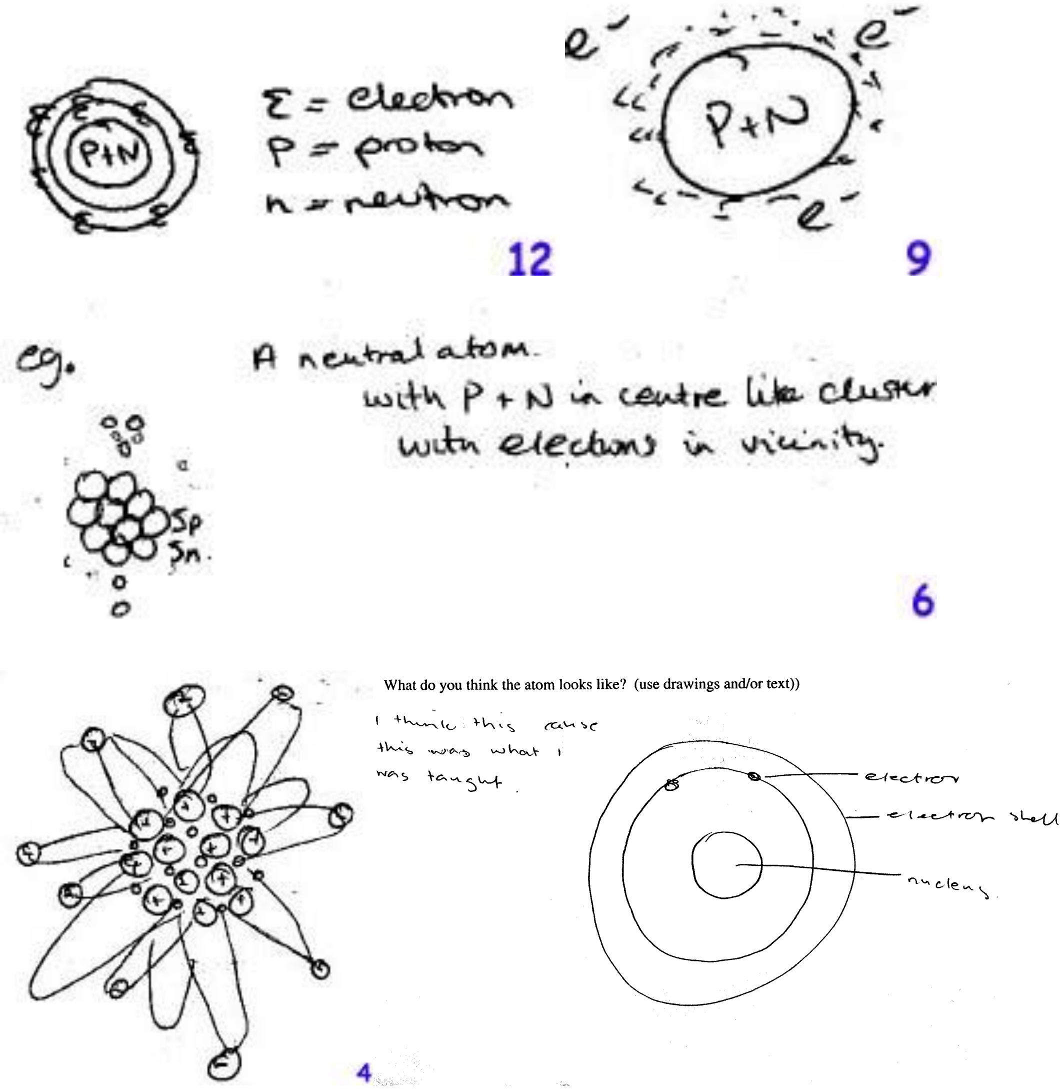
Considering that the atom is the basic building block of all matter and forms the basis of the sub-microscopic level of chemistry, it is an important concept to understand. However, its nanoscale, dynamics and the fact that it is mostly empty space make the concept of an atom difficult to grasp. This is reflected in the variety and detail of the students' drawings. These results confirm those reported by Ben-Zvi and Hofstein (1996) who suggest that students' learning difficulties in chemistry are a result of their inadequate knowledge structure. Consequently, the teaching/scientific model can be an important tool to help students understand the sub-microscopic level of chemistry. The value of a model or a representation is in its ability to explain something or predict something; students need to use a model to be able to learn from the model.



Note: the numbers refer to the students' identification number

Figure 6.3 Responses to the Question "What do you think the atom looks like?"

In Study 3, the unit Chemistry 117 briefly refers to the structure of the atom, assuming students understand that it is one model or representation of a possible many models that supports the atomic theory of matter, before covering chemistry concepts such as equilibrium, organic chemistry and different chemical representations. Taber (2003) discusses the complexities of the atom and the disservice that it is given when it is not presented accurately. Because everyone has an everyday idea of an atom – it is assumed to be understood – however the concept deserves a higher-level and more scientific treatment. Taber also emphasises the importance of an atomic ontology that is consistent with the notion of developing a schema of knowledge, as discussed in section 3.4.2, in this case, specifically about atoms. Learning complex and sophisticated chemistry concepts before mastering the basic knowledge upon which the more complex concepts are built, could lead to difficulties in learning chemistry.



Note: the numbers refer to the students' identification number

Figure 6.4 Responses to the Question "What do you think the atom looks like?"

6.3.2 Worksheet 2 – Physical State and Chemical State

Question 2 of Worksheet 2 (Appendix I) required students to categorise some diagrammatic representations of substances according to their state, physical composition and chemical composition (Figure 4.1). Johnstone's (1991) suggestion that the concepts of elements and compounds, the electron, bond energy photons and structures and molecules "exist only in the mind" (p. 77) provide some insight into why students beginning chemistry find these concepts so difficult to grasp. The results are presented in Table 6.3. The classification of matter in terms of its state would appear to be a simple task; however, not all students agreed with the expert's classification (Sanger, 2000). Most students were able to distinguish the gaseous state; four students incorrectly included picture #3 as a liquid instead of a solid. Sanger describes the particles in the liquid state: "the particles do not fill the entire space and are randomly spaced" and in the solid state as "the particles do not fill the entire space but have a definite repeating pattern" (Sanger, 2000, p. 762). The results from this study reflect that very little attention is given to the detail of the states of matter in the class notes and no particulate drawings were used. This contrasts with the results of the study by Sanger with nearly all the students who had had instruction with particulate diagrams, classified the drawings according to the state of the matter correctly (Sanger, 2000). Sanger emphasised the accuracy and detail of the diagrams even though the diagrams were a representation.

Table 6.3 Classifications of Chemical Representations from Worksheet 2 According to State, Physical Composition and Chemical Composition by Student Volunteers (n=8)

Identification Number (ID)[1]		Expert	3	4	6[2]	7	8	9	10	11
Experience			Yr10	Yr11	None	Yr12	None	Yr11	Yr11	Yr11
States of matter	Solid	1,3[3]	1	1,3	1,3	1,3	1	1,3	1	1
	Liquid	4	4,3	4	4	2,4	3	4	3	3
	Gas	2,5	2,5	2,5	2,5	5	5	2,5	2	5
Physical composition	Pure	3,5	3	3	3	3,5	3	3	3	3
	Heterogenous	-[4]	-	1,2,4	-	1,2	4	1,2,4	4	4
	Homogenous	1,2,4	-	5	-	4	3	5	5	3
Chemical composition	Elements	3,4	-	3	3	3,4,5	3	3	-	3
	Compounds	5	-	1,2,4 5	1,2,5	1,2	5	5	-	3
	Both	1,2	-	-	1,4	-	1	1,2,4	-	1

[1]Identification number assigned to students in Study 3 – abbreviated ID.
[2]Identification number for the student referred to as Narelle
[3] In the body of the table 1, 2, 3, 4, and 5 refer to the drawings on Worksheet 2 (Figure 4.1) representing atoms and molecules.
[4] The "-"corresponds to no response by student.

Because the terms heterogenous and homogenous were not familiar to students, the item referring to physical composition was not analysed. Students were familiar with the term pure; however, all students except one (who had a good chemical background) classified only picture #3 to be pure. Picture #3 contained one type of atom, an element (Figure 4.1). Most of the students did not consider picture #5 with two different atoms joined as a molecule – a compound – to be pure. Sanger (2000) reported similar results with 98% of the control group classifying picture #3, but only 28% classifying picture #5, as a pure substance. The students associated purity with single atoms or elements possibly because they regard something as pure when it is alone and not contaminated with anything else. Here is a situation where the everyday definition does not correspond to the chemical definition.

Students' classification of chemical representation based on the chemical composition about the classification of matter as elements or compounds indicated that some students did not have a good understanding of the fundamental chemical concept of elements and compounds. All students agreed that picture #3 with only one type of symbol was an element, but many students did not recognise the possibility of two elements being in a container together – mixed but not reacting together. Those students with ID numbers 3, 6, 8, 10 and 11 (Table 6.3) did not categorise all diagrams suggesting frustration or ignorance at not knowing how to classify the representations. These results are supported by the students' responses to questions 2 and 3, requiring students to categorise diagrammatic representations as elements or compounds in the first interview of Study 3 (Appendix J). The small sample size (n=7) resulted in only one student categorising all eight diagrams (Figure 4.4) correctly, 2 students categorising seven of the eight diagrams correctly, one student categorising six of the eight diagrams correctly and three students categorising four of the eight diagrams correctly. Understanding what the diagram represented along with understanding the criteria or basis of the classification proved to be key issues in students' ability to categorise the diagrams correctly.

The students in Study 3 who often have little or no chemical background are required to learn a great deal of chemistry content in a short period of time, so attention to the detail of the particulate nature of matter is not always possible. However, if the instructor emphasised the sub-microscopic level, this may improve students' conceptual understanding of basic chemical concepts. Sanger (2000) had improved students' results on a test on the particulate nature of matter by including particulate drawings at the macroscopic and sub-microscopic levels in the instruction.

6.3.3 Worksheet 3 - Symbolism in Chemistry

Students' understandings of the common symbols used in chemical equations were investigated in Worksheet 3 (Appendix I). Generally, the majority of students chose the most accurate descriptors of the symbols; however, for these most basic symbols a unanimous result of correct response was expected. The results of Worksheet 3 (Table 6.4) showed that 89% students chose the best description of the arrow in an equation: "react to form". Only 22% of students agreed that the + sign on the left hand side of an equation means "reacts with", which is considered to be a more accurate description than "is added to" which 67% of students chose. For the + sign on the right hand side of an equation, 78% of students selected "and". For the meaning of the square brackets used in equations, 56% of students chose "volume of concentration of NO_2", while only 33% chose the more correct descriptor – "number of moles of NO_2 per litre". For the double arrow characteristic of chemical equilibrium reactions, 78% selected "the rate of the forward reaction is equal to the rate of the reverse reaction". For the symbol $2NO_2$, 67% of students chose the correct response of 2 molecules of NO_2 while 33% chose 2 atoms of NO_2.

Despite the small sample size, the results of Worksheet 3 highlight subtle differences in students' understanding of common symbols and emphasise the need for attention to detail when using any chemical representation and chemical terminology to ensure that the meaning is understood. There are similar results supporting students' misunderstandings of seemingly simple representations (Ben-Zvi & Hofstein, 1996; Patrick J. Garnett et al., 1995b). Distinguishing moles and molecules, atoms and molecules and elements and compounds, as well as being able to represent these chemicals using words, symbols, and depictions of three-dimensional arrangements of the atoms in various combinations, in addition to linking these representations to the reality of the physical state and appearance of the substances highlights the complexity of the tasks that students are asked to undertake.

Table 6.4 Results of Worksheet 3 – Symbolism Used in Chemistry (n=9)

1. In a reaction equation A + B $\longrightarrow$ C + D The arrow $\longrightarrow$ means	% Results
A) react to form	89
B) gives	0
C) are converted to	11
D) are equal to	0
E) go to	0
2. In the same reaction equation the sign + on the left hand side of the equation means:	
A) reacts with	22
B) is added to	67
C) combines with	11.1
D) plus	0
E) and	0
3. In the same reaction equation the sign + on the right hand side of the equation means:	
A) reacts with	0
B) is added to	0
C) combines with	0
D) plus	78
E) and	23
4. In the notation [NO_2], the square brackets mean:	
A) volume of concentration of NO_2	56
B) mass of NO_2	0
C) number of moles of NO_2 per litre	33
D) number of moles of NO_2	0
E) quantity of NO_2	11
5. In the reaction equation $N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)}$ The double arrow here means:	
A) that equilibrium has not been reached yet	0
B) the rate of the forward reaction is equal to the rate of the reverse reaction	78
C) a relatively large amount of product is formed	11
D) the amount of reactants is equal to the amount of products.	11
E) that equilibrium has not been reached yet	0
6. The notation $2NO_2$ represents:	
A) 2 atoms of NO_2	33
B) a total of six atoms altogether	0
C) two molecules of nitrogen combined with two oxygen molecules O_2	0
D) to molecules of NO_2	67
E) two atoms of nitrogen combined with four atoms of oxygen	0

6.3.4 Laboratory Experience

There were 11 three-hour laboratory sessions during the semester for students in Study 3 undertaking Chemistry 117. Students conducted the experiments, primarily consisting of quantitative inorganic analyses, either individually or in groups of two. The students were required to write up the experimental results and submit them for assessment. During the laboratory tasks, students developed skills in handling laboratory equipment safely, following instructions, collecting and processing data, taking measurements, accuracy, precision and interpreting data. As a demonstrator, I marked the laboratory reports and observed a range of ability and understanding in students' responses. Students had to relate the chemical equations, questions and diagrams to their macroscopic activities. Consequently, students had to relate their macroscopic experiences with the symbolic representations with the intention of developing an understanding of the reaction at the sub-microscopic level. Students with little or no previous chemical experience were bewildered and perplexed by the chemical language in which they were submerged during the first few weeks of the class, but by using the symbols and working through the laboratory reports their understanding improved dramatically.

6.3.5 Interview Results

Because the first set of interviews was conducted within the first few weeks of semester and the second set of interviews occurred after the end of the semester, it was possible to compare students' responses. For all students there was an improvement in their confidence and ability to talk about chemistry, as well as their knowledge of chemistry. Those students with little or no background knowledge at the beginning of the semester made huge advances in the 14-week semester.

During the first interview, students were questioned about their understanding of various diagrammatic representations of atoms, molecules, elements, and compounds. Their dialogues corroborate the results from the initial questionnaire. Slightly less than half the interview sample had reached the level of Year 11 chemistry or better (Table 5.15). Several students had had bad experiences with learning chemistry at school and had failed or dropped the subject. The negative attitude towards chemistry among students and even some teachers is common (Stocklmayer & Gilbert, 2002). There was a range of abilities. For example, when asked about the atoms in an element this was the response from Gabby who had a very strong background in chemistry:

Int.: What do you think of the atoms themselves?

Gabby: I think of them in round circles; I imagine them circular; the electrons moving.

It shows the shells, I can see; there are more electrons closer in to the nucleus and the shells. The electrons are in concentric shells.

I would draw it like circles; the lines just represent the shells. They are not really lines.

	Round circles, circular, nucleus at the centre, with free electrons moving around. I only have the drawings to go on; I picture them as 3D arrangements.
Int.:	What about if it was a liquid like mercury? How would you picture it?
Gabby:	A solid is closely packed together and a liquid can flow, so the bonds between the atoms are less strong. (3.8.7.6-9)

Gabby's description revealed a well-developed mental model and she expressed herself confidently and accurately using typical chemical vocabulary and descriptive phrases. This level of understanding was not the norm; Gabby had completed Year 12 chemistry, two years previously and came from overseas. Most students had no confidence about chemistry and were unable to express any kind of understanding as is illustrated by the following two students' comments:

Int.:	What do the atoms look like to you?
Leanne:	[You] Can't see them (3.8.12.6).

Int.:	What do you think of the atoms themselves?
Russell:	Hard to say, I would probably think of them more as solid balls (3.8.8.6).

The diagrams that the students drew in the initial questionnaire support these comments (Tables 6.1 and 6.2).

Students were asked to select their preferred representation for water from Focus Card 3 (Figure 4.5). The most popular representation with students (5/7) was the ball-and-stick model #5a and #5b (Figure 4.5) followed by the structural formula #3. The ball-and-stick model provides an image of the molecule that is consistent with the molecular formula and the students' understanding.

In the first interview, Russell referred to the diagram #8 on Focus Card 3 showing the two bonding pairs of electrons and the lone pairs of electrons (Figure 4.5). He explained how it helped him to understand why the water molecule was bent. He preferred the space-filling model because he thought it was a more accurate representation than the ball-and-stick representation. Russell's comment epitomizes this mental model:

Russell:	The stick sort of puts me off [because it implies] that that's an actual bond – I have to think, about it whereas there isn't a stick at all. (3.9.8.28)

Remembering that this was at the very initial stages of their course and that some students had very limited background knowledge, the naïve responses may be understandable. On the other hand, considering that they were enrolled in a degree in an Environmental Biology degree course, these simple mental models or representations are unexpected.

By the end of first semester, a marked improvement in students' understanding of chemical representations was observed as demonstrated by the comments of Russell and Leanne in the second interview:

Int.:	Do you have more of a mental picture of the subatomic particles?
Russell:	Theory side, sort of. I can get a picture of what's happening but if it comes to the actual reality of it, its sort of harder to put into the real world, you can picture it in the book.
Int.:	The pictures in the book do they have an impact on how you picture it in your mind?
Russell:	They always do - the more visual picture in a book – one or two pictures in a book can explain better than one or two pages of writing. The same with the organic-things - I couldn't understand the SN1 and SN2 reactions but I saw one of the textbooks it showed that when the atoms joined on - the other one switches sides and everything. Then it all became very clear but without that picture, I had actually read it in the PSI notes and it didn't make much sense. (3.9.8.31-36)

Int.:	Models are frequently used in chemistry teaching and learning. Can you recall any chemical model that you have learnt in your chemistry module?
Leanne:	I liked the electron-dot representations – they made sense but when it came to organics it was hard to picture them. Benzene was difficult. (3.9.12.6)

The ease with which Leanne and Russell used chemical phrases and terminology in the second interview compared to the difficulty they had expressing themselves in the first interviews demonstrated their growth in confidence and conceptualisation over the first semester.

Abraham was a mature-aged student with a strong chemical background who participated in the study in the later months (ID20). His comments in the second interview revealed an active and sophisticated approach to the sub-microscopic level:

Int.:	Do you have a mental picture of the reaction occurring?
Abraham:	That's how I learn best, Absolutely.
Int.:	So with your notes, you don't have any graphics in them at all, do you find that a detriment?
Abraham:	To a certain extent, yeah, I'm very much a picture person. If I can link it [a reaction] to a picture in my mind, then I find that it generally stays around longer, Like the periodic table, I can picture the periodic table in my mind.
Int.:	Last time I interviewed you, we talked about the mental picture you have of a chemical phenomenon. Can you give me an example of a chemical phenomenon?
Abraham:	Absolutely, the very simple reaction of a metal with an acid, HCl or H_2SO_4, where it gives off hydrogen gas.
Int.:	What do you picture it as?
Abraham:	I picture the acid, eating the metal, and the little hydrogens almost getting in the

way of the new friendly salt, and getting kicked off.

Int.: So you see it at a molecular level?

Abraham: Yes I find that if I was unable to do that, then I wouldn't be able to understand what was going on at the molecular level. (3.9.20.16 –20)

Abraham spontaneously jumped from macroscopic level to various symbolic representations. He displayed a well-developed mental model of the sub-microscopic level, obviously complimented by his experience.

Abraham and Russell are both mature-age students and seem more reflective and knowledgeable about their own learning than the younger students. Abraham had extensive chemical experience that was evident in his confidence and ease in discussing the sub-microscopic level, while those students who were unfamiliar with the sub-microscopic level considered it obscure and unreal. Students with little or no chemical background, such as Leanne and Kathy, could not talk seriously about the sub-microscopic level because it was not real to them, as is evident from Kathy's response to question 13 in the second interview.

Int.: Last time I interviewed you, we talked about the mental picture you have of a chemical phenomenon. Can you give me an example of a chemical phenomenon?

Kathy: No not really. If you think of the reaction of photosynthesis- I know the equation; I know what really happens and the equation describes what happens. But I don't picture the little carbon dioxide molecules combining with the water molecules, it just happens; we just know that it does. (3.9.1.50)

With experience, the sub-microscopic level becomes real to the learners because they begin to understand its value in explaining why and how the atomic and molecular movements occur. However, Kathy had no need to know any more about the sub-microscopic level than she already knew. Both Kathy and Leanne considered the questions about the sub-microscopic level to be trivial.

In the second interview, students were asked to comment on how chemical representations had been of value to their learning. Students expressed an improved understanding of the value of the representations:

Stuart: With diagrams, oh you know the 'chair', it took me a while to get that - you look at it and say that's like that and then you read about it – see how that is, that's positive and that's negative. If it's there and it is explained in relation to the diagrams, it makes it a lot easier. (3.9.13.62)

Two students referred to the models used in their biology lessons, appreciating their role in learning biology and that the biology models were representing the "microscopic" level. Unfortunately it was not always evident that students were aware of the chemical models in the same way. For example:

Simon: Well we've done this cell biology map, everything's on a microscopic level, and the Krebs cycle and stuff, so we've done models; we've got through models. (3.9. 9.56)

Maureen: In cell biology, we use models to make lipids etc.

Int.: And that was useful?

Maureen: Yeah I found that better if you got it sitting in front of me and you can play with it [i.e. work with the model] rather than sitting out the front (3.9. 5.38)

There was a development of students' appreciation of chemical representations throughout the semester. Initially, students' understanding was dependent on their previous experience. Attention to the detail of the sub-microscopic level was lacking by some students and this could be a result of the speed and quantity of content that was presented. Experience using the various chemical representations increased students' confidence, with students claiming to appreciate the value of the representations more towards the end of the unit.

6.3.6 Summary and Response to Research Question 2.2

Research Question 2.2, "What are students' understandings of each level of chemical representation of matter in relation to the chemical phenomena they experience?" drew upon data from Study 3 to respond to the question. However, this question is a major focus of the research and data from Studies 1 and 4 could also address this question. Data presented here shows that students' practical and theoretical experiences have contributed to improving their understanding of the three levels: macroscopic, sub-microscopic and symbolic.

Most students had a sound understanding of the macroscopic and symbolic levels of representation of matter, but there was evidence that many students did not understand the sub-microscopic level. Considering that the sub-microscopic level is real and theoretical, and abstract and not visible, this result is not surprising. Students do not have difficulty understanding the macroscopic level that is obviously real or the symbolic level that are representations. This issue was discussed in sections 2.2 and 2.3.1.

Some students exhibited difficulties with mapping particular representations. This observation emphasises the need for the learner to have a very good understanding of what each part of the representation illustrates and to have the opportunity to practice mapping. The detail and accuracy in such tasks are most important.

Students with strong chemical backgrounds recited chemical representations accurately and with detail – as they had been taught. This strong foundation knowledge proved to be very useful to their learning and understanding of the chemical concepts introduced in the lectures. It is important to emphasise the detail and accuracy of the symbolic representation because it is this detail and accuracy upon which students build their understanding of the sub-microscopic level. However, this does not mean that the sub-microscopic level is in fact accurate or precise or detailed – it is not known in that way yet. Despite this, students need to have clear, accurate and detailed symbolic representations that they can draw on to construct their own understanding of the sub-microscopic level. Students appreciate that the symbolic level of matter is a representation and as such is not necessarily like the real thing (i.e., not accurate or precise), while the sub-microscopic level of matter is real. There are a large variety of symbolic representations all with differing limitations used to represent the sub-microscopic level.

The data here confirm the value of previous knowledge and the gradual enculturation of the sub-microscopic nature of matter. Being introduced to the concept of the sub-microscopic nature of matter at a young age and building on the concept during the school years provides students with a solid foundation on which to build chemical explanations. Students without this foundation often found the chemistry difficult to understand. Nevertheless, among the student volunteers who had little or no chemical background there were examples of those who gained an excellent understanding of the sub-microscopic level in the period of the semester, albeit through perseverance, practise and effort.

6.4 Transferring from One Level To Another – Study 1

Research Question 2.3 asks, "How does students' understanding of the three levels of chemical representation of matter enable them to effectively transfer from one representational level to another?" As discussed in Section 2.2, research shows that many secondary school and college students, and even some teachers, have difficulty transferring from one level of chemical representation of matter to another (Boo, 1998; Gabel, 1998). This most important process is investigated here with a variety of examples from Studies 1, 3 and 4. This section will review examples from Study 1, section 6.5 will review examples from Study 3 and section 6.6 contains examples from Study 4. The summary for Research Question 2.3 is presented at the end of section 6.6.

In Study 1, high school students were required to build models of the organic compounds as a means of achieving some of the learning objectives of the unit (Appendix C) such as:

a) Identify alkanes as saturated hydrocarbons which contain only single bonds between carbon atoms (Objective 6.3).

b) Identify alkenes as unsaturated hydrocarbons which contain a double covalent bond (Objective 6.3).

c) Identify alkynes as unsaturated hydrocarbons which contain a triple covalent bond. (Objective 6.3)(Curriculum Council, 2001, p. 26).

The students used the ball-and-stick models and the structural formula models, in particular, to explain the properties of simple organic compounds and gain an understanding of their molecular structure. Four examples of model-based explanations using symbolic representations to depict the sub-microscopic level of chemical representation of matter are reported as typical of how students worked with these models.

6.4.1 Linking the symbolic and sub-microscopic chemical representations

The teacher described models as representations of chemical substances and students practiced transferring from the three-dimensional symbolic ball-and-stick representation to the two-dimensional symbolic structural formula representation. The teacher highlighted the differences between the two representations being used.

Teacher: It is not always convenient to have your models with you so we draw a structural formula - a two-dimensional representation. (1.4.813)

Teacher: Obviously an advantage of our model is that it allows us to visualise three-dimensional models. It also allows us to remember that these things have energy and that these things are moving all the time twisting, turning vibrating. (1.4.812)

Although energy, or the twisting, turning and vibration of the methyl group cannot be seen, the teacher was able to effectively use a model which provided an image and a meaning to explain the sub-microscopic level. The teacher's use of the phrase "twisting, turning, vibrating" (1.4.812) illustrated his attempt to focus on the sub-microscopic level of representation. However, modelling skills are not inherent in learning or teaching and the analogical relations of the reality and the model or representations need to be established by the student. The teacher appreciated this and stated:

Teacher: Now it doesn't matter if this methyl group is over here or over there. You can imagine because you can flip these around (referring to the structural formula) just like you can with your plastic models [the ball-and-stick model]. (1.4.979)

Subsequently, the ability to transfer from one symbolic representation to another was practised in these lessons, with the teacher always reverting to the structural formula representations on the board to explain and compare chemical compounds. Students eventually chose to work without the ball-and-stick model, with one student saying, "just do it on paper, we don't need the model" (1.4.445). The symbolic and sub-microscopic chemical representations considered in this scenario take on a relational form of understanding which helped to forge links between familiar and unfamiliar concepts (Collins & Gentner, 1987).

6.4.2 Model-based explanations of the structure and formula of alkanes.

In this learning episode, when students made models of pentane, their conversation with each other reinforced the number of carbon and hydrogen atoms required and the lengths of the bonds. The explanation of the structure was primarily instrumental learning in that the students were required to follow specific instructions (Skemp, 1976). In the following dialogue during this activity, students reinforced their understanding of the bonding structure for carbon, the general formula for an alkane, and compared the symbols for different bonds and different atoms.

S2: What are the green ones?

S1: Green is chlorine.

S1: Andrew, you used the wrong bond on the top.

S3: That's a better pentane.

S1: These bonds are long bonds at the top

Int.: How many carbons?

S1: Five and twelve hydrogen, pentane?

Teacher:	Yes that's pentane.
S1:	For octane we'll just expand it further.
S2:	Is it really chlorine? Chlorine!
S1:	Gotcha. This will destroy your lungs.
S2:	Chlorine gas, chlorine gas (1.4.719-740).

The students' dialogue confirmed their nomenclature rules with the aid of the ball-and-stick models. The reference to chlorine gas when referring to the green balls suggests that students were linking the symbolic representational level to the macroscopic level. Students were able to identify the pattern in the nomenclature and structural formula suggested by the comment, "for octane we will just expand it further". Working in pairs proved to be an effective way for students to help and challenge each other. The students' explanation of possible structural configurations to each other using the models and the diagrams was indicative of a relational level of understanding. This example supports recommendations of Harrison and Treagust (1998, p. 424) that "learning to model should be overtly social and involve discussion and negotiation of meaning".

6.4.3 Model-based explanations for isomeric structures.

The following dialogue provides evidence of model-based explanations where the students used the ball-and-stick models and the structural formula to help identify alternative and feasible isomers and understand the naming conventions. Students made inferences based on their observations of the model. Skemp (1976) refers to relational explanations as "building up a conceptual structure (schema) from which its possessor can (in principle) produce an unlimited number of plans for getting from any starting point within his schema to any finishing point" (p. 25). In this scenario, the students used the ball-and-stick model to explain the differences between isomers and related these differences to other representational forms such as the structural formula. In this way, the symbolic representations provided explanations that had a relational understanding.

S1:	Next one, you are going to have two chlorines in the middle. That means 2, 2 dichloropropane, it is all dichloropropane.
S2:	This is what we have just done it is still …
S1:	It is all propane and it is dichloropropane and it is just the number and the fact that the number is 1,1; 1,2; 2,2.
S2:	Perhaps 1,3 … What about 1,3?
S1:	Fine. 2,2 is here and 1,2 is just like this.

S2: 2,3?

S1: No it will be 1,2

S2: I see. I did not realise you were getting at it. It will be what?

S1: On what?

S2: 1,2; 1,3

S1: 1,2; 1,3

S2: and then 2,2; …1,2.

S1: What about 1,1; 1,2; 1,3 and that is it?

S2: Yeah! (1.4.1033 -1046)

This dialogue illustrates students frequently repeating answers to each other, asking their partner for confirmation that they were correct. The collaborative approach to learning was effective in promoting such dialogue between students. This group activity contrasted to the students' routine chemistry classes that were more teacher-centred. Similarly, the use of the ball-and-stick models to determine the cis and trans isomers for the compound $C_3Cl_2H_6$ was described in section 6.2.2.

The discussion between peers and the teacher helped the students to confirm their understanding and acceptance of the representation. Both instrumental and relational levels of understanding were exhibited. Understanding the meaning of the new terminology of trans and cis, applying the naming rules to the new compounds, and identifying all the possible structures, are examples of instrumental understanding. Transferring from the three-dimensional, ball-and-stick model to the two-dimensional, structural formula they recorded in their notes showed a relational level of understanding.

The cooperative discussions observed were enriching to both the explainee (S1) and the explainer (S2). The task of explaining their ideas to fellow students revealed their misunderstandings and helped clarify their ideas. Students frequently asked the teacher for confirmation, even though they had already discussed an answer with their peers, and were confident they were correct. Horwood (1988) identified the value of this process and concluded that the most neglected function of an explanation is its ability to "enable the learner to become an independent explainer" (p. 48).

6.5 Transferring from One Level To Another – Study 3

Worksheet 1 and Worksheet 4 (Appendix I) provide data about the confidence of some university students in their understanding of the sub-microscopic and symbolic level.

6.5.1 Worksheet 1

Having experienced laboratory experiments with ionic solutions and lectures on the ionic nature of some compounds, the students were asked to declare their level of confidence in the accuracy of statements about the sub-microscopic level of chemical compounds on a scale of one to five. The results are presented in Table 6.5. The false statements – items 4, 6, 9, and 15 – were mostly recognised with low means of 1.57, 1.67, 2.75, and 2.17. The mean values support the finding that the majority of students completing this worksheet confidently held correct conceptions about the sub-microscopic nature of ionic matter. Understanding the charged nature of ionic species, the movement of ions and electrons and the characteristics of a solution infer an understanding of the sub-microscopic level of chemical representation of matter.

6.5.2 Worksheet 4

Worksheet 4 was completed near the end of the semester. Students made predictions about the changes to an equilibrium system using diagrammatic representations of the sub-microscopic level. The responses were mostly correct with eight out of ten students, showing transference from the symbolic representations on paper to the sub-microscopic level and to the macroscopic level. It is advantageous or even essential to understand these three levels in order to be able to understand the concept of equilibrium (Tyson, Treagust, & Bucat, 1999).

Two excerpts are provided to illustrate the students' responses. Russell (ID8) a mature-aged student, a very diligent worker with no chemistry background, provided a succinct answer to question 1.2 on Worksheet 4, making predictions about changes to the equilibrium when the volume is suddenly decreased:

Russell: Equilibrium shifts to the right with more NH_3 because less molecules per volume. (3.6.8.1.2)

Table 6.5 The Mean Response and Standard Deviation for Worksheet 1 (n=9)

Item	Pref[1]	Mean[2]	SD[3]	DK[4]
1. The white crystals have no net charge.	5	3.44	1.33	0
2. Sodium nitrate consists of positively charged parts and 3. negatively charged parts which are attracted to each other.	5	4.25	1.17	1
3. When the salt dissolves, it breaks down into very small microscopic particles consisting of one or a few atoms.	5	3.67	1.51	2
4. When the salt dissolves the ions in the salt are attracted to each other and stay bonded to each other.	1	1.57	1.00	1
5. When the salt dissolves the ions are mixing with the water at a microscopic level.	5	4.14	1.21	1
6. Particles held in suspension are not broken down into ions.	5	1.67	0.82	1
7. The water molecules help to drag the charged atoms away from the solid crystal thus dissolving it.	5	3.57	1.62	2
8. The dissolved ions cannot be seen with the eye.	5	4.50	1.07	1
9. The ions are mixing in the water, but they are not reacting.	5	2.75	1.49	1
10. When a precipitate forms a chemical reaction has occurred.	5	4.13	1.36	0
11. Some ions stay in solution and do not react.	5	3.38	1.06	0
12. An insoluble substance can be seen with your eye.	5	4.20	1.10	1
13. In a precipitation reaction, one ion gives electrons to another ion to form a chemical bond.	5	4.00	1.15	1
14. The dissolved ions cannot be seen but they can react to form an insoluble substance which can be seen.	5	4.14	1.22	1
15. The soluble ions can be separated by filtering.	1	2.17	0.98	3

[1]The preferred – the “best” answer
[2]Mean value – mean of students’ responses to a five level confidence scale where 1 means not at all confident, 3 means confident and 5 means is very confident.
[3]Standard Deviation
[4]Number of Don’t Know responses

Margaret (ID11) is a low achieving student with little confidence in chemistry. Her responses to the other worksheets were less than expected and in question 1.2 on Worksheet 4 she understood what had happened when the volume is suddenly decreased, but did not go on to the explain the resulting changes to the equilibrium situation.

> *Margaret:* There is a higher concentration of NH_3 and N_2 because the volume has decreased and now there is the same amount but in less volume therefore higher concentration. (3.6.11.1.2)

It seems that Margaret could relate the macroscopic qualities of concentration and volume with the symbolic representation of gas molecules, but failed to relate the symbolic representations to the chemical reaction that was proceeding.

The results of Worksheet 4 provide evidence that some students were able to interpret a chemical equation by using the diagrammatic representation of the molecules to predict the changes that would occur at the sub-microscopic (molecular) and macroscopic levels. Students who successfully interpreted the data were performing at Grosslight et al.’s (1991) Level 3 of modelling ability.

6.5.3 Interviews

When asked about the meaning of symbolic representations in the second interview, most students were able to link the symbolic representation to the macroscopic phenomena. For example, in a series of acid/base titrations, the results were described graphically and by equations, then interpreted and used to calculate the acid equilibrium constants. This observation is confirmed by a student comment in an interview:

Stuart:	I can relate the equation to the experiment; I can understand the equation more now. (3.9.13.48)

This experiment, the discussion, and calculation demonstrated students transferring between the macroscopic and several symbolic levels of representation. However, only a few students believed that they had a sub-microscopic depiction for the particular phenomena. This observation is consistent with the lack of discussion or reference to the students' mental model of the chemical processes during the lecture part of the course. After all, the sub-microscopic level is a result of the students' interpretation of the information they receive. Students depend on information from the text, laboratory work, and the lecturer to develop their understanding and their personal mental models. In response to a question about the value of chemical models in learning chemistry, Gabby expressed the value she places on understanding the basic concepts.

Gabby	I think it is important for someone to understand the basics. If there were no pictures I would not be able understand anything but now I have pictures in my head. I think the pictures that you get are very important because that is what you remember (3.9.7.36).

Johnstone (1993) proposed that students cannot handle more than two levels in their working memory at one time, and that the sub-microscopic level appears to be neglected. The results here appear to support Johnstone's proposition.

In the laboratory, all students were required to perform numerous titrations and then use equations to calculate unknown concentrations. Despite this, a number of students claimed that they just did the calculations without understanding the chemistry. The question in the second interview asked about laboratory write-ups:

Int.:	So when you write up that equation do you relate that to the actual chemicals that are reacting.
Margaret:	Sometimes.
Sharon:	Not really. No I just think, oh I have to put that in there and then do a calculation

and that's it. (3.9.11.6-9).

Int.: Can you recall any lab session/practical that you found to have been difficult in your learning?

Wally: Yeah like compounds have really huge names, which throws me way off, pretty much. So like on the last one, column chromatography, manganate plus equations, they throw me out.

Simon: Yeah about one in every two or three I stuff up.

Wally: I think it's more like in the potassium permanganate environment, with sulfate, but in the equation they only put the permanganate. Not seeing the whole thing throws me off.

Int.: In lab-work can you relate the equation to the experiment?

Simon: Usually can, unless it is a complicated equation, then I have troubles.

Wally: Nah I can't do that.

Int.: Do you fill in the blanks in the calculations?

Simon: No I just copy what's on the board, then whack in the numbers. (3.9.9.49).

Russell: I do just fill in the blanks and often don't have time to go over anything later. (3.9.8.27)

Students with weak background knowledge who did not have a good appreciation of the sub-microscopic level could use the macroscopic and symbolic levels independently of each other, without finding it necessary to relate them to each other. Although a range of answers were recorded it would appear clear that effort is required to understand the experiments and to make the connections between the equations, the calculations and the observations, as is demonstrated in Abrahams comments.

Abraham: No I understand what I'm calculating and that was brought about by one specific practical where, we had to go through and because I didn't understand the calculation clearly enough, I went back through and did my own calculation. (3.9.20.14)

The repeated use of chemical equations, mathematical equations and quantitative analysis helped many students in the university chemistry unit to learn how to use the various representations and relate them to the macroscopic experience.

6.6 Transferring from One Level To Another – Study 4

This section reports on volunteer university students (n=19) who were interviewed about their understanding of the diagrams used in the online pre-laboratory exercises and how these diagrams influenced their learning. Where possible, each volunteer student was interviewed twice – after week 5 and after week 12 of second semester. However, there were fewer students, only five, available for the second interview because of the pressures of examinations. Also at times, interviews were cut short because students had other commitments. As a result, the pool of students that are reported does vary. The interview protocol was followed as outlined in section 4.3.4. This cohort had completed Chemistry 117 in first semester and was taking Chemistry 118.

The analysis examined the students' responses to questions about the diagrams used in the online pre-laboratory exercises (Appendix O). Included in the analysis are diagrams for distillation, fractional distillation, column chromatography, equilibrium, states of matter, strong and weak acids and various structural formulas. The coding that was developed in conjunction with the interview questions were used to highlight particular aspects of each diagram. The transcripts of the interviews were coded according to themes concerning the three levels of chemical representation of matter as well as the plausibility, intelligibility, and fruitfulness of each diagram to the individual learner. In the diagram numbering, e.g., diagram 2.1 – the first number refers to the week of the second semester and the second number refers to the question number of the pre-laboratory exercise. The interview data form the basis of the analysis.

All diagrams in chemistry are symbolic representations of the macroscopic and or sub-microscopic levels of representation of matter that help explain some chemical phenomena. Some diagrams, for example, show how to setup equipment; others show what the molecules are doing and others present data graphically or in tables. In the interviews, all the students were able to describe the type of diagram they were looking at, however they did not normally refer to the level of representation of matter being portrayed.

The 'correct' answers to the questions may appear obvious, and generally students provided the expected results but how the students use the diagrams for learning especially in terms of the three representational levels of matter was the analysis of interest. The students' understanding of the particular concept – its intelligibility, their ability to accept the symbolism of the diagram – its plausibility, and its value to their learning – its fruitfulness, are considered. Sometimes students' misunderstandings became apparent during interviews and similarly some students found the interviews to be a learning experience. The validity of the analysis is based on looking at multiple student responses to a variety of types of diagrammatic representations.

6.6.1 Distillation

The distillation diagram provided a pictorial representation of the apparatus at the macroscopic level (Figure 6.5). It was considered to be helpful in setting up the laboratory equipment as is demonstrated in the following comments:

> *Kay:* Well, basically it makes me sort of have a good picture of how to put it together when I go to do my lab. But maybe it might not be detailed enough for me to be able to follow it exactly, so I'm going to have to cheat and look around [laughs] and see how others are doing it. Yeah, I think that would be the main point. (4.5.18.9)

> *Katrina:* Yeah, so when you first look at it. It's complicated but I like seeing the diagrams because then you know how to set it up. Because I had no chemistry experience. So when they say to get out this equipment, I haven't got a clue what it is, so all I can do now, I can look at it, and then you can kind of make your way around and find what you really need to use. (4.5.17.9)

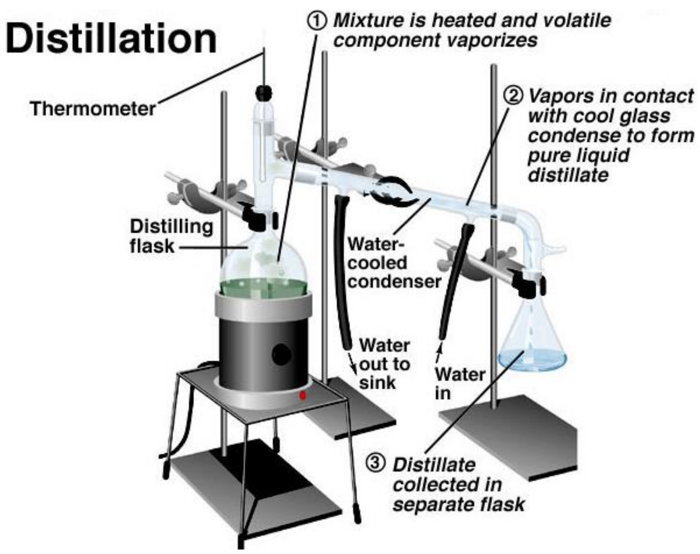


Figure 6.5 Distillation Column as Presented in Diagram 1.1 of Pre-laboratory Exercises

Even at the macroscopic level, misconceptions can arise from misinterpretations of diagrams. It may be surprising that some students (5/17) had not completely understood the workings of a condenser even though they had performed the experiment. For example:

> *Int.:* Where does the water go in and out?

Alice:	In there, [pointing to the water-in tube in the diagram] And then it came out the top bit? Didn't it? Did it?
Int.:	What was the point of this condenser here? Do you remember what it does?
Alice:	Um. Not really.
Int.:	And the water in, the water from the tap, did that water mix up with this mixture in the distilling flask?
Alice:	No, I don't think so. Did it? I don't know. I don't think so. (4.5.3.16-21)

Most (11/17) of the students interviewed claimed that they did not have an understanding of distillation before doing the experiment. All students claim to have gained some understanding from performing the experiment. Generally students' descriptions referred to the macroscopic level, which is consistent with the diagram and their experience. All the students confirmed that the diagram did not show the molecular level, and it did not help them understand the molecular level. The students only referred to molecules when prompted by the interviewer. This is in contrast to my understanding where I think of the molecular or sub-microscopic level automatically. For this analysis, this way of thinking about chemical processes will be referred to as the *sub-microscopic view.*

A few students' knowledge of terminology for apparatus and the changes of state were surprisingly poor (4/17) considering that they had completed the pre-laboratory exercises and the experiment. This is demonstrated in subtle differences like talking about evaporating liquid rather than boiling, referring to all liquids as water, and using the terms vapour and steam interchangeably. For example:

Alice:	The water turns everything into a vapour from this, and I don't really know. (4.5.3.41)
Marc:	It used to be like, steam or something. (4.5.10.39)

Karen points out that the distillation diagram is a replica of the apparatus but it does not explain what is happening:

Int.:	Do you think the diagram helps you understand what distillation means?
Karen:	It just tells you what each thing is. It doesn't actually tell you how it happens. Like I still don't grasp how one long tube is a condenser. (4.5.13.37-41)

From these observations differences are identified in what people 'see'. When teachers or experts look at the distillation diagram they see the macroscopic and sub-microscopic view and the implied explanation that the level provides, but when novices look at the diagram they just see the macroscopic equipment. So even though the students here have described the diagram as plausible and intelligible, the level at which the student comprehends the diagram limits the fruitfulness of the diagram.

6.6.2 Fractionating Column Experiment

As previously mentioned, explanations of chemical phenomena rely on the sub-microscopic level of representation (section 2.2), but for students with weak chemical backgrounds this level was poorly understood (section 5.4). Diagrams such as the fractionating diagram (Figure 6.6) combined the macroscopic and the sub-microscopic levels with the purpose of explanation.

All interviewed students (n=17) appreciated that Figure 6.6 represented the movement of particles in the fractionating column:

Carol: It's showing more of the molecular version. (4.5.9.48)

Jen: It helps you understand more of what's happening with the molecules. (4.5.8.68)

Sue: Yeah, I reckon that's right. It doesn't show- like the other one showed you more the actual method like what was gonna happen whereas this one just shows you one bit of it. (4.5.7.70)

Lee: Basically showing you what you can't see. And then, observing. (4.5.6.71)

Figure 6.6 prompted students to examine how the fractionating column operated by considering the molecules of the three different liquids present in the mixture. All students realised that the letters A, B and C in circles were symbolic representations – some students thought the letters represented the molecules, while others considered the letters to represent the different chemicals in the mixture.

There was a mixed response to the interview question: Do you think these letters A, B, and C represents molecules?

Sue: Different molecules or gases or liquids or something that you're trying to get to, to work. (4.5.7.48)

Bob: Three different molecules. (4.5.12.120)

Ned: No, not molecule. A chemical within the mixture. (4.5.11.122)

Debra: I think that could be inferred, yes. (4.5.19.58)

Kay: No, just to label the different [substances], like in one liquid there may be certain substances, certain different things. (4.5.18.79)

Caz: I guess at the time I probably didn't, but now, yeah they would be the actual molecules of the liquid. At the time I just thought of it as liquid, and not so much on the molecular level. (4.5.4.43)

Mat: Different liquids in the mixture. (4.5.5.59)

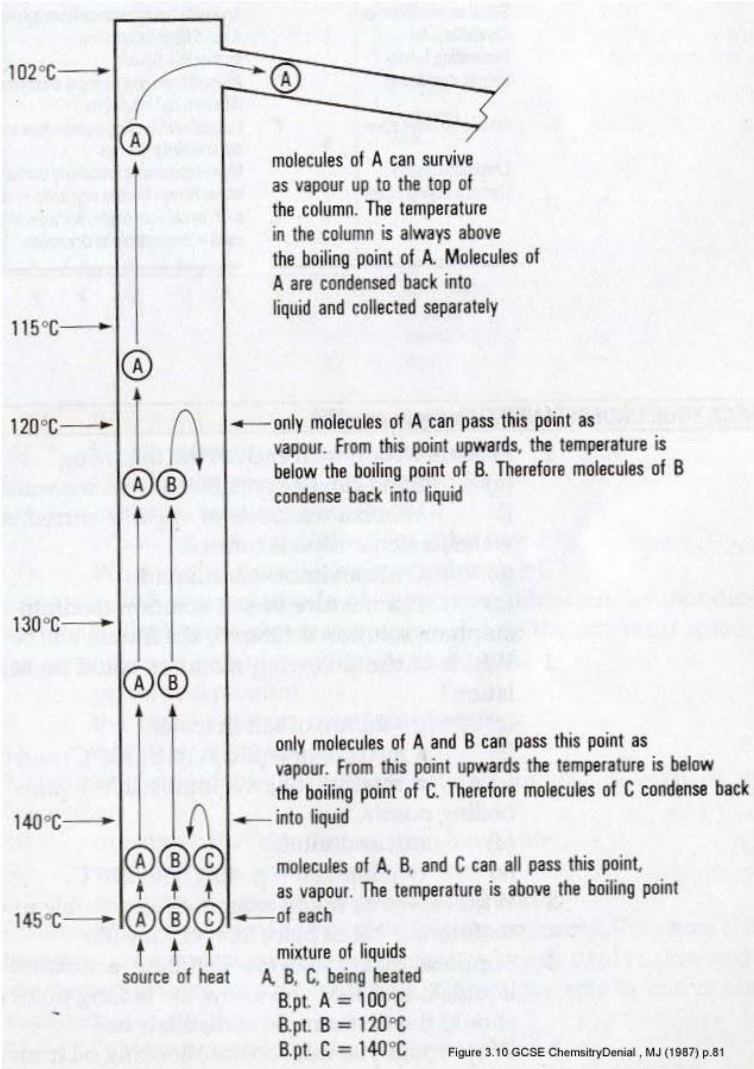


Figure 6.6 Fractional Distillation as Presented in Diagram 1.5 of Pre-laboratory Exercises

The symbolism is assumed understood, but there are many interpretations. Although those students had performed a very similar experiment, only three students (3/17) actually referred to it.

There was a wide range of understanding of the diagram and the process of fractional distillation among the students who were interviewed. A minority of the students (4/17) expressed a clear understanding of the diagram. For example, Mat with a background including A level chemistry, related the symbolic diagram with the sub-microscopic level in referring to the concentration of the constituents in the sample.

Mat: Well from the diagram, what it actually shows is that for example in this case, liquid C does condense around 140 degrees, which means that the liquid is formed which means it goes back into the mixture. Whereas the molecules for liquid B, they condense - it condenses at a much lower temperature higher in the column. And so for me this does explain the concept of varying concentrations. (4.5.5.75)

However, due to their lack of chemical background knowledge, some students' made incorrect assumptions, used common language inappropriately in a chemical domain, did not know common chemical terminology, and misinterpreted data. For example:

Karen: Well, as the temperature's decreasing, molecules with less efficiency, I suppose are reaching the top. (4.5.13.84)

Betty: I'd probably say that these ones [referring to A] are smaller because these ones [referring to C] are too heavy to-. Because as it cools, they condense, and just fall back down to the bottom, but these ones [referring to A] aren't, so they continue up. (4.5.14.86)

Sue: Maybe when they hit like the certain temperature, it causes them, like when they hit a certain temperature, it causes them to not fractionally distillate? (4.5.7.50)

Karen: Is vapour a gas? (4.5.13.155)

There was confusion with basic principles of change of state evident from the interviews with some students (6/17). In the diagram (Figure 6.6), the chemical 'A' would have to be in the gaseous state; however, some students had not grasped this:

Int.: What sort of state is A in up here? Is it a gas, a solid or a liquid? [referring to the upper part of the fractionating column]

Sue: Um, liquid.

Int.: All right.

Sue: Or a gas. It wouldn't be a solid.

Int.: Okay.

Carol: I think if it travelled all the way up there it would be a gas, wouldn't it? (4.5.7.72-77)

As these comments show, initially these students were not confident about the most basic principles; however, through the discussion their understanding quickly improved.

Typically, several students responded unthinkingly – without reading the notes or looking at the diagram carefully, and misinterpreted the diagram. There were some common misconceptions. Here an excerpt from a conversation highlights the problems of associating mass with boiling point.

Int.: What state are they in here in the column?

Jen: They're below the boiling point. I don't know.

Int.: So what do you think is happening? Why are some of them turning round and going back down the other way?

Carol: They're too heavy.

Int.: They're too heavy?

Carol:	Too dense.
Int.:	What happens to the column as you're going up? What changes in the column as you're going up?
Sue:	The temperature decreases.
Int.:	So what's the effect of that decrease in temperature?
Jen:	It would cause them to become more solid. Whatever the stuff was. So then, like Sue said, when they get too heavy they fall back down. (4.5.7.50-60)

The comment above shows how the diagram may have caused a misconception of mass influencing the change of state and highlights the need for the meaning of each symbol to be understood. Bob and Ned are typical of the interview conversations and their responses are used here to demonstrate that the students had some correct ideas mixed with some misinterpretations and that they changed their ideas after interpreting the diagram more critically and listening to each other and me.

Ned:	It just shows that the different points are the different temperatures, and which, um, some of the substances are going to be, what do you call it, fractionated?
Int.:	Fraction-, yeah, or separated, yeah.
Ned:	Fractioned or separated off.
Int.:	What about you Bob? [laughter]
Bob:	Yeah, no, yeah, just clearly shows that, like, A will actually go all the way through but B and C won't. (4.5.11.53- 57)

This description above is from a cursory inspection of the diagram and does not include a description at the sub-microscopic level. Ned and Bob have simply described the diagram without interpreting it. Ned realised he cannot escape and looks more earnestly at the diagram. When a more detailed explanation is asked for, the students' responses lacked consistency.

Ned:	Um, oh here we go. Have to think about this again, or it tells you here. All right. A has got the lowest boiling point. So C, when it's introduced, pretty much stays where it is, because of its boiling point. B goes up, comes out there. A goes out the top.
Int.:	Is it coming out here? What's happening here?
Bob:	B actually stays in the beads, or whatever, and it travels back down to the base.
Int.:	Right. Good. Okay. Why does it fall down there?
Bob:	Because the-
Ned:	It has to wait until all of A has been expelled? (Is that right?)
Int.:	Hm. That's a good question. What do you think?
Bob:	I think just wait 'til the actual temperature's high enough. Like when you get to that point, the temperature should be high enough to keep it going up.
Int.:	High enough.
Bob:	Yeah, so like the temperatures high enough.
Ned:	Oh, yeah, because the…

Bob: To get it to there, but the temperatures of it is too low to keep it as a gas, so it travels back down. So as long as you keep it going towards the temperature, gets higher, the further up the column it goes.

Int.: Okay. What do you think? It's quite, -.

Ned: Essentially it is that it gets up to temperature, and then stays at a constant temperature until all of A has been expelled from it, and then it will go down into B.

Int.: Okay.

Bob: We had to wait for those-

Ned: And then it will go down to C, but I'm not-.

Bob: The temperature range at the top of the beads, to reach the actual boiling point for the liquid, and then it will actually escape the beads. (4.5.11.60-77)

There were other examples of conversations very similar to this one in which students began with a cursory description that failed to explain the diagram properly and often highlighted some misconception such as the temperature scale, confusing temperature and heat or the 'heaviness' factor. The declining temperature scale on the column was confusing or unexpected for quite a few students. However, the discussion through the interview usually clarified the students' understanding. Here is the continuing discussion with Bob and Ned:

Int.: So what happens - as you're going up the column, what's happening to the temperature?

Bob: The temperature drops.

Int.: Why?

Bob: The heat source is at the bottom.

Int.: So what happens here at 140°C?

Bob: Well C will turn back to a liquid because it's-

Int.: So it follows that arrow down there.

Ned: So it actually travels back down again.

Bob: Because it's no longer a vapour, it's actually started to liquefy and go back down.

Int.: Why does it liquefy?

Bob: Because the temperature's gone under the boiling point.

Int.: Okay. What happens at B then?

Ned: B goes back down because it hasn't reached the yeah.

Bob: The temperature ….. boiling.

Int.: Okay. So same thing. And what about A?

Ned: A's got enough, so it's expelled. It's been boiled so it stays vapour and gone out through the .

Int.: At 102°C here, is it still going to be in one state.

Ned: It's still going to be a gas.

Bob: It's still a vapour, yeah. (4.5.11.78-96)

The questioning prompted students to re-examine the diagram. More time and more critical examination was needed for Ned and Bob to understand the diagram.

The dialogue demonstrated Ned and Bob deciphering what the diagram was trying to say – being dissatisfied with their initial interpretation, and eventually, through some prompting by the interviewer and discussion, being able to explain what was happening at the molecular level and why it was happening. Their explanation was intelligible and plausible and so Bob and Ned's status of the concept of fractional distillation was raised. Bob and Ned referred to their experience in the laboratory in their discussion, as did Caz in the following excerpt from her interview.

Int.: Does it help you understand what's happening at the molecular level?

Caz: Only to the point where you could see, that its condensation points it goes back to, for the gas to act-.

Int.: You could actually see something going on?

Caz: Yeah, you could see it condense and run back down.

Int.: So, you knew at that temperature it was changing from a gas to a liquid.

Caz: Yep. (4.5.4.36-41)

Here Caz has demonstrated transferring from the macroscopic level to the sub-microscopic level, using the symbolic diagram as the medium. Doug, a mature-age student, who was performing very well, commented on his approach with the fractionating column diagram.

Doug: It took me a couple of minutes looking at it with the questions there, the A, B and C thing, there. It actually made me think about what was happening temperature-wise in the fraction column, as compared to the boiling point of the material. (4.5.115.38)

The need to explain the process in detail requires thinking at the sub-microscopic level and the macroscopic level simultaneously. Surprisingly, the fractional distillation process that appeared simple and obvious proved to be difficult for students to grasp.

Investigating students' understanding of the fractionating column highlighted that many students did not understand the process being depicted: These students held erroneous ideas such as the effect of the mass or size of the particle, the temperature in the column, and the state of the substance at 140ºC. In addition, many students did not relate their laboratory experiences to their theoretical interpretation of the process.

6.6.3 Column Chromatography

Although nearly all the students interviewed about this topic (13/15) agreed that the diagram was useful in explaining what was happening to the mixture in the column, many students were critical that the diagram of the column chromatography equipment (Figure 6.7) was not more similar to the equipment actually used in the laboratory. Consequently, they did not think that it was helpful to their laboratory work. Without the experimental work to support it, they had not appreciated the detail of the diagram until after they had completed the experiment, as is expressed in the following excerpt.

> *Katrina*: Yeah. I think it helped, 'cause having no idea about it, it definitely helped. It was a little bit difficult to understand at first. When I looked at it first I really didn't know what was going on in it. But yeah when you went into the lab and you saw what you had to do, then you could figure out how to relate it back to the picture.
>
> *Int.:* Okay. And are you the same?
>
> *Kel:* Yep. I guess like, from doing this prelab you don't fully understand until you actually do the practical, when you mix, like, the two of them together. (4.5.16.199-201)

I considered the textbook diagrams to be most suitable and informative; however, many students were critical about them, claiming them to be too complicated or too detailed. According to one student, the diagram is more about explanation than about the physical set-up.

> *Doug:* I find diagrams that actually show the set up of the equipment we are going to use in the lab far more instructional than conceptual diagrams, if you like. And I would regard that [referring to Figure 6.7] as a conceptual diagram, whereas where it came to actually setting up the lab equipment, I think a lot of people were having the problem of that, having to extrapolate and saying what we do with this. (4.5.15.88)

On the basis of the students' comments, a simpler diagram that more accurately portrays the actual laboratory equipment would be recommended. This may help students better understand the physical set-up of the experiment at the macroscopic level but it may not help them to understand the changes that are occurring at the sub-microscopic level.

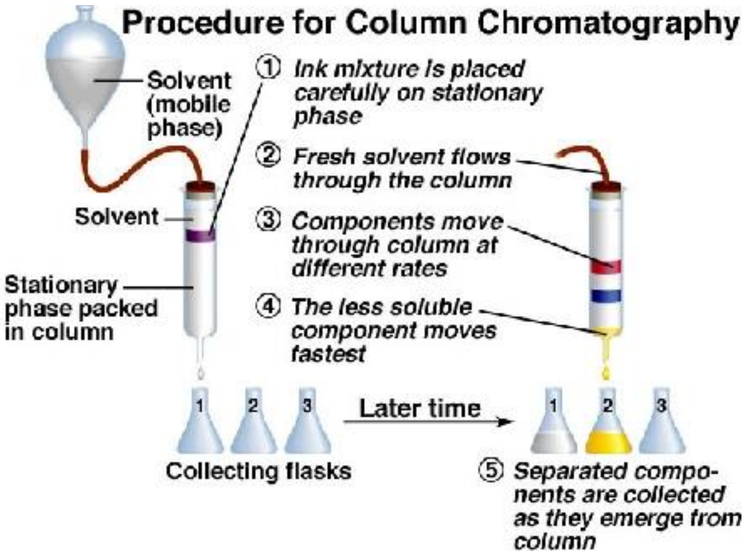


Figure 6.7 Column Chromatography as Presented in Diagram 3.4 of Pre-laboratory Exercises

Students' understanding of the chemistry underlying the column chromatography varied. When prompted to consider the molecular level in the interview, only three of the students interviewed understood the molecular level perfectly (3/17), some couldn't provide a description at all, while for others their descriptions revealed some misunderstandings. For example:

Ben: I haven't thought about it. I would have assumed that the one with the higher solubility, the molecules wouldn't stick together as much, they would actually move through, because they would be smaller. Whereas with the less solubility, the molecules would stay closer together and so therefore they wouldn't move through all the particles as quickly, because they'd be larger. (4.5.12.213)

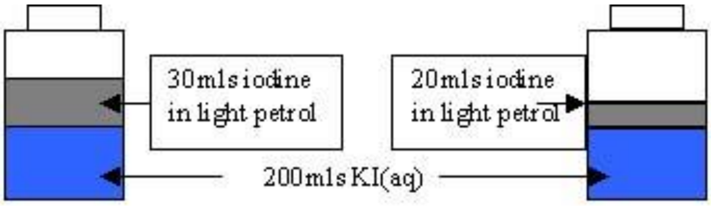
Alice: I think that the smaller molecules pass through first, and then the medium ones and then the larger ones. (4.5.3.137)

Without the interview questions to prompt them, most students considered this process at the macroscopic level only, without considering the sub-microscopic level. Only the very able students automatically gave an explanation at the sub-microscopic level:

Mat: I think for me what I learnt was that the technique is based on the polarities of different substances to different materials. So, from the evidence that I got from the chromatography, that (theory) became more clear to me. (4.5.5.131)

Mat displayed a sub-microscopic view – considering the macroscopic and sub-microscopic levels simultaneously and spontaneously as described in section 6.6.1.

6.6.4 Chemical Equilibrium



Shake each jar for 15 minutes
Identify two layers- aqueous and organic
For EACH jar –
-pipette 50mLs aqueous layer and titrate with 0.02 M $Na_2S_2O_3$
-pipette 5mLs organic layer and titrate with 0.002M $Na_2S_2O_3$

Potassium iodide (I^-) is in solution; it doesn't dissolve in light petroleum.

Iodine (I_2) is dissolved in light petroleum, it doesn't dissolve in water.

The aqueous solution and the organic solvent (light petroleum) don't mix.

There are two equilibriums occurring:

- in the aqueous layer
- between the aqueous and organic layers

In the aqueous layer:

$$I_{2\,(aq)} + I^-_{(aq)} \longleftrightarrow I_{3(aq)}$$

(From Iodine in light petrol) + (from KI)

At the organic / aqueous interface:

$$I_{2(org)} \longleftrightarrow I_{2(aq)}$$

Figure 6.8 Equilibrium Experiment as Presented in Diagram 4.3 of Pre-laboratory Exercises

The aim of the experiment for Week 4 was to determine the equilibrium constant for the iodide/tri-iodide system (Appendix Q). In discussing the equilibrium experiment, students were using multiple representations that included:

- the physical jars and solutions – the macroscopic level.
- the ions and molecules - moving within and across the two solvents – the sub-microscopic level.
- the drawing (Figure 6.8) and equations – the symbolic level – representing the macroscopic and sub-microscopic level respectively.

Interview comments confirmed that students realised that Figure 6.8 did not show the molecular level, but as Kel explained, its presence is assumed:

> *Kel:* Yeah, but when you shake it; you know that the mixture will mix, so there's something happening with the molecular level that you know of. But you can't tell from that. (4.5.16.289)

This comment suggests that Kel was developing a sub-microscopic view.

All students attempted to describe the process. Nearly all students interviewed (94%; 16/17) were able to describe the term dynamic state indicating that they understood the equilibrium process. Betty spontaneously used an analogy to describe the equilibrium process:

> *Betty:* We've got a thousand people and we've got, because I catch the Armadale train to here. So we've got five hundred people in Perth and five hundred people in Armadale but we've got, you know, trains just going back and forth, and at the end of it we end up with like seven hundred and fifty in Peth, two hundred and fifty people in Armadale, the rate of people travelling this way. (4.5.14.183)

Despite this high level of understanding for the equilibrium process in general, there were a large percentage of students who could not understand the equilibrium process occurring in the experiment. The interview data showed that some students (59%; 10/17) had difficulty understanding the chemicals they started and ended with and were often confused about the species – iodine, iodide ion and tri-iodide ion – and the medium. But there were students who understood the relationship between the two equilibrium systems, as is demonstrated with this excerpt from the interview with Caz:

> Int.: Okay, so do you have any idea what was happening?
>
> Caz: The iodine was being pulled from the organic layer into the aqueous.
>
> Int.: OK
>
> Caz: And then, because that already had, I can never remember which way to pronounce.
>
> Int.: Oh, it was iodide.
>
> Caz: Iodide, (begin) because that already had iodide in it. It was going between iodine and tri-iodide.
>
> Int.: So the new things-. What did you start with? You actually started with iodine organic?
>
> Caz: Yep.
>
> Int.: And then what was the other one?
>
> Caz: That was potassium iodide. So you're adding the iodine organic and then that's going into tri-iodide.
>
> Int.: So these are new products, that weren't there before. You've understood that idea?
>
> Caz: Yep. The iodine was being pulled from the organic layer into the aqueous. (4.5.4.112-113)

Throughout these interviews I repeatedly drew the equations onto Figure 6.8, transposing the sub-microscopic level onto the drawing of the macroscopic level. Many students (56%; 9/16) could not relate the equations to the macroscopic diagram:

Int.:	Now we're talking about these symbols and these equations. You understand the equations? What they mean?
Katrina:	I'm not very good with equations. As soon as I see something like that I just, yeah, I just, I don't know. Just seems to freak me out.
Int.:	Okay, that's-.
Kel:	It's understandable, but, I wouldn't know, like, because you have two mixtures, I wouldn't know which one goes in which. (4.5.16.280-283)

Kel wanted to match each equation to a solution and treat them separately. I assume he considered the equilibrium was occurring at the interface. This misunderstanding was common, for example:

Int.:	Do you think the experiment showed you something was at equilibrium?
Jen:	Yeah, because you had the layers. If it wasn't at equilibrium then they'd just mix, wouldn't they?
Int.:	No.
Sue:	This is where I look back I lack that kind of understanding, like I can't relate the two layer thing to the idea. (4.5.7.288-292).

Karen:	If it's in equilibrium it will be separate, won't it?
Int.:	No.
Karen:	Oh isn't it? (4.5.13.405-407)

This was a common mistake. Students were drawn to the prominent macroscopic physical feature of the two immiscible layers because they could see it and assumed that this was a manifestation of the equilibrium situation. While Katrina and Kel interpreted the two separate layers as meaning that no reaction was occurring because the solutions were not mixing:

Kel:	It shows there's nothing happening, because there's two mixtures that are separated. If there was something happening there would be a whole pool mixture.
Katrina:	Yeah.
Int:	Okay, but they're two immiscible liquids.
Kel:	So it shows you that they can't be mixed together.
Katrina:	Yeah. That-.
Int.:	Okay. So what do you have to do to mix them?
Kel:	Shake it, is it?
Int.:	That's why you shook it for twenty minutes. Remember?
Katrina:	Yeah, it took ages. (4.5.16.267-276)

Reminding students of the link between the physical shaking of the flasks at the macroscopic level and the chemical reaction occurring at the interface of the two liquids and within the organic liquid proved valuable. This comment by Caz, illustrates that she was aware of the difference between the physical features and the molecular features that were occurring.

Int.:	So can you understand why it's important to understand what's happening at the molecular level?
Caz:	Yeah. Because to look at just physically what you're doing, just shaking it. But that doesn't really tell you anything about what's going on, 'cause it's not about the two layers, it's what's in the layers. (4.5.4.162-163)

With two interrelated equilibrium reactions occurring simultaneously, the experiment highlighted some of the misunderstandings between the macroscopic and sub-microscopic levels of chemical representation of matter. Karen also assumed that the equilibrium was across the two layers. She thought the top layer of the equation referred to one equilibrium system and the bottom to another equilibrium system:

Karen:	But I would assume that that's one layer, and that's two - the bottom layer.
Int.:	Oh.
Karen:	Yeah, that's how I looked at it.
Int.:	Did you?
Karen:	Yeah.
Int.:	Okay.
Karen:	Because I thought, well that's the top layer and that's the bottom layer, and I know that that's in the bottom layer and that's in the top layer. I didn't realise it was dividing. (4.5.13.383-389)

Karen inferred that the two immiscible layers in the flask corresponded to the numerator and denominator of the equilibrium constant. Other students wanted to treat the equations separate from the experiment. They could understand each level of chemical representation of matter but could not relate the representations to each other. This is described in the quotation from the following interview:

Int.:	Does this data, – the image, the equations and the experimental work – make sense to you?
Sue:	Yeah, they make sense.
Int.:	And the equations?
Lee:	They make sense, but I can't really relate them back to what's happening.
Jen:	Yeah, yeah.
Lee:	Kind of separate.
Int.:	Okay, so you think you've got them separately.
Jen:	Yeah.
Int.:	And the lab work. Did you link the lab work to the picture and to the equation?

Sue:	Definitely to the picture.
Jen:	Yeah.
Int.:	But not so much to the equations?
Sue:	No. (4.5.7.251-263)

While students were able to appreciate the macroscopic properties of the laboratory experience and Figure 6.8 illustrating the laboratory equipment, for some students the sub-microscopic properties eluded them. These students commonly described having difficulty linking the laboratory work, Figure 6.8 and the equations together. In the interviews, Doug and Mat, two very capable students, both described spending time after the laboratory session working out what had happened at the sub-microscopic level. It was a complicated experiment and the sub-microscopic view was not always evident even for the most able students. As he described his personal mental model, Doug's response illuminates the difficulties students encountered:

Doug:	I guess in truth I actually treated them a little bit separately with that, because I found it not so much that there were changes occurring in the aqueous and the organic layers and there was an equilibrium being attained by mixing the iodine or whatever. But the actual changes were occurring to the iodine in that movement, I had to spend a long time checking about with that one.
Int.:	The problem here is that you didn't actually see any difference between the pre-equilibrium and post equilibrium situation. What I mean it is all-mathematical – It is hard to understand a process that has no visible change.
Doug:	Yeah. I guess-. I was trying to at one stage trying to visualise, (something) you had the two layers and you actually had the solid and then whatever and the mixing, and I was trying to visualise the actual shape of the molecule absorbed, in a pictorial representation of molecules (be at the ball).
Doug:	And separating out, with the, negative staying there and moving up and stuff like that. I couldn't grab it, but I think that may have actually been a more workable option to show the movement of the ions. (Referring to the researchers drawings – adding the equations to Figure 6.8) (4.5.15.114-118)

In Doug's endeavour to understand the sub-microscopic level he drew on models and representations, demonstrating a chemical way of approaching the problem. Mat described here how he went about trying to understand the experiment:

Int.:	But when you were doing the lab, you probably didn't have a good understanding of what was happening.
Mat:	No. I didn't know what was happening at the molecular level. But when I sat down after looking at the procedure that we had carried out in the lab, and looking at the questions, and then what we were asked to find out, I could link the experiment to the question. Try to develop some point of view.
Int.:	All right. So when you did that, how did you go about making that link. Did you actually draw pictures or did you just think about 'well I've got this organic layer and I've got this aqueous layer - Did you do this sort of thing what I've done here?
Mat:	I did have an idea of, I had an idea of the setups, and what was added to each setup. So, in some way, I didn't have the diagram on paper, but I had an idea in my mind that this was what was happening.
Int.:	And you definitely understood that the equilibrium constant you measured was for which equilibrium system?

Mat:	The equilibrium that I measured?
Int.:	Mm.
Mat:	Well it was for the iodine moving from the aqueous, the iodine in the aqueous layer reacting with the iodide that was added in the aqueous layer.
Int.:	So it was for the equilibrium just within the aqueous layer.
Mat:	Just within the aqueous layer. And I think there was some point where we had to subtract the organic layer. (4.5.5.204-213)

Mat is a very able student and worked at understanding the changes that were occurring at the sub-microscopic level in the experiment. He demonstrated transferring from the macroscopic level to the sub-microscopic level.

A common observation was students processing the equations and mathematical calculations without relating this data to the macroscopic laboratory experience. This is not surprising considering that in this experiment no observable changes occurred at the macroscopic layer, making it difficult for students to understand if equilibrium had been attained. Titrations were performed on the substrates to identify ions that were not reactants, thus indicating that reactions had occurred. All students agreed that Figure 6.8 did not help them understand the experiment at the sub-microscopic level. Some students wanted there to be more sub-microscopic data included on the diagram of the macroscopic equipment.

Students appreciated the results table in the laboratory worksheet (Appendix Q) that they used to calculate the equilibrium constant even though they had difficulty relating the mathematical constant to the state of equilibrium.

Caz:	Well that just gives you your equilibrium constant which, I haven't' quite got my head around what that actually is, at this stage it's just a number. But basically that would be your equation at the point where it's equal amounts on either side, that's - I suppose that's a fractional value. (4.5.4.145)

There was confusion with some terminology; for example, the term solvent was used carelessly, some students thought that aqueous meant liquid instead of water, and light petrol and organic were used interchangeably; with some students not understanding that in this situation their meaning was the same. Also many students did not appreciate that when using the K_D value in the calculations for the reaction occurring across the two mediums, it was assumed that that system had attained equilibrium.

In discussing the experiment, the researcher was continually drawing the sub-microscopic particles onto the macroscopic diagram – in an attempt to help the students understand the equilibrium process. Most students admitted that they had difficulty with this experiment. Nevertheless, discussion with students showed that all levels of representation – Figure 6.8, the equations, and the experimental work - contributed to the students' ideas of chemical equilibrium. These results confirm those reported by Dori and Hameiri (2003) whereby students' mathematical ability was a significant factor to their problem solving ability as well as the emphasis on the macroscopic, microscopic, symbolic and chemical process of the problem.

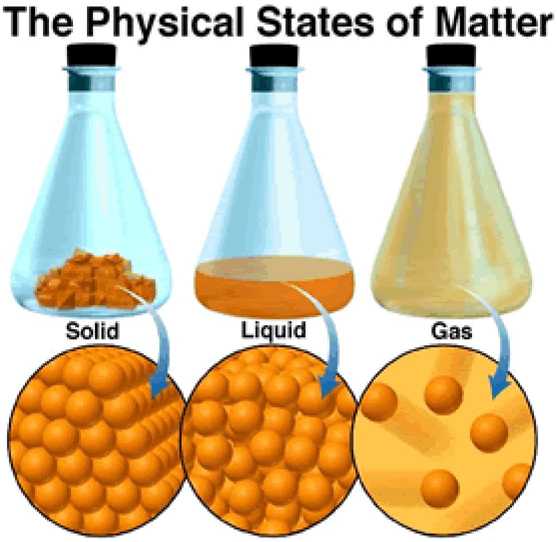


Figure 6.9 Physical States of Matter as Presented in Diagram 5.1 of the Pre-laboratory Exercises

6.6.5 Experiment Freezing Point Depression

All students interviewed were very familiar and comfortable with the ball-type representation of solids, liquids and gases as shown in Figure 6.9. The model was logical to them because their experiences with the macroscopic features were consistent with the model of the sub-microscopic level. Students were able to talk about the model easily:

> *Alice:* It's easy to, um, well understand it something like, yeah. [pause] Well it makes sense, like a solid having lots of particles close together, and then a liquid having, yeah, and then a gas having just molecules everywhere. (4.5.3.283)
>
> *Debra:* Only that, as I said, explaining or reminding me that, even when there is nothing there, there is actually a gas. (4.5.19.242)
>
> *Kay:* Um. It's like when it's liquid, there's not a proper structure, they can move around so freely, and when it solidifies they sort of set, and, and they… (4.5.18.305)

The model was so familiar to students that they often treated it like it was the real thing. However, all students appreciated that the representation was not real.

Int.: Are they really like these little balls?

Betty: No. Unless you get crystals or something, so they might be structured like that, but I don't think that they are. This is like a stack of cans - like a stack of apples at Coles. (4.5.14.217)

The accuracy of the ball-type model to each state of matter proved to be an important point in students valuing the representation.

Int.: Do you think it is real? Or is it a representation.

Doug: No, I think it's a representation.

Int.: Do you think it is useful?

Doug: Um, it's simple. It's ah - you can easily look at it and make the link from the level of packing of the individual atoms from solid to gas, and the relative movements of the molecules, then in them. I think if you actually try to um give a base understanding of it or of, you know, the bottom line, a base line of understanding of what comprises solid, liquids and gases, it's a fine diagram. If you're looking for something a little bit more advanced than that then you gotta go into something a little bit more in detail but for what it's trying to represent I think it's fine. (4.5.15.194-196)

Betty: Because it just describes the relation between like the molecules. And for the solid they're not, necessarily that rigid, but they might be like play-dough. But a solid, you can squash it, whereas with a liquid they're constantly moving over each other. And gases just (bumping it) around with big gaps between them. (4.5.14.205)

Kel and Katrina, commented on the value of the ball-type model in helping to visualise the sub-microscopic level.

Int.: Does the representation of solids, liquids and gases as round balls help you to understand the change of state from one to another.

Kel: Yep. You never think of it other than a round ball. You wouldn't think of it as a triangle.

Katrina: Yeah. I would think of it as round balls. (4.5.16.504-506)

The students who were interviewed were mostly able to link the model with the changes of state that they observed in their laboratory work. The model worked best for a pure substance and some students commented that it was difficult to know how it would be different for an impure substance. The experiment in Week 5, using freezing point depression, encouraged students to think about the differences of pure and impure substances as is demonstrated in this comment.

Kay: Yeah um, no it wasn't clear. When it's pure, I have a proper understanding and maybe a good picture in my mind but when it's sort of not pure and these are mixed together, then I don't think I have a good picture of it. (4.5.18.321)

The model has the potential to explain the difference between pure and impure substances; however, not many students explored this. Here the diagram of the physical states of matter was a useful model for students when considering the freezing process and the impact of impurities. Because students were familiar and comfortable with the model, they were able to discuss it and apply it readily.

6.6.6 Strong and Weak Acids

In explaining about strong and weak acids, Figure 6.10 was included in the pre-laboratory exercises. Although the diagram represented the macroscopic and sub-microscopic levels expertly – three out of the five students interviewed claimed that the diagrams were difficult to understand. Comments from students, Rae and Marc, who isolated the two levels and did not relate them to each other, are illustrated in the following excerpt from the interview.

Int.:	So is this sort of diagram useful? [referring to Figure 6.10]
Rae:	Probably not, because I don't understand these pictures.
Int.:	The molecular pictures.
Rae:	Yeah, but having the equation down there and having the graphs, it is helpful.
Int.:	You understand what that means. The HA. It's all dissociated.
Rae:	Been used up.
Int.:	Yeah. Whereas this one it's not all dissociated.
Rae:	Yep. Only a bit.
Int.:	Okay, but you don't link that to that picture. What are the changes that are occurring to the chemicals at the molecular level? You don't use this molecular level?
Rae:	No. I get confused sometimes with stuff like this because it's just like- it's- I don't know why. I don't find that useful to me, personally.
Int.:	Okay. That's all right.
Rae:	Because I like to see it like this, because then I can go, okay that's a plus and that might join up to a minus, and stuff like that. [referring to the equation] (4.6.1.109 – 123)

Int.:	Do you think these pictures are of any value? This is at the molecular level.
Marc:	It didn't help for me but it might help for someone else.
Int.:	Do you get more out of the graphical representation than the molecular?
Marc:	Yeah. Because here you can see like all the acid's used up. (4.6.10.117-122)

Both Marc and Rae have weak backgrounds in chemistry and this could be why they resisted using the sub-microscopic level. A similar observation was made with a student in Study 3 (section 5.4.2c).

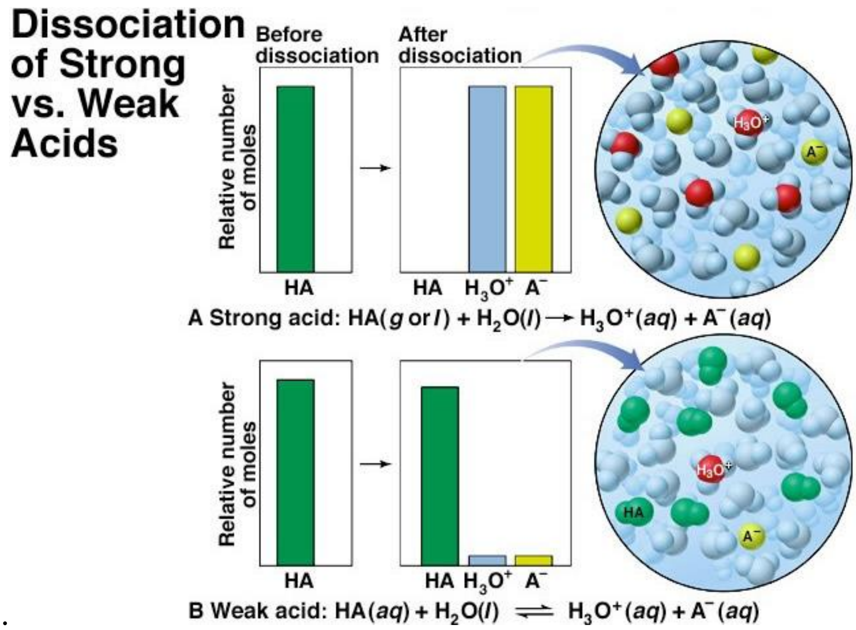


Figure 6.10 Strong and Weak Acids as Presented in Diagram 8.8 of Pre-laboratory Exercises

6.6.7 Structural Formulas

Those students with limited background knowledge in chemistry did not easily connect alternative symbolic representations of the same molecule. For example, molecular and structural formulas were frequently not identified by students to be the same compound – simply because they looked different. Students were asked about the diagram of a triglyceride ester (Figure 6.11) and when interviewed were not in the habit of drawing out the molecular formulas to show the structural formulas. Consequently, they did not easily identify the carbonyl group.

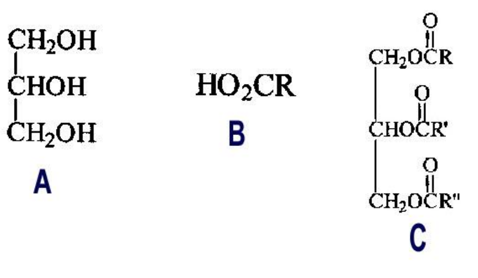


Figure 6.11 Triglyceride Esters as Presented in Diagram 6.3 of Pre-laboratory Exercises

Students' comments show how they had to learn to use the diagrams:

Gina: I probably would have noticed if I'd drawn it out, but um, I've done it - I'm not in the habit of drawing them out. (4.6.2.79)

Rae: Yeah, I just used to chuck, like put in, I'd put in triglyceride ester (into an internet search) and it would come up with all these different sites and I just go into the ones that....

Int.: Okay. So do you understand what that formula there for say B would mean?

Rae: Yeah, I actually draw them out like that [referring to a expanded structural formula] in the tests because I understand them better, than that.

Int.: So, okay, and the same with this?

Rae: Same with all of them.

Int.: So you actually draw out the structure?

Rae: That's the first thing I do when I get a problem like that. (4.6.1.35-41)

To experienced chemists the structural formula is self-evident from the molecular formula; however, with these students, with very little experience, it is not. For the common hydrocarbon families, the Silberberg (2000) textbook provided spatial and structural formula as well as common uses. These diagrams were used in the pre-laboratory exercises for aldehydes and ketones (Figure 6.12), carboxylic acids and amide molecules. These diagrams highlighted the common group and provided multiple representations and terminology of the compounds, showing the structural and spatial representations. The students interviewed (n=5) considered these representations to be useful to varying degrees.

Gina: Yes, because it reinforces then, the point you're actually trying to make. And the other thing is that some people see things in different ways. See, I wouldn't look at that alone. But the three together [spatial, structural and text] was good. (4.6.2.312)

Gina: Yeah, I think that's useful for me anyway, because, being in the everyday world, they can see what you're using it for, and then you can link it back to the diagram, and it makes more sense for me, personally, because I'm not a chemist. (4.6.2.322)

Rae: That means nothing to me. [referring to the spatial representation]

Int.: So the balls mean nothing to you. Okay.

Rae: I like that there [referring to the structural formula]

Int.: What about the uses underneath. Do you think they are of any value? Did you look at them?

Rae: No.

Int.: No. Wasn't interested?

Rae: I looked at it and then thought I don't need to remember that. (4.6.1.291-297)

Rae's comment indicated that her motives might be leaning towards learning to pass rather than to learning for understanding. She can still have the attributes of an intentional learner – but one motivated and intending on passing. Rae had already dismissed the sub-microscopic level – learning and passing without it.

6.6.8 Logarithmic Relationships

Many students undertaking this unit find their mathematical skills to be lacking. For the topics of acids and bases, students need to have an understanding of the logarithmic scale. All students interviewed valued the diagram in Figure 6.13 that showed clearly the relationship between a logarithm and a number and also gave some perception of the size of the concentrations that were being considered.

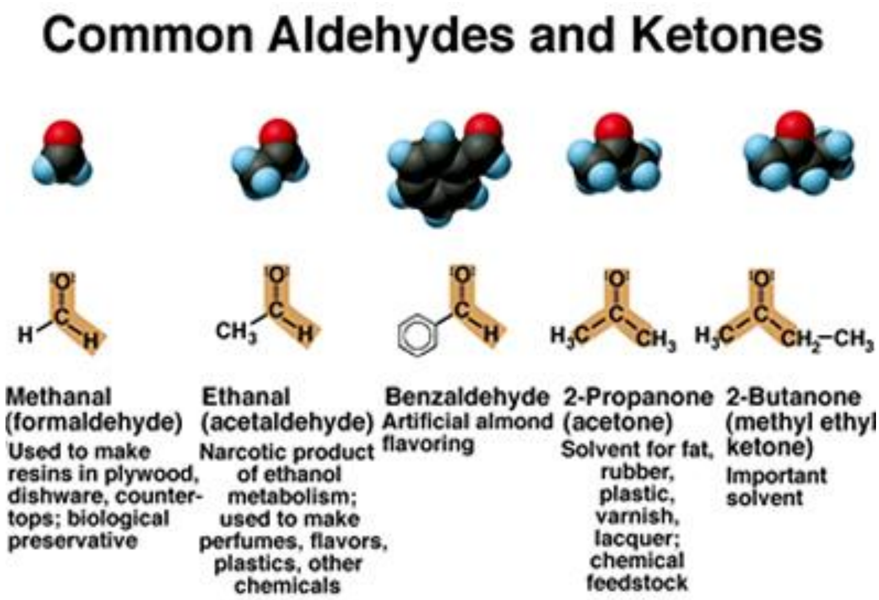
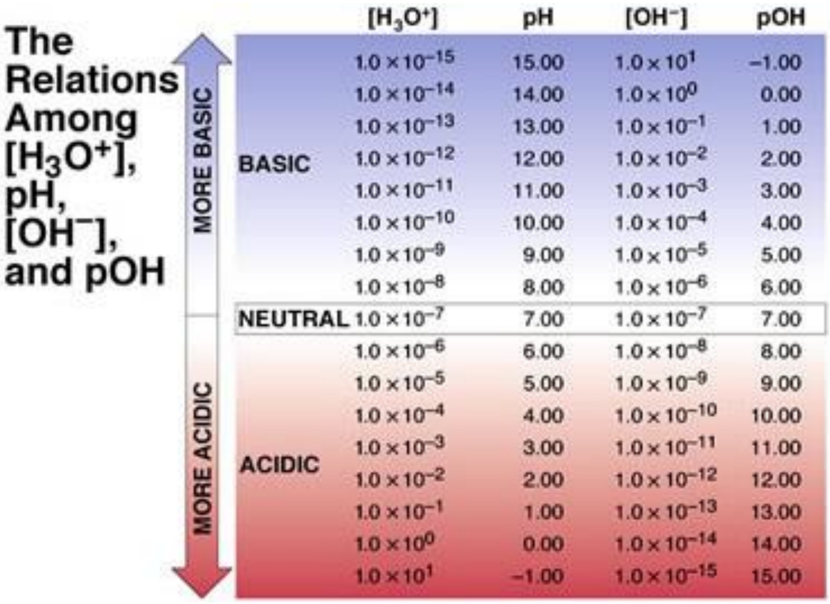


Figure 6.12 Common Aldehydes and Ketones as Presented in Diagram 12.5 of Pre-laboratory Exercises

Some students were confident using the symbolic representations such as graphs, or trend diagrams but found the sub-microscopic representations foreign and of little value. This observation is consistent with the results in Study 3, from which Figure 5.8 was formulated, depicting the situation where some learners used only two sides of Johnstone's triangle – the macroscopic and symbolic levels. In this study, a similar result is observed – those students with weak chemical backgrounds avoided the sub-microscopic level.



The Relations Among $[H_3O^+]$, pH, $[OH^-]$, and pOH

		$[H_3O^+]$	pH	$[OH^-]$	pOH
MORE BASIC		1.0×10^{-15}	15.00	1.0×10^{1}	−1.00
		1.0×10^{-14}	14.00	1.0×10^{0}	0.00
		1.0×10^{-13}	13.00	1.0×10^{-1}	1.00
	BASIC	1.0×10^{-12}	12.00	1.0×10^{-2}	2.00
		1.0×10^{-11}	11.00	1.0×10^{-3}	3.00
		1.0×10^{-10}	10.00	1.0×10^{-4}	4.00
		1.0×10^{-9}	9.00	1.0×10^{-5}	5.00
		1.0×10^{-8}	8.00	1.0×10^{-6}	6.00
	NEUTRAL	1.0×10^{-7}	7.00	1.0×10^{-7}	7.00
MORE ACIDIC		1.0×10^{-6}	6.00	1.0×10^{-8}	8.00
		1.0×10^{-5}	5.00	1.0×10^{-9}	9.00
		1.0×10^{-4}	4.00	1.0×10^{-10}	10.00
	ACIDIC	1.0×10^{-3}	3.00	1.0×10^{-11}	11.00
		1.0×10^{-2}	2.00	1.0×10^{-12}	12.00
		1.0×10^{-1}	1.00	1.0×10^{-13}	13.00
		1.0×10^{0}	0.00	1.0×10^{-14}	14.00
		1.0×10^{1}	−1.00	1.0×10^{-15}	15.00

Figure 6.13 The Relations Among $[H_3O^+]$, pH, $[OH^-]$ and pOH as Presented in Diagram 8.8 of Pre-laboratory Exercises

6.6.9 Summary and Response to Research Question 2.3

Data from Studies 1, 3 and 4 have been presented to address Research Question 2.3: “How does students’ understanding of the three levels of chemical representation of matter enable them to effectively transfer from one representational level to another?” Throughout the instruction in each study, students’ understanding of the three levels improved with practice and use of the three levels of representation, enabling them to transfer from one level of representation to another more easily. In Study 1, the high school students became proficient at transferring between various symbolic representations and transferring from the symbolic level to the sub-microscopic level by practicing the tasks repeatedly, discussing their understanding and getting feedback from peers and instructors. With Studies 3 and 4, the repetition of the quantitative experiments in the laboratory – there were seven laboratory sessions in semester 1 involving quantitative inorganic analysis – each involving numerous titrations – meant that students practised transferring between these two levels. These efforts are valuable in helping students to understand the sub-microscopic level, which is the most abstract and not surprisingly, shown to be the least understood.

Study 4 provided evidence of the diagrams of the macroscopic and sub-microscopic level of matter to be useful teaching tools, but there is also evidence of possible misconceptions arising from their use. The results reinforce some conclusions already discussed about the accuracy and precision of representations, and the descriptive and predictive value of representations. Students' responses to the questions about the diagrams used in the pre-laboratory exercises from the interviews were often basic and primitive revealing their lack of understanding and weak background knowledge. Their responses highlighted the fact that the vocabulary used in chemistry is precise and limited and some students were not familiar with the regular chemical vernacular. The research results here suggest that the inadequate chemical background of some students can lead to them misinterpreting diagrams, so careful consideration needs to be given to the choice of the diagram, the detail of the diagram, their level of representation and the use of terminology and symbolism.

6.7 Understanding Chemical Explanations

Research data are drawn on to address Research Question 2.4: "How the variety of representational forms, which students encounter in chemistry, impact on the epistemology, ontology and social factors that have been shown to contribute to conceptual change?"

6.7.1 Three Levels of Chemical Representation of Matter

The students' understanding of the three levels of chemical representation of matter forms the foundation of their conceptual understanding of chemistry. Kozma and Russell (1997) identified significant differences in the representational competence of experts and novices, suggesting that the development of skills in identifying and transforming representations are advantageous to learning chemistry. Students may not know the names that have been assigned to the levels but have demonstrated an ability to transfer from one to another making analogical relations (Collins & Gentner, 1987; Gabel, 1998).

The data in sections 6.3–6.6 have attempted to show the important role of the three levels of chemical representation of matter in explanations of chemical phenomena in a variety of ways:

- The use of a variety of symbolic representations of the sub-microscopic level.
- The use of a variety of symbolic representations of the macroscopic level.
- The macroscopic level through laboratory experiments.

The use of symbolic representations of the sub-microscopic level in explaining the macroscopic nature of chemical phenomenon can expand the learners' understanding of chemical phenomena. The abstract nature of chemistry and the need for the learner to develop a personal understanding of the sub-microscopic nature of the chemical nature of matter necessitates the use of an extensive range of symbolic representations such as models, problems and analogies.

The results of the Studies 3 and 4 are consistent with the exploding triangle framework discussed in chapter 2 (section 2.4). Students were taught all three levels simultaneously, with numerous representations at particularly the symbolic level of representation. However, the links between the three levels have been shown not to always be present. The results confirm Johnstone's warning against using all three levels simultaneously with novices, as mentioned in section 2.2.2.

The sub-microscopic level has been described as abstract and the least well understood by students. If students think spontaneously at the sub-microscopic level, I have described them as having a sub-microscopic view, an insight into the chemical nature of matter. This insight is not magical, but an application of knowledge. There are three important facts (section 6.3.6) that need to be understood in order to gain a sub-microscopic view:

- Many symbolic representations are used to help understand the one sub-microscopic level of chemical representation of matter.
- The symbolic level of chemical representation of matter is a representation, while the sub-microscopic level of chemical representation of matter is based on real observations at the sub-microscopic level.

- Accuracy and detail provided by multiple symbolic representations are sources of information to understand the sub-microscopic level of chemical representation of matter.

This chapter is addressing objective 2, to investigate students' perceptions of scientific representations, in particular chemical representations of matter at the macroscopic, sub-microscopic, and symbolic levels. The data presented here suggests that most students in the three studies had a fair understanding of the macroscopic and symbolic levels of representation; however some students' understanding of the sub-microscopic was lacking, despite it enhancing explanations of chemical concepts. For those students, the sub-microscopic level was not plausible, intelligible or fruitful. Nevertheless, there are some good examples of students having a personal, independent and well-developed sub-microscopic view of a macroscopic event.

Distinguishing the chemical content from the explanatory tools is not always obvious and consequently the role of explanations and the relationship of the symbolic representations to the macroscopic and sub-microscopic levels should be overtly discussed. Some students, particularly those with a weak chemical background did not consider the sub-microscopic nature of matter simultaneously with the symbolic and macroscopic levels of chemical representation.

Erduran and Scerri (2002) have identified the autonomy of chemical explanations as a significant component of the philosophy of chemical education. The results from Studies 1, 3 and 4 presented here provided numerous examples of the consistent and repeated use of the three levels of representation in many chemical explanations. In this way, the students are indirectly learning the way of knowing about chemistry – a philosophical approach. The styles of the explanations reflect a philosophy of chemical education. This idea is consistent with Erduran and Scerri (2002, p. 21) when they discuss a new curriculum that "uses acid-base chemistry as a context for developing learners' understanding of the role of models in chemistry". Hence the content of the acids and bases or the content knowledge serves as a context not as an end. Hofstein and Mamlok (2001) use a similar approach in integrating the content of chemistry with societal, environmental and technological implications when investigating how tomatoes grow under plastic sheeting. This philosophical change to emphasising the way of knowing about chemistry should promote more meaningful understanding.

6.7.2 Chemical Explanations and Learning

Chemical explanations rely heavily on the sub-microscopic level so it is important for students to have an understanding of this level. The high school students in Study 1 were given a substantial amount of time dedicated to building an understanding of the sub-microscopic level of matter, mainly using the ball-and-stick models and structural formulas. Discussion about the molecular structures occurred in the group work and there were opportunities for questions. The teacher summarised the important points of each lesson, directing the students' learning. On the other hand, the first-year university students in Studies 3 and 4 experienced a more isolated learning experience, with the main opportunity for questions and discussion occurring in the weekly laboratory sessions during which laboratory experiments had to be completed. The laboratory work and exercises required students to transfer between the macroscopic and symbolic levels; however, relations to the sub-microscopic level were not accentuated. The mature students with no chemical background were a valuable source of data for this study because they were aware of their own learning and had an appreciation of the changes to their understanding. It was surprising how little some students knew in the first few weeks of Studies 3 and 4. The students with no chemistry background had to learn about the sub-microscopic level and the role of representations quickly.

The learning theory described by Skemp (1976) in section 3.7.1a, has been applied to the three levels of chemical representation of matter (Figure 3.1). Because chemistry is observed, represented and explained at different levels of chemical activity, the ability of a student to transfer from one level of chemical representation to another does provide an indication of their level of understanding of the chemical concept. The diagrammatic representation simplifies the process excessively. It would be naïve to infer that learning proceeds linearly as represented – in fact it is much more complicated with students working at a range of levels for a range of concepts. But generally as students' ability at transferring from one representational level to another improves, then there is a development in the students' understanding.

The application of learning theories such as the instrumental/relational, or conceptual change theory are consistent with a constructivist position in which learning science-knowledge involves the process of knowledge-construction. The reorganisation of one's views on existing data can be a process of assimilation where the new ideas are integrated into an existing knowledge framework or accommodation that requires the construction of a new knowledge framework. Learning is probably a combination of both, with the former being more common, consistent with Kuhn's idea of intermittent progress in science. The process of learning as a result of model construction is described as being fundamental to theory formation in science (Clement, 2000; J. K. Gilbert & Justi, 2002). This is because models play a special role in the development of scientific ideas and in the scientific method.

Students' appreciation of the symbolic representations in the form of teaching models and scientific models and also students' experiences with the macroscopic and sub-microscopic levels of representation of matter contribute to the development of their mental models of the scientific phenomena. This is portrayed in Figure 6.14 with the mental model the product and the centre of the triangle – connecting all three levels of chemical representation of matter. The learners' interpretations of the multiple representations of matter are reflected in their mental model. The expressed model communicates their mental model.

The mental model in chemistry is the personal mental model of the sub-microscopic level of matter. The representations at the symbolic level probably contribute most to the students' mental model. Using the rising iceberg framework, (section 2.4) initially inexperienced students' mental models are undeveloped, corresponding to the small triangle; as they learn more chemistry, then their mental model expands as they focus on the sub-microscopic level.

In exploring the answers to Research Question 2.4 concerning conceptual change, the epistemological aspect, the ontological aspect, and the social/affective aspect of learning are considered with respect to the three representational levels of matter.

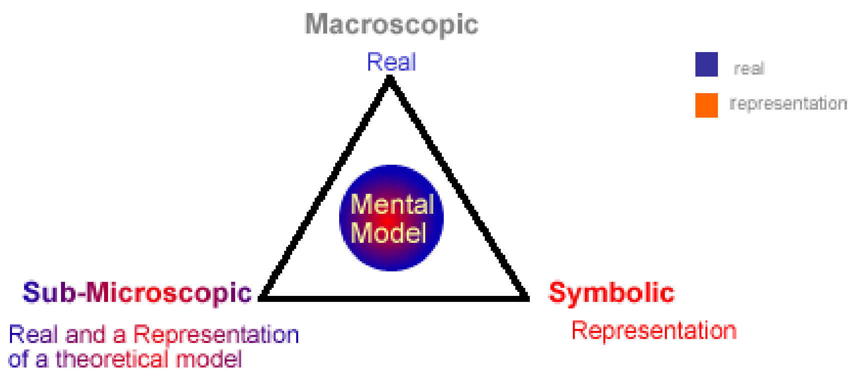


Figure 6.14 The Relationship Between the Three Levels of Chemical Representation of Matter and the Mental Model

6.7.2a The epistemological aspect

This aspect considers how the macroscopic, sub-microscopic and symbolic levels of representation of matter can help students in their process of knowing about knowledge. The explanatory function of the three levels supports a framework of knowledge that can help the development of a students' epistemology. The qualitative data showed that the students in Study 1 were using the teaching models to model chemical compounds. Through modelling, students were able to gain an understanding of the analogous relationship between the model (analogue) and reality (target) as discussed in chapter 3 (J. K. Gilbert & Boulter, 1995). Grosslight et al. (1991) suggest that "different levels of understanding models reflect different epistemological viewpoints" (p.799). This important link between modelling and epistemology is evident in the students' responses to the VOMMS instrument (section 5.3.4), where many students expressed an understanding of the role of models in the process of science. The teaching models provided learning opportunities for students when used in an active manner. The model-based teaching approach undertaken in Study 1 encouraged students to use the model to identify and name chemical structures and make predictions about chemical structures and their reactivity.

In Study 1, the students were modelling the scientific process by using the ball-and-stick models to identify possible chemical structures; the students were themselves, in a controlled way, practising scientific inquiry. In addition, the use of a variety of chemical teaching models emphasised the importance of providing different perspectives. It is through these processes that the students can develop their epistemology. Despite the model-based instruction, the results of the MCR survey were less than anticipated and it may be that the understanding comes with maturity and experience.

The results of the MCR survey for students from Study 3 and the results of the VOMMS instrument with the students from Studies 3 and 4 showed that the more mature students had a very good appreciation of the roles of models in the scientific process. For many students in Studies 3 and 4, there were dramatic improvements in their epistemology of chemistry; through hard work and application of knowledge, students developed a way of thinking about chemistry. There are examples provided in this chapter of improvements to many students' understanding of the sub-microscopic level. As discussed in section 5.5.2, the sub-microscopic level of matter promotes a chemical way of thinking – a chemical epistemology. For others however, the learning experience was driven by the course requirements encouraging a rote-learning regime that did little to improve their epistemology of chemistry. These students circumvented the sub-microscopic level of matter.

6.7.2b The ontological aspect

This analysis is an attempt to relate the students' level of understanding of chemical representations of matter to their ontological networks of knowledge for chemistry at the macroscopic and sub-microscopic levels. The ontological aspect refers to students' understanding of the nature or status of things in the world – the way students link their ideas and knowledge (Monk, 1995). The ontological perspective describes the learners "beliefs about the fundamental categories and properties of the world" (Chinn & Brewer, 1993, p. 17). The examples provided in this chapter of students identifying the three levels of chemical representation of matter and transferring between the levels gives support to each student having some ontological network of chemical knowledge.

In all three studies considered in this chapter, students experienced the three levels of chemical representation of matter. For many students this ontological framework for thinking and learning about chemistry was new to them. In order to use multiple chemical representations, students had to understand the relationship among the various representations. Examples of this have been provided, with some students finding the sub-microscopic level difficult to grasp, along with examples of improvements in students' understanding, inferring the development of an ontological framework in the learner. Several issues arise here such as students' perception of the reality of a representation and their understanding of the relationships between a representation and its target.

As Chi (1992, p. 179) described the "instruction about a new ontological category must proceed by teaching this new ontological category of concepts independently of the old or existing conceptions". However, it takes time, requiring "extensive learning about the new domain or ontology of concepts" (p. 180) for the new ontology for the concepts to be learnt. For students such as Leanne in Study 3 and Alice and Rita in Study 4 who learnt the new concepts for the macroscopic and sub-microscopic levels separately and did not link the two together, they hold separate ontological networks. Other students have separate ontological trees that are linked at some point, while experienced students like Mat demonstrated an integrated ontological knowledge network.

6.7.2c The social/affective aspect

The three levels of chemical representation of matter can be a source of motivation, learning and explanation. This was demonstrated in Study 1, where active participation by students with chemical models encouraged predictive, descriptive, and reasoning tasks. The excerpt below is typical of the dialogue between pairs of students - working together to build chemical compounds during Study 1 at high school.

S1:	Lets make decane.
S2:	Shall we take this apart?
S1:	No just add another row in there.
S3:	See I got it, got it.
S1:	There are different versions of each of these I hope you know. (778-782)

Characteristically the students were engaged in the task, discussing the problem before them. This cooperative learning experience exemplifies a social constructivist environment that is conducive to learning.

Studies 3 and 4 were more frenetic, with students required to learn a great deal of content, acquire necessary skills, pass required tests and submit laboratory reports in a 14 week semester. The first year university students worked collaboratively in the laboratory. The learning environment was driven more by assessment with the pressure of continual testing and course requirements forcing students to take a very focused and disciplined approach to learning, often resulting in a rote-learning regime. Many students in Studies 3 and 4 demonstrated a rapidly developing understanding of the chemical nature of matter.

6.7.3 Appropriate Depth of Learning

Not withstanding the importance of the framework consisting of the three levels of chemical representation of matter that has been described in the previous section, it is vital to question the relevance of some theoretical and highly mathematical chemistry to students who are non-major students, like those investigated in Studies 3 and 4, and high school students who are either just beginning to learn chemistry or have chosen not to continue science as a career. There is a need to assess the appropriate depth of chemistry that they should be required to learn. Johnstone (1982) uses an analogy of the use of a car – for most of the time the car exists at the descriptive and functional level (macroscopic) – detailed explanations of the mechanisms of the car (sub-microscopic level) are not needed or cared about by the general public. In chemistry, even without the sub-microscopic understanding, excellent scientific questions can be posed and experiments tested at the macroscopic level. Johnstone (1982, p. 379) suggests that "it would be arrogance … to assume that chemistry must have all three levels if it is to be respectable". So using this concept, the non-major chemists could still be thinking chemically, in a scientific manner, but have a more practical approach. This approach could direct learning to a higher level of conceptual understanding rather than the rote learning that has been observed in Studies 3 and 4. And consistent with a constructivist philosophy, the curriculum must take into account the students' prior knowledge – both chemical and mathematical – as well as what the students' needs for future careers.

The analogy of the car is consistent with the rising iceberg framework. Johnstone (1982) is in favour of exploiting the macroscopic level and introducing the sub-microscopic as needed. Through using more macroscopic references the chemistry could be more contextual and help to promote a higher standard of chemical literacy along with giving chemistry a better image.

6.7.4 Summary and Response to Research Question 2.4

Research Question 2.4 asked "How do the variety of representational forms, which students encounter in chemistry, impact on the epistemology, ontology and social factors that have been shown to contribute to conceptual change?" This research question has focussed on the explanatory tools and the process of learning that is demonstrated through students' understanding of the chemical content and processes. The data from Studies 1, 3 and 4 show how a variety of representational forms are used in helping students understand chemical concepts. The learning process has been related to students' ability to effectively transfer among the three levels of chemical representation of matter and their ability to identify each of the three levels and relate one level to another. This skill assists in the understanding of chemical explanations. The analysis delved deeper to examine the epistemological, ontological and social factors that are incorporated in the representational forms. Chemistry is unique and as such requires a particular *chemical* way of thinking that has been described as a chemical epistemology, which is closely aligned to having a sub-microscopic view of an event. The ontological network of chemical knowledge is closely aligned to students' understanding of each of the three levels of chemical representation of matter and how they are related. The social/affective aspect of students' learning was a source of motivation and learning opportunities.

6.8 Conclusion

This chapter has investigated the role of each level of chemical representation of matter (macroscopic, sub-microscopic and symbolic) in learning about chemical concepts. Although students may not be aware of the three distinct levels by name, they mostly use them appropriately, individually and sometimes simultaneously. This analysis has attempted to highlight how students often use one, two or three levels to explain or to understand a concept

The data were collected from diverse sources and have provided numerous examples of students using chemical representations, including chemical models, chemical equations, diagrams, and pictures in learning chemistry. The data provide good evidence of the value of the various chemical representations as learning tools. Most students had a good appreciation of the descriptive nature of chemical teaching models but some did not appreciate their predictive nature despite having used them in exploratory and predictive roles.

Considering the different abilities, backgrounds and ages of the students in the three studies, considered in this chapter, it is difficult to make generalities; however, overall these examples provided evidence of many students displaying a good understanding of the purpose of each representation. The variety of chemical representations can be classified according to the Johnstone's (1982) three levels of chemical representation of matter. The macroscopic and symbolic levels of representations are well understood by all students in the research. However, there are multiple examples of students, particularly those with weak chemical backgrounds, finding the sub-microscopic level difficult to grasp. Learning about the sub-microscopic level proved difficult for some inexperienced students who grappled with the nanoscale, its reality, and the idea that the atom was mostly empty space.

Explanations of chemical phenomena rely on the sub-microscopic level. There are examples of students transferring from one representational level to another in Studies 1, 3 and 4. However, there are also examples of students who are unable to use the sub-microscopic level. Thinking about chemistry at more than one level is a skill that is commonly introduced and taught in secondary school with the introduction of the atomic theory of matter. The results in this study showed that not all students had a sub-microscopic understanding, especially those with no chemical background. When these students looked at macroscopic diagrams they only saw the macroscopic diagram – whereas a more experienced person would see the sub-microscopic level as well, which was described as the sub-microscopic view. This subliminal understanding or interpretation could be more overtly addressed in lectures and laboratory sessions, so teachers and students understand representations such as models, and diagrams in the same way.

Most significant to the learning of chemistry is the ontological framework that the three levels of chemical representation of matter provide for the learner. By providing the learner with basic criteria on which to understand the explanatory tools commonly used in chemistry, then the understanding of the chemical content may be improved. Armed with this understanding, the learner can develop a way of thinking about chemical phenomena – described as the chemical epistemology – an understanding of the knowledge of how chemical ideas are built and an understanding of the way of knowing about chemical processes.

CHAPTER 7

THE DEVELOPMENT OF PERSONAL MENTAL MODELS

Chapter Outline

This chapter addresses the third objective of the research by focussing on how students learn and students' perceptions of their own learning. Section one presents the research questions that address the third objective. Section two examines the factors that influence students' learning. Section three identifies common learning strategies and section four examines how these learning strategies are related to the students' developing mental models. Section five focuses on the metacognitive aspect of learning that is considered alongside the epistemological, ontological and social/affective aspects that are influential to learning. Lastly, section six concludes the chapter summarising the main points.

7.1 Objective 3

This chapter presents data to address the last objective of the research, namely:

To investigate students' learning of chemical concepts in terms of the development of the learners' personal mental models, considering the intentions of the learner, the metacognition of the learner and conceptual change that is occurring to the learners' understanding.

Objective 3 is addressed with the following research questions in the corresponding sections of this chapter.

3.1 What are the factors that influence how and why students learn chemistry? (Section 7.2)

3.2 What learning strategies do students use in learning chemistry? (Section 7.3)

3.3 How do learning strategies contribute to the development of students' personal mental models of chemical phenomena? (Section 7.4)

3.4 How does students' metacognitive awareness influence their learning of chemistry? (Section 7.5)

Data from Studies 1, 3, and 4 are utilised to achieve the third objective. Because the learning situation for each study is unique – each study is examined separately. The studies provide different perspectives on the research questions and provide further validity to any conclusions that are made. The maturity and experience of the university students in Studies 3 and 4 provide invaluable insight into their personal learning processes.

7.2 Factors That Influence Learning

Research Question 3.1 asks, "What are the factors that influence how and why students learn chemistry?" Although the multiple data sources from Studies 3 and 4 with first year university, non-major students are presented to address Research Question 3.1, there are common issues that are applicable to all students.

Contrasting to the high school students involved in Study 1, the first year university chemistry students in both Studies 3 and 4 are given very little individual assistance and their learning environment is more isolated. Further, opportunity for discussion and asking questions is more limited. The responses from the first-year university students in Studies 3 and 4 revealed an encouraging level of maturity and philosophical understanding of the nature of chemical knowledge and the process of learning.

7.2.1 Factors That Influence Learning – Study 3 – Learning Introductory Chemistry for Non-majors

All the data sources from Study 3 were utilised in addressing the Research Question 3.1, in particular the results of the interviews, observations and interactions in the laboratory, and the university-monitoring instrument – SUE[12]. The SUE instrument that was administered during Study 3 at the end of semester 1, sought students' opinions of the unit Chemistry 117. The results are presented in Table 7.1.

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[12] SUE is an abbreviation for Student Unit Experience.

Overall, the students appeared to be accepting of the structure and organisation of the unit. The Department of Applied Chemistry that offers Chemistry 117 services numerous other faculties in the university. This chemistry unit is a prerequisite for other faculties such as biological sciences and health sciences. To this end, the chemistry unit must meet the needs of the students, the Department of Applied Chemistry and the faculty that is being serviced.

From the data, multiple factors that influence how and why students learnt chemistry were identified. These can be broadly categorised as internal factors and external factors. Internal factors – individual to the students – include the students' prior chemical and mathematical knowledge, modelling ability and the use of representations, time management, and motivation to learn chemistry. External factors – out of the control of the students – include the unit structure and organisation, assessment requirements and teaching resources. Data supporting these factors are provided and discussed.

7.2.1a Prior chemical and mathematical knowledge

Students who had studied chemistry in high school held varying mental models as evidenced by the way they recited memorised definitions such as the symbol for an element, and references to molecular representations such as the electron-dot formula. Students with prior experiences and knowledge in chemistry had an advantage in this introductory chemistry unit over those students with no previous chemistry experience. Many people compare learning chemistry to learning a new language (Fensham, 1994). If this is so, the experienced students already had conversational chemistry, providing them not only with some chemical content but also, more importantly, with a way of thinking about chemical concepts – the structure of the language.

Students' prior knowledge did influence their approach, attitude and perception of chemistry. As might be anticipated, inexperienced students had no concept of the sub-microscopic nature of matter on which chemistry is based and so their mental models initially were unclear or non-existent. When asked during the first few weeks of semester to explain how they see the atom in their head many students including Leanne, Russell, Kathy and Narelle replied, "I don't". The drawings in response to the question “What do you think the atom looks like?” from the initial questionnaire administered to students in Study 3 (Figures 6.3 and 6.4) indicated a basic level of knowledge amongst these science undergraduates.

Item 1 from the SUE instrument (Table 7.1) sought students’ opinions about the amount of background knowledge that was assumed by the introductory chemistry unit. The results show a mean value of 2.79 (SD 1.00) with 34% of students concerned that too much background knowledge is assumed.

The introductory chemistry units required students to perform many mathematical calculations using very large and very small numbers. Some students were inexperienced in using calculators and scientific notation leading to difficulties in understanding what the numbers represented. These students struggled to complete laboratory reports, and had difficulty with the algorithmic questions in the topic tests.

7.2.1b Modelling ability and the use of chemical representations

Understanding chemical explanations requires the learner to have a well-developed mental model of chemistry at the sub-microscopic level. The development of an individual’s mental model is dependent on the use of physical representations such as models, diagrams, explanations or role-plays. The learner is instructed that the physical representation is not exactly like the sub-microscopic level; that it is just one of many possible representations; that it should help to explain the chemistry; that it is useful for describing the nature of things and for making predictions; and that the representation may not remain valid if scientific ideas change (section 5.2.4).

With experience, a learner moves from thinking of the sub-microscopic level in terms of his or her favourite representation to having a personal mental model that incorporates information from all the representations. This shift is significant in the students’ personal construction of knowledge. This building of knowledge requires the learner to identify and select the pertinent attributes of the physical representations, make interpretations of their importance and relate these ideas to the information from other physical representations (Figures 5.9 and 6.14). Without the physical representations, learners would have more difficulty developing their own mental representations.

Students in Study 3 demonstrated a reasonable appreciation of the theoretical qualities of representations and models as are indicated by the selected results of the SUMS instrument reproduced here.

> A model needs to be close to the real thing by being very exact, in every way except for size – 71% agreeing. (3.1.11)
>
> A model is always like the real thing – 67% disagreeing. (3.1.9)
>
> A model should be an exact replica – 68% disagreeing. (3.1.10)
>
> Models are representations of ideas or how things work – 88.2% agreeing. (3.2.1)

Most students understood that the representation was not necessarily like the real thing; however, when asked about particular chemical models in the MCR instrument it becomes obvious, from the responses, that students used particular models to generate mental models. Selected items showing the strongly agree and agree responses for the ball-and-stick model are reproduced from Table 6.2.

> The purpose of the ball-and-stick model is to:
>
> Item 3. Show the shape and structure of the molecule – 100%
>
> Item 4. Show the existence of chemical bonds –91%
>
> Item 5. Help understand the idea of chemical bonds – 82%
>
> Item 6. Help generate a picture in your mind – 100%

The ability to use chemical representations requires the student to be at least at Level 2 modelling ability. As mentioned in section 5.4.2c, when discussing Leanne's modelling ability, her comment, "the electron-dot model gave me a mental picture to think about" (3.8.12.46) demonstrates that students can be aware that a model is a representation and that theoretically it may not be accurate or precise but they also expect a model to be like the real thing.

It is often this model or representation that the student uses to build their mental model. Thus the confusion about the symbolic level and the sub-microscopic level is understandable. One very important role of any representation is to help visualise something that is too small to be seen, even if that visual image may not be like the real thing. As technology advances and the representations approach reality then the mental models will advance also.

Table 7.1 Percentage Responses, Mean and Standard Deviation for Items in the Student Unit Experience (SUE) Questionnaire with Study 3 (n=61)

Item	Descriptor	% Response+ 5	4	3	2	1	Descriptor	Mean	SD
1. Background knowledge assumed	Too little	7	9	51	23	11	Too much	2.79	1.00
2. The amount of material covered	Too little	0	0	62	31	7	Too much	2.55	0.63
3. I found the unit	Too easy	0	10	42	41	7	Too difficult	2.56	0.77
4. The unit content followed a logical progression	Very logical	7	29	36	25	4	Not logical	3.11	0.98
5. The unit outline was	Easy to understand	22	32	25	17	3	Hard to understand	3.53	1.12
6. The statement of objectives was	Very clear	19	34	45	2	0	Very vague	3.71	0.79
7. Unit expectations (i.e. what was expected of you) were	Very clear	14	48	24	14	0	Very vague	3.62	0.89
8. The unit activities (e.g. lectures etc) were	Well organised	17	50	24	5	3	Poorly organised	3.72	0.93
9. The teaching staff were	Very helpful	47	42	10	2	0	Very unhelpful	4.33	0.73
10. The availability of unit material	Readily available	12	36	39	12	0	Not available	3.44	0.91
11. The unit materials were	Very clear	12	33	47	7	2	Very unclear	3.47	0.86
12. The feedback I received on my progress was	Very helpful	9	36	31	16	9	Of little help	3.21	1.09
13. The assessment weightings were	Very appropriate	16	48	29	3	3	Not appropriate	3.69	0.90
14. My interest in the subject as a result of taking the unit has	Increased significantly	9	29	38	20	5	Decreased significantly	3.16	1.02
15. The organisation of the laboratory class was	Very good	22	44	24	8	2	Very poor	3.76	0.95
16. In helping me understand content, the experiments were	Very helpful	10	22	28	28	12	Of little help	2.91	1.19
17. The clarity of laboratory manual / notes was	Very clear	14	28	34	21	3	Very unclear	3.28	1.06
18. The lab reports were returned promptly	Always	59	28	9	5	0	Never	4.40	0.86
19. I read the laboratory notes before the session	Always	16	33	25	16	11	Never	3.28	1.22
20. The unit was	Very good	7	59	28	7	0	Very Poor	3.66	0.71
21. Overall, the organisation of the unit was	Very good	10	60	26	3	0	Very Poor	3.78	0.68
22. In comparison with other units this unit was	Very good	5	49	28	14	4	Very Poor	3.39	0.92

+5-point scale is related to the two descriptors included in the table

7.2.1c Motivation

Students were motivated to pass the unit because it is a compulsory component of the Environmental Science degree course. Indeed, it appeared that many students were intent on passing the unit rather than understanding the chemistry and this intention was encouraged by the unit's assessment format that encouraged an algorithmic style of learning. Item 14 of the SUE questionnaire (Table 7.1) asked students for their opinion about how the unit had affected their interest in the subject. A distribution, approaching normal, resulted in a mean of 3.16 (SD 1.02). So, for some students (38% choosing 4 or 5), this unit had significantly increased their interest and for some students (25%, choosing 1 or 2), the unit had significantly decreased their interest.

In the second interview, students were asked if the chemistry unit had been relevant to them and asked for examples. The responses were generally negative with only a few contextual examples. Abraham, an experienced and mature student, who was studying viticulture, replied:

> *Abraham:* Probably about 20% (is relevant) and its mainly the organic chemistry and the practical component, such as titrations, stuff that we actually do in the lab in the wineries. (3.9.20.12)

Other students could only see the relevance to their immediate studies and did not think to careers, employment or outside the university frame of reference.

> *Wally:* I thought organics was [relevant], petroleum and stuff like that, but other stuff before that I virtually have no clue about, why it is or where it comes from.
>
> *Simon:* Very basic chemistry is relevant to some of the biology, but it really is only the very basic stuff.
>
> *Int.:* Does it help you in biology to have done the chemistry?
>
> *Simon:* Yeah, a little bit. (3.9.9.44-47)
>
> *Richard:* Organic chemistry can be applied to this semester's work. The chemistry is not particularly relevant. (3.9.8.19)

These data suggest that there is a perceived lack of contextual relevance of the chemistry unit for these non-major students, which could be influencing their motivation and interest in the unit. Certainly, links to the future professional services could promote students' interest and motivation. In keeping with this concern, since this research was conducted, this chemistry unit outline has been modified to include *Professional Skill Outcomes* and *Unit Aims and Objectives,* in line with an outcomes-based approach to teaching and learning. Implementing and evaluating these outcomes could provide contextual relevance that appeared to be lacking.

7.2.1d Unit structure, organisation and time management

Because of the fast pace at which the unit proceeds, most students interviewed (93%) used only information from the unit notes, laboratory sessions and lectures without referring to any additional resources.

The lecturer described the chemical concepts in detail during the weekly lectures and provided students with rules and key points to apply to problems. For example, he consistently used the same format, providing detailed explanations of the balancing of equations such that the symbolic level of chemical representation of matter was used almost exclusively. The macroscopic features such as colour and properties of the reactants were generally not mentioned. The students were drilled in how to answer questions similar to those in the PSI tests, the understanding of why and wherefore was not addressed. Within the first few weeks of the semester my observations included:

> Students in this class see chemistry only as a means to the environmental studies and so just need to pass. Consequently, the algorithmic, learning approach suits them. (3.7.19)

Because of the students' lack of background knowledge, initially there was a lack of correlation between the level of theory that had been covered in lectures and the understanding expected or needed to perform the laboratory tasks. This resulted in the demonstrators using worksheets in the first few laboratory sessions to assist students with complicated calculations promoting an algorithmic approach. As the unit progressed there was a closer connection between the theory and the practical; however, students failed to recognise it as is indicated by their comments in the second interview.

> *Sharon:* The stuff we do in labs is so different from what we do in the lectures and it's just hard to say this is that or whatever. (3.9.10.104)
>
> *Margaret:* Yes they don't match do they, its like you are doing two different topics. (3.9.11.105)

The structure of the chemistry unit provided students with every opportunity to succeed, so long as they have a disciplined approach and manage time effectively. This chemistry unit was flexible, but with this flexibility comes responsibility and the need for students to discipline themselves. Because with this flexibility also came the option for the students undertake the topic tests in the PSI testing room when they were ready. There was no deadline for the topic tests and consequently many students lapsed behind, resulting in them possibly having a lecture on one topic, trying to learn a previous topic in preparation for a PSI test, in addition to learning another chemistry concept for the laboratory experiment. This situation was difficult for some students to manage as described by Leanne in her second interview.

> *Leanne:* The test, lab and lectures can be completely out of sync- at the end of last semester I was studying for test, listening to lectures that were two weeks ahead and doing practicals that were not related to the lecture work at all. Also at the beginning we were doing practicals and were required to know formula that we hadn't even been introduced to yet in the lectures – that was very unsettling. (3.9.12.42)

Leanne (ID12), like several other students, Narelle, Margaret and Wally, reminded me of her non-existent background in chemistry repeatedly during the second interview declaring how difficult the introductory unit had been for her.

> *Leanne:* This was a difficult unit because I have never done chemistry before. (3.9.12.3)

> *Leanne:* All of it has been difficult to learn – takes time and hard work. (3.9.12.13)

> *Leanne:* I didn't know any chemistry – so it has been difficult I did up to year 10 and then I was in the non-chemistry group. (3.9.12.19)

Obviously, the students with the very weak chemistry backgrounds felt disadvantaged. Margaret engaged a tutor.

> *Margaret:* I hadn't done chemistry at school. I did year 10. I swore I would never do it again but… (3.9.11.3)

> *Margaret:* I have found it quite hard. I went to lecture one in semester 1 and wondered what was happening it was oh where are all these things coming from? But um …. I got a tutor and that helped me a lot and it's coming together and I still have one now, that's how I got through. I find that [for] first year chemistry, especially for people who haven't done it before there should be a tut [tutorial] involved. (3.9.11.4)

The common criticism by students that the unit is disjointed is a product of catering for students with a variety of backgrounds and using the student focused approach (PSI) to teach the chemical theory and practical skills required by the faculties that this unit is servicing. Students with no chemical knowledge flounder with the onset of the chemical language that they are expected to master, and the PSI nature of the assessment requires the individual student to determine when he or she is ready to sit for a PSI test. This requires and assumes the student to be an intentional learner – self-disciplined, well organised and motivated, as described in section 3.4.3 (Bereiter & Scardamalia, 1989).

Considering item 2 from the SUE questionnaire (Table 7.1), with a mean of

2.55 (SD 0.63), no students considered the amount of chemistry to be "too little" but 38% did consider it to be "too much", choosing the values 1 and 2. These results support the comments by the student volunteers about the volume of material and resulting pace with which it was covered. Similarly, with item 3 the students generally considered the unit to be more difficult than easy with a mean of 2.56 (SD 0.77) with 48% of responses choosing 1 or 2. Despite these opinions, the chemistry unit needs to be challenging and have value. Maintaining academic standards is vital, and students completing a science degree should be expected to have mastered a certain minimum level of chemistry.

This chemistry unit is non-competitive – in that students are competing only against themselves and not the other students and can elect the grade for which they wish to aim. All students initially aim for the highest grade but demands on students' time and their ability, results in some students reverting to the pass option. The unit structure and organisation play an important role in directing the students' time management, their learning style and strategies and providing learning opportunities and guidance to students.

7.2.1e Assessment

The formative assessment structure provides feedback for students continuously throughout the unit (Appendix F). The course required the students to demonstrate self-discipline and perseverance – learning and passing each topic test. Consequently, students quickly, identified learning strategies and made pragmatic decisions about learning to achieve passing grades (80%) in the tests. All students interviewed described rote-learning to be the primary method of preparation for tests. Indeed, this can be attributed to the assessment scheme, the volume of material that the students have to learn and the speed at which it is covered. This is exemplified in the following excerpt from the second interview with Simon:

Simon: I think I pretty much rote learned a lot of it. I don't think I'd be able to get 80% in my tests now, but I think I'd pass. (3.9.9.34).

The questions in the 11 topic tests are mainly of an algorithmic style and do not require conceptual understanding. Rote learning can have a valuable role in chemistry (Battino, 1992); however, the process of learning should not be marginalised by the need for assessment.

The assessment components of this introductory chemistry unit, wherein 90% of the total marks are from the PSI tests and the optional examination, may be considered unfairly weighted. However, the results of the SUE questionnaire indicate that students considered the weightings of the unit assessment to be appropriate – with item 13 having a mean of 3.69 (SD 0.90), with only 6% of students considering the system to be inappropriate (Table 7.1).

Only 20% of the students interviewed obtained help from peers and there was no formal provision for collaborative discussions as part of the teaching program except in the laboratory sessions. The assessment format of testing and examination appears to promote an individualistic approach to study. Students such as Margaret (ID 11) who had to engage a tutor suggested that optional tutorial groups would help students who feel isolated and help overcome the workload. Learning strategies incorporating teamwork, collaborative and cooperative behaviour are promoted by educationalists for meaningful learning (Thomas & McRobbie, 2002).

Although the teaching strategies in the laboratory and the lecture did encourage meaningful learning, the primary focus on algorithmic style test items directed students towards a rote-learning regime and did not foster the development of students' mental model of the chemical phenomena. Radloff and Murphy (1992) associate "memorising isolated bits of information" with surface learners who are "overly concerned with assessment" (p. 66). The influence of assessment on students' learning style is well documented (Treagust, Jacobowitz, Gallagher, & Parker, 2001) and in this study, the algorithmic style questions along with the PSI scheme of allowing multiple attempts encouraged a rote-learning style.

7.2.1f Teaching resources

The mean value of 3.47 (SD 0.86) for the item from the SUE instrument concerning the clarity of the unit materials indicates that most students were reasonably content with the standard of the unit materials. However, because many students did not purchase the textbook and used only the printed study notes, they did not have ready access to graphical resources that can be so important in explaining abstract chemical concepts. This issue emerged in interviews with students, as discussed in chapter 6, for example:

Sharon: Could we have more pictures in the yellow book?

Maureen: Yeah in the book to make it clearer. When you are reading it at home you don't know what you are doing and you get here and you still don't know. (3.9.10.116-117)

This was one impetus for the introduction of the online resources, making colour pictures accessible to all students.

7.2.2 Factors That Influence Learning – Study 4 – Learning Introductory Chemistry and the Implementation of Online Pre-laboratory Exercises for Non-majors

In addressing Research Question 3.1 concerning the factors that influence how and why students learn chemistry; the results from Study 4 are consistent with those from Study 3. While the results for Study 4 focus on the implementation of the website and the online pre-laboratory exercises, the students have provided reflective comments about their learning using the pre-laboratory exercises and the unit in general that are valuable and are used here to address Research Question 3.1.

Gathering data about students' learning experience in Study 4 included using two quantitative instruments: The instrument Students' Evaluation of Educational Quality (SEEQ) was administered to all students undertaking Chemistry 117 (n=98) in semester 1; and the Online Survey was administered to all students undertaking Chemistry 118 (n=115) in semester 2. The items in both the SEEQ and the Online Survey asked students about their learning experience using the online pre-laboratory exercises. The responses for both surveys were anonymous. The same item numbers have been used in both surveys where the items were identical; however, the Likert scale for each survey was different.

Questions 20 - 27 in the Online Survey asked students to respond with written answers (Appendix N). Questions 20 - 24 sought responses about the pre-laboratory exercises, question 25 asked students to comment on the strategies they used in learning chemistry, question 26 asked students to list things that influenced their learning of chemistry and question 27 sought additional comments.

Of the 265 students who had access to the chemistry website for semester 2, 115 students responded to the Online Survey. Only 10 students of those 115 did not complete any of the items requiring written responses. Many students appreciated the opportunity to give constructive feedback to the instructors about the unit as well as reflect on their own learning. The maturity of students and their appreciation of the position of this unit within their course provided a foundation for their motivation to learn and pass the unit. There were many notable responses to the written questions that provided personal insight into the students' learning. For each question, the comments were scrutinised and coded using N-vivo and categories were created. The frequencies of each category in the questions show the extent of support for the various reasons.

The quantitative results for each instrument are presented in Tables 7.2 and 7.3, respectively. The results are being analysed together because they deal with the same issues, often with the same items. The numerical values will be shown with the SEEQ value first, then the Online Survey value.

Nearly all students responded positively to the introduction of the pre-laboratory exercises, with students commenting on the flexibility of being online, being able to learn at their own pace, getting immediate feedback, working problems out for themselves, having the opportunity to revisit problems and learn from their mistakes, forging links between the theory and practical components of the unit, and building confidence in the subject. Factors identified by the research data in Study 4 that influence how and why students learn chemistry include the value of good explanations, feedback, motivation, self-efficacy, organisation, and utilisation of resources available through the WebCT website. Data supporting each factor is presented and discussed.

7.2.2a Good explanations

For question 26 of the Online Survey – *List things that influence your learning of chemistry* – eight main categories were identified from the analysis and coding of the written responses (Table 7.4). By far the most frequently mentioned factor was good explanations. Explanations are the foundation of understanding; they link the practical and theoretical work; they need to be easy to follow, simple and detailed with step-by-step instructions.

Table 7.2 Percentage Response to Researchers' Items on SEEQ Instrument – in Study 4 - Semester 1 (n=98)

Item		Mean (1-9)	Std Dev	% Frequency SD*	D	N	A	SA
1	I have accessed the online pre-laboratory exercises weekly.	5.6	3.4	30	7	8	10	45
2	I had difficulty accessing the website from home.	2.9	2.7	61	13	8	7	11
3	I had difficulty keeping the website up and running.	2.4	2.1	66	14	8	8	4
4	I had difficulty navigating the website for the unit.	2.2	1.8	70	15	8	6	1
5	The online pre-laboratory exercises allowed me greater flexibility with my time.	6.2	2.6	13	8	17	24	38
6	The online pre-laboratory exercises provided feedback on my understanding.	6.5	2.2	6	6	15	43	30
7	The online pre-laboratory exercises helped me to learn and understand the concepts in the experiment.	6.5	2.1	5	8	15	39	33
8	Getting immediate feedback on the online pre-laboratory was valuable.	7.2	1.9	2	5	15	27	51
9	The online pre-laboratory exercises were challenging.	5.9	2.1	7	15	18	36	24
10	Being able to try an exercise more than once helped me learn from my mistakes.	7.1	2.2	6	1	17	25	51
11	I had to read the laboratory notes in order to do the online pre-laboratory exercises.	6.0	2.2	9	13	19	33	26
12	The online pre-laboratory exercises were useful in confirming my understanding.	6.4	1.8	3	9	18	42	28
13	The online pre-laboratory exercises provided me with valuable feedback on my progress.	6.1	2.0	5	13	15	42	25
14	I understood the experiments better having done the online pre-laboratory exercises.	6.2	2.1	3	17	15	37	28
15	The pictures in the online pre-laboratory exercises were valuable.	6.1	2.1	3	13	19	36	37
16	The online pre-laboratory exercises should be worth more marks.	5.1	2.5	17	18	22	25	18
17	I used the solutions to typical tests on the website regularly.	5.1	2.7	20	23	15	20	22

*The instrument required students to indicate the extent of their agreement with the statements on a 9-point scale where 1=Strongly Disagree, 3=Disagree, 5=Neutral 7=Agree and 9=Strongly Agree. In Table 7.2 the values 1 and 2 correspond to SD Strongly Disagree; 3 and 4 to D Disagree; 5 N Neutral; 6 and 7 to A Agree and 8 and 9 for SA Strongly Agree.

The values have been rounded off to whole numbers

Table 7.3 Percentage Responses to Online Survey — in Study 4 - Semester 2 (n=115)

Item		Mean (1-5)	Std Dev	% Frequency SD[1]	D	N	A	SA
A[2]	My computer skills are good enough to use the Web CT program effectively	4.5	0.8	2	2	6	23	67
B	Without good computer skills I could not use the pre-lab exercises effectively	2.6	0.9	7	47	32	13	2
2	I had difficulty accessing the website from home	2.1	1.1	33	40	14	10	3
3	I had difficulty keeping the website up and running.	2.0	0.9	32	47	11	9	1
4	I had difficulty navigating the website for the unit.	1.9	0.8	34	53	8	4	1
5	The online pre-laboratory exercises allowed me greater flexibility with my time	3.8	1.2	6	10	12	39	33
6	The online pre-laboratory exercises provided feedback on my understanding.	3.7	1.1	6	9	16	52	17
7	The online pre-laboratory exercises helped me to learn and understand the concepts in the experiment.	3.7	0.9	3	8	19	56	14
8	Getting immediate feedback on the online pre-laboratory was valuable	4.2	0.8	0	4	13	46	37
10	Being able to try an exercise more than once helped me learn from my mistakes	4.4	0.8	1	3	6	36	54
11	I had to read the laboratory notes in order to do the online pre-laboratory exercises	3.6	0.9	2	9	30	44	15
14	I understood the experiments better having done the online pre-laboratory exercises	3.8	0.8	0	8	23	52	17
15	The pictures and diagrams in the online pre-laboratory exercises were valuable	3.8	0.8	0	7	23	53	17
17	I use the solutions to the typical tests on the website regularly	3.5	1.2	7	17	19	37	21
C	I monitor the discussion page on the website regularly	2.7	1.2	21	29	23	20	7
D	I find the e-mail facility useful	2.9	1.0	10	18	53	11	9
E	I usually completed the pre-lab exercises before the laboratory session	3.3	1.2	9	17	22	36	16
F	I find the calendar useful	2.7	0.9	10	23	53	12	2
G	The website has directed me to relevant Internet sites.	2.6	0.8	10	33	49	7	1

[1]The instrument required students to indicate the extent of their agreement with the statements on a 5-point scale where 1= Strongly Disagree, 2=Disagree, 3=Neutral 4 = Agree and 5= Strongly Agree.

[2]The numbers of the items correspond to those same items in SEEQ (Table 7.2) – the letters are used for additional items.

The values have been rounded off to whole numbers

In the following examples of students' responses to question 26 on the Online Survey, the students explain why they needed good explanations:

> Good explanations that are easy to follow - you can always memorise something for a test or whatever, but if it has been explained in a way so that you actually get it, I find it tends to 'stick' more. (4.4.26.37)

> Good explanations. Having a good lecturer helps, that explains things in easy to learn/understand ways - providing back up with lots of examples. (4.4.26.90)

> I need to have things explained to me.... I can't just follow ...I need to understand...when I understand something I can usually remember it. My background in chemistry is not that good...but I have a pretty good understanding of maths, which I think helps me get through some of the labs and tests. I want to get better at chemistry because my other subjects are pretty good and I wanted chemistry to be just as good. I love doing the labs.... but I find chemistry the hardest of the subjects I'm taking because for all the others.... you have your basic principles and you apply them...with chemistry you have your basic principles...and for each of them there are a whole heap of exceptions to remember...I don't have that good a memory.... I find that with chemistry a lot depends on what you can remember.... that's why I find it difficult. (4.4.116.26)

These students' responses are typical of the data and provide an insight into the students' learning experience.

Table 7.4 Frequency of the Eight Main Categories for Question 26 in Online Survey by First Year Chemistry Students (n=115)

Category	% Number of times mentioned
Good explanations	59
Motivation – to pass, to learn,	36
Background knowledge chemistry	32
Pace of unit	24
Links theory to practical	20
Models, diagrams	19
Background knowledge mathematics	14
Assessment	12

Why are good explanations that are "easy to follow" and "step-by-step" explanations so important to the learners? In section 3.5.2, multiple perspectives of learning are described. The ontological perspective described the learners "beliefs about the fundamental categories and properties of the world" (Chinn & Brewer, 1993, p. 17). The good explanations provide the student with the necessary ontological perspective, with its "easy to follow" and "step-by-step" detail; it provides the learner with logical reasoning that includes an ontological framework in order to understand the concept. This is consistent with a good explanation communicating a concept as intelligible and plausible so that the learners' status of the concept is raised. The value of good explanations is demonstrated in the following description of Chris, a student volunteer in Study 4, tackling some difficult typical test questions.

My experience with Chris, who was 21 years of age, demonstrated the value of step-by-step explanations. Chris was in my weekly laboratory session. He worked in the laboratory session with Doug (a mature and capable student), usually following Doug's lead. Chris was panicking because he was behind with the PSI tests and was experiencing difficulties with the typical test topic 38 on alcohols. There is a typical test at the end of each topic in the study notes. The solutions for this typical test were available in the library and on the WebCT site as a PDF file. Students normally practised on the typical test before sitting for the PSI test. The questions for this typical test are in Appendix R. Chris and I sat down at the end of a laboratory session and worked through the problems together. I wrote out my reflections on this session, and have summarised it here to provide some insight into the difficulties that Chris encountered.

> Question 1 required the identification of a tertiary alcohol. Chris didn't remember the prefix for the number of carbons eg pent-, but-, hept- etc. This had been covered in first semester, but the names were not in the second semester notebook, and they hadn't used them since first semester. But now we were approaching the end of semester two. He also didn't know how to tackle the question. I suggested that most people would have to draw out the structural formulas to be able to answer the question. He hadn't realised this, thinking that the answer was there in front of him and he couldn't see it. He didn't realise that he had to use the data and manipulate it in some way. Chris's confidence level was pretty low. I mentioned to him that people learn and forget and need to learn again and build on knowledge – you just don't learn something once and then know it forever – it takes practice, regular use. He had the expectation that since he had learnt the carbon number symbols in Semester 1 he should be able to remember them – I pointed out that learning requires building and repetition. Chris had high expectations and was struggling to keep up and felt that it was his fault.
>
> Question 2 was about hydrogen bonding. Chris didn't know what hydrogen bonding was. We went over the notes in the PSI Study Notes emphasising the terms intermolecular and intramolecular. He had not made the distinction between these two terms. We discussed the electron arrangement in the hydroxyl group – using delta positive and delta negative to indicate regions of different electro-negativity to explain why hydrogen bonding occurred. To complete this question it was also necessary to draw out the structures to identify those electro-negativities. After the discussion, Chris was able to answer the question easily.

Question 3 asked about the necessary reagent to convert methanol to bromo-methane. From the notes Chris had understood that hydrogen bromide and concentrated H_2SO_4 was needed. But the question did not provide this alternative. He was not confident that the concentrated hydro-bromic acid would act the same as the concentrated H_2SO_4 and hydrogen bromide.

Question 5 asked for the name of a compound with the molecular formula $C_4H_{10}O$ that evolves hydrogen gas with sodium but does not react with acidified potassium dichromate. Chris had not realised what the question was asking and what the question was telling him. Initially he thought it was a direct question with an answer that he should know – somehow. He hadn't realised the significance of the data that had been provided. I suggested breaking the question up into parts. He picked up on the points easily once they were shown to him. Realising that the formula $C_4H_{10}O$ could be a number of structures; and that because this substance gives off hydrogen then it is an alcohol; and then since it is not oxidised – therefore it must be a tertiary alcohol. Then he was able to suggest and draw a possible structure.

By question 6, Chris's confidence was growing and he was able to understand what the questions were asking. He looked up the notes and was able to tell me that alcohols were needed and then had to work out which were alcohols. He still had to draw out the structural formula especially for (iii). He drew out the structure and then said – but the carbon must have four bonds. – how can that work? He did not know what the substance was, nor did he know its structure. He had to work it out from scratch to identify which of the structural formulas were alcohols.

Question 9 In an attempt to identify the cleavage point I drew out the structure and talked about the electron arrangements and used the answer to work backwards to suggest a possible reason for the point of breaking – considering the effect of H^+ and Br^- ions.

Chris needed explanations that took into account his limited knowledge base, that explained what the question was asking, and provided clues on how to start the question. This is consistent with a constructivist approach to learning in which the starting point is what the student already knows (Coll & Taylor, 2001; Yager, 1999). Several times Chris showed that he did not recognise the type of compound from the molecular formula. He also had not realised the importance of the structural formula and electron arrangements to the explanations. Obviously explanations play an important part in learning. Normally at university level it would be assumed that this type of assistance would not be needed, however this has been shown not to be the case.

Initially, Chris had a very limited conception of particular chemistry concepts, such as hydrogen bonding and the characteristics of alcohols. However, being willing to entertain explanations of the chemical concepts meant that Chris was assessing the intelligibility, fruitfulness and plausibility of the chemical concept. In the excerpt above, the status of these concepts in Chris's opinion grew and developed throughout our discussion. This illustrates Posner et al.'s (1982) description of conceptual change requiring the status of a conception to be raised and incorporated into the learners' schema. Chris was using symbolic representations – structural formulas as well as diagrams of electron affinities – to relate to bond breaking and bond formation.

Learning is about knowing how to tackle problems. Chris did not have the skills to know how to start to address the questions let alone get the correct answers. Chris had access to the solutions – but that had not been enough, he needed the explanation that went with the solutions. Once he heard the explanation, and received feedback on his thinking, he was able to have more confidence in his own understanding. The most significant contribution in assisting Chris with the typical test questions was the improvement in his confidence and self-efficacy.

7.2.2b Feedback

The primary objective of the pre-laboratory exercises was to provide students with feedback on very simple concepts related to the weekly experiment. With 78% and 83% (Tables 7.2 and 7.3, item 8) of students from semester 1 and semester 2, respectively, agreeing that "getting immediate feedback on the online pre-laboratory exercises was valuable", and 76% and 90% (Tables 7.2 and 7.3, item 10) of students from semester 1 and semester 2, agreeing that "being able to try an exercise more than once helped me learn from my mistakes" (Tables 7.2 and 7.3, item 10); the value of feedback and renewed opportunity appears to be appreciated. Similar results for items 6, 12, 13 and 14 confirm this conclusion.

7.2.2c Motivation and Self-efficacy

The responses to items in the SEEQ instrument and the Online Survey provide support for the social/affective perspective of learning that included detailing the motivational, social and self-efficacious beliefs of the student proposed by Tyson et al. (1997) and described in section 3.4.2c. For example, item 7 with responses of 70% and 72% (Tables 7.2 and 7.3) of students agreeing that, "the online pre-laboratory exercises helped me to learn and understand the concepts in the experiment".

The following examples are indicative of the students' written responses and demonstrate the claim that the pre-laboratory exercises helped students to build understanding and confidence in the subject:

> The [pre-lab exercises] have certainly helped me to gain a better understanding of the labs when I go into the experiment having already completed the pre lab questions. And I like knowing how well I understand each topic, so the feedback is extremely helpful in that sense. (4.4.22.23)

> This is the first time that I have done any chemistry, and I have to admit that the first semester was a chore, and I did not enjoy it. However, this semester, I have gained my confidence in the lab, and through the structure of the unit I am actually enjoying it. (4.4.27.39)

> I personally benefit from WebCT as I can access it from home. It gives greater flexibility to my time and helps me clear doubts I have during my course of learning. (4.4.22.73)

> In labs, I feel more confident as a result of doing pre-lab exercises and reading hints. (4.4.21.113)

> Chemistry is not my strong subject...so doing the pre lab exercises I'm not so worried when I go to a lab and see the equipment we have to use because most of the time a picture of it has come up in the pre lab...usually with a description on how to use it...also by knowing what experiments will be carried out and what should be expected...helps with the confidence for the lab...I feel its better then going into the lab with no idea....by doing the pre lab beforehand we can straight into starting the lab. (4.4.23.116)

The comments about confidence and preparedness as well as those referring to understanding the content, provide some insight into the importance of the students' self-efficacious beliefs about their learning.

Students were motivated to pass the unit and also, but not always, were motivated to learn. The phrase – "to meet course requirements" – was written nine times by various students in their responses. This attitude is represented by comments such as:

> Having to pass it so I don't ever have to do it again. (4.4.16.26)

> Need to pass exams to meet course requirements. (4.4.71.26)

> Persistence, the need to pass. (4.4.77.26)

However, many students were motivated to learn and understand the content of the unit as demonstrated in these written comments:

> A desire to want to learn the subject. (4.4.15.26)

> Motivations for chemistry are real lifework with chemical applications, which I

find, are more interesting than commerce. (4.4.33.26)

[I'm] somewhat interested in chemistry even though it's not my core unit, but also the need to know the chemistry for my core unit. (4.4.43.26)

The desire to learn chemistry is the most important. (4.4.79.26)

Motivation is also important because without it, it is really hard to want to learn anything. (4.4.99.26)

All the above are important, especially motivation, perseverance and discipline as 118 is really a self-paced course. (4.4.105.26)

The motivation factor is part of the social/affective perspective of learning that is described by Tyson et al. (1997) to include the motivational, social and self-efficacious beliefs of the student.

7.2.2d Organisation

There was evidence from Study 3 that the university students lacked organisational skills. Many students (59%, 59%) in Study 4 agreed that the pre-laboratory exercises forced them to read the laboratory notes (Tables 7.2 and 7.3, item 11) and the majority of students agreed (62%, 72%) agreed that the online nature of the pre-laboratory exercises allowed them greater flexibility with their time (Tables 7.2 and 7.3, item 5).

7.2.2e Utilisation of the resources available through the WebCT chemistry site

The record of the utilisation of the website (Tables 7.5, 7.6 and 7.7) shows high scores on the pre-laboratory exercises in line with objective of the exercises being reasonably easy to build students' confidence and give them positive feedback. The tasks were compulsory so that students were better prepared for the laboratory session each week. Having to access the website regularly to complete the online pre-laboratory exercises meant that students could become more familiar with the additional resources available on the website. Although the pre-laboratory exercises were worth only a very small percentage of the students' total marks, many students took advantage of the opportunity to redo the exercises and improve their score as is seen in the average number of attempts shown in Table 7.5, of 1.7 and 1.9 for semester 1 and 2, respectively. The mean score for the pre-laboratory exercises was 83.2% and 87.7 % for each semester (Table 7.5). This very high score is in line with the objective of the exercises to give the students confidence and to help them learn from their mistakes.

Table 7.5 Record of the Number of Students, the Time Taken, the Number of Attempts and the Score for the Pre-Laboratory Exercises for Semester 1 and Semester 2

	Average no. Students/week	Mean % score for pre-lab exercises	Average no. of attempts	Average time/test* (min)	Average time* /week (min)
Semester 1 11 weeks	102	83.2	1.7	10.2	17.6
Semester 2 12 weeks	122	87.7	1.9	7.0	13.4

*Time student was online with the test-page open – not necessarily the time taken to do the test)

Table 7.6 The Number of Times Students Accessed the Website per Semester

Frequency	Semester 1 n=130*		Semester 2 n=264*	
	Number of students	Percentage of students	Number of students	Percentage of students
0	16	12.3	93	35.2
1-20	49	37.7	41	15.5
21-40	17	13.0	33	12.5
41-60	12	9.2	20	7.6
61-80	5	3.8	20	7.6
81-100	4	3.1	16	6.1
101-120	10	7.7	13	4.9
121-140	8	6.2	8	3.0
141-160	4	3.1	7	2.7
161-180	4	3.1	7	2.7
181-200	1	0.8	2	0.8
>200	1	0.8	4	1.5

*Semester 1 the pre-lab exercises and website was used only with chemistry 118, while in semester 2 it was made available to other PSI chemistry units including chemistry 128, 012 and 028)

The exercises were designed to take only 10–15 minutes aiming for regular positive reinforcement, designed to better prepare the students for the laboratory session. The results of 17.5 minutes/week for semester 1 and 13.4 minutes/week for semester 2 spent by students completing the test per week are consistent with this objective.

The use of the additional facilities available through the website has been monitored. The number of times students accessed the website throughout the 14 week semester varied considerably, with some students not accessing the site at all, to a few students accessing the site more than 14 times per week of semester (Table 7.6). More students accessed the site in the second semester. From the results of the SEEQ instrument and the Online Survey, 42% and 59% of students, respectively, agreed that they used the solutions to the typical tests on the website regularly (item 17, Table 7.2 and 7.3). This is confirmed by the written comments from the Online Survey:

> Solutions to the typical tests – very valuable as you don't have to access the library. (4.4.20.8)
>
> Having typical test answers available. (4.4.20.32)
>
> The lab hints this semester have been very useful, as well as having the pre-lab exercises. The typical test solutions showing the workings has been extremely helpful in LEARNING, not only getting the answers, as each problem has been set out step by step. (4.4.20.39).

The results indicate that the other facilities such as e-mail, calendar, discussion, and links to websites were not valued so highly by the students. Even though many students did not post messages themselves, the data indicate that they did access the page to read what other students had written (Table 7.7). There were 95 postings on the discussion board during semester 1 and 55 postings to the discussion page during semester 2. Similarly, through the discussion page, some students in Study 4 organised a tutorial group. The communication through the discussion page is shown in Figure 7.1 Students here are taking responsibility for their own learning which is consistent with the philosophy of the intentional learner as described by Bereiter and Scardamalia (1989).

Table 7.7 The Number of Times the Discussion Page was Accessed per Semester

Frequency	Number of students accessing the discussion page	
	Semester 1 n=130*	Semester 2 n=264*
0	50	160
1-20	44	65
21-40	6	15
41-60	3	24
61-80	7	
>80	20	

*Semester 1 the pre-lab exercises and website was used only with chemistry 118, while in semester 2 it was extended to other PSI chemistry units, including chemistry 128, 012 & 028, for whom using the website was not compulsory – hence the large number of students who did not access the site.

7.2.3 Summary and Response to Research Question 3.1

Learning is not done in isolation. There are many factors that influence the learning process – some factors are in the control of the students, some are in the control of the instructor, and still there are others that cannot be controlled. Research Question 3.1 asks, “What are the factors that influence how and why students learn

Message no. 48 Apr 23, 2002 20:53
Subject tutor
I am finding some of the parts of some of the topics difficult to understand. i was wondering how i should go about finding a tutor?????? thanks K.

Message no. 51 on Wed Apr 24, 2002 11:56
Subject Re: tutor
Perhaps a study group? on Tuesday is good for me if anyone is interested. We could grab a study room in the library.

Message no. 52 on Wed Apr 24, 2002 20:27
Subject Re: tutor
Id be in this too, need all the help I can get Tuesday suits me as well L.

Message no. 54 on Thu Apr 25, 2002 23:01
Subject Re: tutor
Well, I'll find out the name of one of the study rooms in the library and if it can be booked etc. and I'll post the results and a time. I'll be there sometime this weekend. If anyone has any preferences for a time on Tuesday then either reply to this or email me on

---

Message no. 55 posted by Co-ordinator on Sat Apr 27, 2002 15:39
Subject Re: tutor
This is fantastic. The best way to learn is to teach each other. Give the study group a go and I am sure you will all benefit greatly. However, should you feel you still need some help, I could organise a tutor to join the group (but you will have to pay him/her). Good luck and well done for taking the initiative.

Message no. 56 on Mon Apr 29, 2002 09:09
Subject Re: tutor
hey V,
yeah i would possibly be interested in studying for chem. in a study group... provided work got done C.

Message no. 59 on Tue Apr 30, 2002 20:08
Subject Re: tutor
what time on Tuesdays???

Message no. 62 on Mon May 06, 2002 11:58
Subject Re: tutor
It's more of a study group than a tutor. Nothings been arranged for a tutor. just a group of people getting together to help each other out. it's on Tuesday on level 6 of the library, room 6110 from 1 to 3pm. The only prob[lem] is that its only 1 table in the room cause of the library's rules but we should be able to scab the extra one. Therefore there is only room for about 12-16 I think. if anyone knows a place we can book a bigger room for more people tell me and ill see what I can do about it.

Figure 7.1 Excerpt from the Discussion Board of the WebCT Site for Chemistry 118 chemistry?" Factors that have been identified by the students as being important to their learning include internal factors – prior chemical and mathematical knowledge, modelling ability and use of chemical representations, motivation, metacognitive ability, time management and self-efficacy, and external factors – unit structure and organisation, assessment, teaching resources, getting feedback and good explanations.

7.3 Learning Strategies

The learning strategies used by students in Studies 1, 3 and 4 are drawn on to respond to Research Question 3.2: "What learning strategies do students use in learning chemistry?" The factors that influence how and why students learn chemistry, discussed in the previous section, are closely aligned with the students' choice of learning strategies.

7.3.1 Learning Strategies Study 1 – Learning Introductory Organic Chemistry in Secondary School

Observations in the high school classroom where students worked with several teaching models – structural formula, ball-and-stick models, a computer program, and the space-filling models – provided information about the students' learning strategies and their dialogue provided some insight into their thinking and learning. Contextual examples of students' learning processes are provided.

Students were required to build ball-and-stick models to correspond to a particular chemical formula and then name it and vice versa. Two examples of dialogue between pairs of students, discussing the naming tasks are shown here:

S1: We had connected two chlorines in the middle with two chlorines coming off.

S2: Is that right?

S1: Yeah.

S2: So that will make it, umm. See they are in a straight line so 2,2 dichloro 1, 2, 3, methane - no, propane - methane has 1 carbon (1.4.96-99).

S3: Have you changed it around?

S4: Then what would that equal?

S3: 1,2,3,4,5 - five is your longest chain and you've got one coming out.

S4: methylpentane - it doesn't sound right. (1.4.610-613).

Students made predictions about the names of compounds they had constructed with the models by using the new vocabulary and the naming rules. The audio tapes and the video evidence (Figure 5.3) showed that the students used the model to identify the longest chain, then counted along the ball-and-stick model, looking for branches. The physical model provided students with a means of supporting their naming of the model. Students worked with a partner to confirm their understanding – another learning strategy. The dialogue demonstrates how students constantly asked for confirmation from their partner that they were giving the right answer. This social construction of ideas was a supportive learning environment.

While initially using the ball-and-stick models to represent organic hydrocarbons, students became familiar with the bonding rules and constructed feasible compounds. Students observed that no matter how they manipulated the model of hexane, for example, it would not form a 'straight' chain. This observation, along with rotating all the atoms in a compound, made it possible to view the structure from a different perspective, which helped students to understand the significance of the angles between the atoms in the organic compounds. So, for example, a straight chain alkane can look like a straight chain or a u-shaped chain depending on how the atoms are rotated in relation to each other. Within the parameters of a given number of carbon and hydrogen atoms, the students managed to quickly build a variety of compounds within the bonding rules. Students discovered several structures obeying the same general formula, thus identifying isomers – different structures with the same general formula – although they had not been instructed in this nor did they know the term isomer. Later, more detailed isomers were investigated with comments like "so it does matter what side you stick them [the model atoms] on" (1.4.425), when referring to the cis and trans isomers of dichloroethene.

The following excerpt supports the inference that students identified the positioning of the balls and sticks with the shape of the molecule.

S2: We have to do C_6H_{14}.

S1: Yeah.

S1:	1,2,3,4,5,6, He says there's five eh? (Referring to the teacher claiming there are five possible isomers).
S2:	We'll see.
S1:	This is hexane.
S2:	1,2,3,4,5,6, Yeah that's got six - then it goes straight on. Just change the position of one of them.
S1:	I did that and altered the shape.
S2:	No you actually have to pull a bit off. You got it yet? Have you changed it around?
S1:	Then what would that equal?
S2:	1,2,3,4,5, five is your longest chain and you've got one coming out.
S1:	Methyl-pentane - it doesn't sound right. (1.4.588-613).

The hands–on approach manipulating the ball-and-stick models encouraged students to be attentive to the detail of the model such as the positioning of atoms, bond lengths and angles. Breaking the plastic tube and rejoining it to another part of the ball and chain is analogous to the breaking of chemical bonds that is necessary to form a completely new substance.

Once acquainted with the three-dimensional nature of the compounds, the students began drawing the structural representations on paper, repeating this task with many different examples. This sequence of learning, beginning with the three-dimensional concrete model and then moving onto the two-dimensional drawings, proved to be advantageous and is a suggested pedagogical sequence. The repetition of this task for a variety of different substances over the three-week teaching period ensured that the students became confident at switching between the two forms of representations.

The ability of the students to use multiple representations successfully in the lessons of organic chemistry was most beneficial in enhancing their ability to learn the structure, function and nomenclature of those simple organic molecules. Grosslight et al. (1991) valued the power of the use of multiple models claiming, "it is especially important to think of models that do not just provide physically different spatio-temporal views of the object but different conceptual vantage points" (p. 821). The uses of a variety of representations throughout the topic of organic chemistry provided alternative ways of viewing the same compound and were useful tools in generating mental models of simple organic compounds.

The computer-modelling program was used later in the unit to reinforce work already covered in the classroom and to present it in a slightly different format providing alternative and dynamic representations of organic compounds at the push of a button. Students' comments, such as, "we could make half of these" (1.4.259) when referring to the ball-and-stick type images on the computer screen showed that they were familiar and confident with the chemical representations.

7.3.2 Learning Strategies Study 3 – Learning Introductory Chemistry for Non-majors

The interviews (Appendix O) revealed that the well-known, traditional and proven learning strategies were the most commonly used by the volunteer students in Study 3. These included highlighting, memorising, studying worked solutions, practising problems and getting help with mistakes after doing topic tests. The responses to the interview questions indicated that all students were able to identify the learning strategies that they used. For example:

Int.: How did you go about learning the section/topic? What strategies did you use?

Sharon: I wrote out the notes.

Int.: You actually wrote out notes from the yellow textbook?

Sharon: Yes. (3.9.10.2.39-41).

Students did work collaboratively in the laboratory and were encouraged to help each other; however, it took time for students to get to know each other – especially meeting only at the weekly laboratory session or possibly at one of the two lecture times – and ask each other for help.

Several students referred to analogies or metaphors that they used when learning abstract concepts such as equilibrium.

Wally: All I know about equilibrium is like a crane.

Simon: I find it hard to put it in words. I know what it means; um I'd say it's supposed [to be] when everything's happy when it's not reacting any further. (3.9.14.71-72)

The assessment process encouraged students to adopt learning strategies that reinforced the memorisation of facts and algorithmic understanding (Nakhleh et al., 1996). In the interview with Stuart, he described his learning strategies.

Stuart: Prior knowledge helped me - I had good background knowledge. Did the tests, most were OK, when I failed one I went home, learnt it all from the yellow book and practised the problems, worked them backwards to understand what they were trying to do; it is just hard work. I learn the stuff from each unit - crammed for each unit, memorised it, pass the test and then, that's it, I don't always remember it. (3.9.13.11).

Stuart had developed strategies that took advantage of the PSI system that worked for him. He recognised shortcomings of this type of learning but did not seem to consider it a drawback.

Stuart:	Sometimes if I don't know how I'm going, so I book in [to do the test] and try the test and get feedback.
Int.:	That is a strategy you have worked out to help you succeed. Have you failed any tests?
Stuart:	Yeah I failed two organic ones.
Int.:	What did you do to get around that?
Stuart:	I went home and stayed up all night studying.
Int.:	OK, How did you learn it when you were studying? Did you memorise it?
Stuart:	Yeah basically I got the book out and went over it and I did a topic test and if I failed it I went back and went over it. (3.9.13.104).

The following excerpt describes Leanne's and Simon's learning strategy that is aligned with the philosophy of the PSI approach.

Int.:	How did you go about learning the section/topic? What strategies did you use?
Leanne:	I booked [in to do] the test, and then I had to go [attend], even if I didn't pass – I learnt from it, got help and then could try again. (3.9.12.9)
Simon:	I went in [to the PSI testing room] when there was no one else in there and I just sat down with the tutor before I did the test and went through everything, so yeah that was helpful. (3.9.9.27)

Overall, the results of item 12 in the SUE instrument (Table 7.1) concerning the value of the feedback students received support these excerpts with most students finding the feedback helpful. The mean for item 12 was 3.21 (SD 1.09) which included 45% choosing 4 or 5 favouring the very helpful response whereas 25% chose 1 or 2 indicating the feedback was of little help.

From the interviews, it was apparent that for many students the motivation was to learn to pass the tests and hence the unit, rather than to learn for understanding. This is understandable, remembering that chemistry is not their major field of study, but certainly not desirable.

Int.:	Which section did you find difficult to learn? Why was it difficult?
Sharon:	All of the organics!!
Int.:	Why do you think was so hard? Because it was at the end of semester?
Sharon:	No it was just more complicated than the first stuff they didn't give you like rules, so you had to learn the rules and apply it. There were these things you had to know things you had to know in and out and if you didn't know it in and out then you couldn't do the test well enough to pass.
Int.:	OK, Do you think it was valuable learning it? Was it worthwhile?
Sharon:	Not for our course. (3.9.10.27).

Students were able to elect what grade they were aiming for by the number of tests they completed by the end of the semester. Students completing just the compulsory tests would achieve a pass grade whereas students completing all the compulsory topic tests and the optional topic tests were able to take the optional examination to be eligible for a higher grade. Again the fact that chemistry was not their major field of study became a determining factor in their attitude and learning approach.

> *Int.:* How did you go with the tests?
>
> *Simon:* Yeah good I got them all done, so I didn't do the exam, so I was just basically going to be a pass, so as soon as I got them done, I knew I passed, so I just concentrated on my other units, which I don't know is a good thing or a bad thing. (3.9.9.7).

Time management was a common dilemma with the need for students to have realistic expectations about the time needed to learn, and the allocation of that time. Without any formal time restrictions, many students fell behind schedule with the PSI tests, resulting in a student possibly losing the opportunity to re-sit tests as often as was needed to pass, or learning masses of content superficially without understanding in order to pass. The ultimate deadline at the end of the semester resulted in many students queuing to take the PSI tests, the system was overloaded, and the philosophy of feedback and reflective learning lost to the pressures of time. The philosophy behind the self-paced learning program is outlined in Appendix H. The guideline specifically guards against the time management dilemma:

> Strict quality guidelines in the Unit Outlines ensure that students meet their obligations within sensible time frameworks (Curtin University of Technology, 2003c).

Despite these warnings the problem still remained and its repercussions were contrary to the philosophy behind the PSI testing scheme. It may be unreasonable to expect all these non-major students to have a 'passion' for chemistry, but it is desirable that they gain an appreciation of the chemistry from their learning experiences. The pressures of time, the amount of content that had to be covered and the rigour of the assessment regime directed even interested and earnest students to those learning strategies that prepared them for tests. Evidently, the traditional learning strategies best-prepared students for the algorithmic style questions of the PSI tests, which comprised the major component of their assessment.

While, only two out of the 12 students participating in the second interview mentioned the internal factor of personal preferred learning style, for example using visual and diagrammatic data, all students interviewed, referred to the external factors as being significant in determining their choice of learning strategies. The external factors – such as those described above – assessment requirements, time pressures, and the volume of material to be learnt – influenced students' learning strategies to the end that the assessment was driving the learning instead of the preferred situation in which the primary focus is the individual's learning and assessment is secondary to the learning.

7.3.3 Learning Strategies Study 4 – Learning Introductory Chemistry and the Implementation of Online Pre-laboratory Exercises for Non-majors

The students' written responses to question 25 of the Online Survey, asking students to list any learning strategies they make use of in learning chemistry, were coded and ten categories were distinguished and presented in Table 7.8. The students were aware of the multiple learning strategies they used and responded openly to the question. The traditional learning strategies identified in Study 4 with a large anonymous group (n=116) are similar to those identified in Study 3, with a small volunteer group (n=19). As with Study 3, the learning strategies were influenced by the assessment scheme of the chemistry unit. The most common learning strategy was working out problems, practising problems, using solutions (Table 7.8), and confirming that the students used learning strategies to match the assessment scheme. However, considering the students' backgrounds, the volume of chemical content and the speed at which students must digest it, this assessment scheme may be the most appropriate to achieve the unit objectives for these non-major students.

The learning strategies that promote rote learning style rather than conceptual understanding did not readily foster the development of students' mental models of the chemical phenomena. Nevertheless, despite the assessment scheme, some students commented about the impact of particular learning strategies on their understanding and demonstrated that they were developing personal mental models of chemical phenomena.

Table 7.8 Frequency of the Ten Categories for Question 25 Concerning Learning Strategies in the Online Survey by First Year Chemistry Students (n=115)

Category	Frequency
Underlining, highlighting copying notes, rewriting notes	49
Memorising and reading	45
Working out problems, practising problems, using solutions	67
Working with other students, tutors	48
Researching texts, course notes, websites	35
Drawing concept maps, diagrams	25
Lectures	4
Sequential learning	2
Laboratory work	3
Contextual learning	1

The strategy of students reconstructing the concepts for themselves and expressing the concept in their own words was common. Examples that illustrate this are as follows:

> Re-writing the work covered in the lectures in my own words as if I were explaining it to someone else. (4.4.90.25)

> I divide the topic units into sections, using different colours to separate out different aspects of the topic. This reduces the (given) notes into manageable units, and makes it easier for me to handle. Talking it through, even just talking aloud to myself, often clarifies things. Telling myself it's just another foreign language; I enjoy learning languages, and do so easily. (4.4.113.25)

> I’m always taking notes.... and sometimes these notes are repeating themselves...but I always have them with me for reference...and I write little notes all over the place...usually in pencil so I can erase them when I have to hand something in....I personally find it easier to work on my own and going to find help when I need it.... I also have a small chemistry pocket book that has basic chemistry facts that’s useful for definitions and helps put things into different words when sometimes I do not understand something. (4.4.116.25)

Some students referred to the importance of mind maps, models and diagrams to learning, as is demonstrated in these responses:

> Models of atoms, compounds help [me] understand processes and the chemical reactions occurring. (4.4.4.25.68)

> Practicing problems and checking answers with solutions drawing diagrams memorising. (4.4.4.25.76)

> All of the above to different extents, but especially highlighting, working out problems and mind maps. (4.4.4.25.92)

> Reading and rewriting the notes. Memorising formulas and theory. Drawing concept maps and trees. (4.4.4.25.111)

> I find diagrams and pictures far easier to assimilate in this regard than descriptions. (4.4.22.8).

One student wanted to link the theory to practical applications.

> [Being able to] understand the concept, get a good basis with a few calculations and formula, do questions with practical application, discuss the numbers obtained from the calculation and relate the numbers to real life. (4.4.25.33).

From the students' responses to the Online Survey, it was apparent that the traditional learning strategies continued to be the most popular. The new technologies provided an alternative means of approaching the traditional methods. The learning process is individualistic, requires mental effort by the learner and cannot be short cut. But more importantly, how are we utilising the technology to assist the traditional learning strategies? In Study 4, the online pre-laboratory exercises provided the learner with greater flexibility, immediate feedback and e-mail contact with other students and staff. These facilities may have assisted in providing a better learning environment to promote the learning process, and the comments from students confirm this, but the learner still had to put in the mental effort of memorising, thinking, reading, practising and applying knowledge that are the foundations of learning.

7.3.4 Summary and Response to Research Question 3.2

Research Question 3.2 asks: "What learning strategies do students use in learning chemistry?" The learning strategies identified in this research include: working collaboratively with other students – the discussion of ideas, listening to others, and negotiation of meanings; the practice and repetition of tasks to build familiarity, confidence and self efficacy; the manipulation of physical models and experience with a variety of models to help visualisation of the sub-microscopic level; the transference from one type of model to another and to reality – to consolidate the mental mapping; highlighting, memorising, writing and reading out notes to promote learning; studying worked solutions and practising problems to identify trends and patterns in problem solving; and making use of analogies, metaphors, mind maps, models and diagrams to aid understanding.

The choice of learning strategies by students and instructors is influenced by the factors that influence learning, discussed in section 7.2, and this choice consequently determines the type of learning that will occur. The contrast of learning strategies between Study 1 and Studies 3 and 4 is marked with Study 1 using collaborative and problem-solving approaches while Studies 3 and 4 were using memorising and algorithmic approaches. In Studies 3 and 4 students choose and use learning strategies to match the assessment scheme. This choice influences the type of learning that occurs, with Study 1 promoting a deeper learning approach and Studies 3 and 4 promoting a rote-learning approach.

It is naïve to pronounce that all learning should be deep and meaningful. Different students have different needs that have to be catered for and the learning strategies should be appropriate to these needs.

7.4 Development of Mental Models

Research Question 3.3 asks, "How do learning strategies contribute to the development of students' personal mental models of chemical phenomena?" Data from Studies 1 and 3 are used to respond to this research question. A personal mental model is a result of an individual's interpretation of all the representations, explanations, ideas, and their experiences.

7.4.1 Development of Mental Models – Study 1 – Learning Introductory Organic Chemistry in Secondary School

Throughout the model-based instruction students began to develop their own mental models for the chemical structures. For example, students frequently returned to the ball-and-stick models to identify the longest chain of an organic molecule. Initially, many students were confused by the variety of equivalent structural formula representations such as butane, displayed here.

$CH_3—CH_2—CH_2—CH_3$ and CH_3
|
$CH_2—CH_2—CH_3$

– and returned to the ball-and-stick model, manipulating the carbon and hydrogen positions to show their equivalence.

The video data showed students trying to rotate atoms around double bonds in response to a question about the implication of the double bond. A statement by a student towards the end of the unit, "Just do it on paper, we don't need the model" (1.4.445) could indicate transference from physical manipulation to mental manipulation. Similarly, "No, if that's the drawing then it's not 1,1. Both of the chloros aren't coming off the first one so it can't be 1,1" (1.4.455) – indicating that the student could transfer from the ball-and-stick model to the structural formula. This transference was practised repeatedly in the classroom, helping students to make the link from three-dimensional to two-dimensional representations more easily and build up their mental models of the structure and motion of the molecules. The classroom environment allowed time for students to practice this activity.

With increased experience, students were able to build models quickly and the manipulation of these teaching models provided students with an opportunity to discuss the structure and the nomenclature of each organic compound. The collaborative approach to learning was effective in promoting dialogue between students. This group activity contrasted to the students' routine chemistry classes that were more teacher-centred. As illustrated in the following dialogue, students frequently repeated answers to each other, asking their partner for confirmation that they were correct.

S1:	Next one you are gonna have two chlorines in the middle. That means 2,2 dichloropropane, it is all dichloropropane.
S2:	This is what we have just done it is still …
S1:	It is all propane and it is dichloropropane and it is just the number and the fact that the number is 1,1; 1,2; 2,2.
S2:	Perhaps 1,3 … What about 1,3?
S1:	Fine. 2,2 is here and 1,2 is just like this.
S2:	2,3?
S1:	No it will be 1,2.
S2:	I see. I did not realise what you were getting at it. It will be what?
S1:	On what?
S2:	1,2; 1,3.
S1:	1,2; 1,3.
S2:	and then 2,2; 1,2.
S1:	What about 1,1; 1,2; 1,3 and that is it?
S2:	Yeah (1.4.1033-1045).

Students repeatedly counted along the model identifying the longest chain.

This was invaluable for naming compounds correctly, as in the examples: “1, 2, 3, 4, so it’s butane, so it’s methyl butane” (1.4.839) and “1,2,3,4. Four is the longest chain we can get. Umm butane” (1.4.649). The transcripts of students’ dialogue commonly included truncated phrases, with students often not completing sentences. The conversations, as displayed in this example, indicated that students were assisting each other to understand the differences between the various isomers of C_4H_8. The conversations in which students express their understanding, provide insight into their understanding, and can be described as their expressed model.

S1:	Yes, I think it is butene.
S2:	So the double chain, double bond is in different spots.
S1:	Double chain!
S2:	Double bonds!!
S1:	This is the one that was there before?
S2:	This one is another one.
S1:	Is it?
S2:	Yes definitely.
S1:	What is this one called?
S2:	No, we made this one before.
S1:	Its methyl propene.
S2:	Again!!
S1:	How many are there because I think we have them?
Teacher:	Could you draw that one on the board?
Teacher:	How many have you got?
S2:	3.
S1:	Ohh, How do we name the second one?
S2:	I have no idea. (1.4.371-393)

Similarly, the student’s comment “I don’t know but it’s connected, sharing electrons” (1.4.39) implies that the student had connected the representation of the region between two balls with a covalent bond. The pronunciation and correct use of new vocabulary was practised. The talking and the building activities helped students to become familiar with the new names and structures. This confidence building is a significant part of learning – promoting students self-efficacy.

The model-based approach to learning in Study 1 has emphasised the development of students’ verbal and manipulative skills. Beginning with the three-dimensional concrete model, then moving onto the two-dimensional drawings assisted the students' mental model development and is a suggested pedagogical approach. As the teaching unit progressed, students' confidence in their own knowledge and understanding of the material increased. This is displayed by comparing the constant need for affirmation at the beginning of the unit to a student saying that the physical model is not needed, towards the end of the unit. This development is an important component of the students' self-efficacy and can promote the personal control of their learning. The data showed that the teaching models of simple organic molecules are a manifestation of the scientific theory and scientific model and assisted these students in developing their own mental model.

7.4.2 Development of Mental Models – Study 3 – First Year University, Non-major Chemistry Course 2001

Students' mental models of the abstract but real sub-microscopic level of chemical phenomena appear to be neglected in this PSI program of chemistry education according to the results of Study 3. Yet, as already explained, the sub-microscopic level is the basis of chemical explanations.

It would appear obvious that students' conceptual understandings of chemical phenomena are intertwined with their mental models, with mental models being reflections of the students' understanding. During the first interview conducted in Study 3, Russell, who had had no previous chemistry experience except for the first four weeks of this unit, was asked to comment on a variety of representations for water (Figure 4.5). Russell focused on one representation that showed the lone and bonding electrons to help explain solubility.

Int.: How do you visualise the ions in solution, because we have gone from a solid to solution?

Russell: Well knowing what I know, visually I can't comprehend it, but in my head, knowing what I know, I know that they sort of separate disassociated, and that they are surrounded by a shell of water.

Int.: Do you think the charge factor has helped you understand what's happening?

Russell: Yes because otherwise I wouldn't have understood exactly why the water would be around it, and why it would be pointing certain ways and things.

Int.: Have you seen any dynamic videos or anything that's portrayed that?

Russell: No, I've seen a couple of diagrams in the odd chemistry book, but that's about it, the actual diagram didn't help to explain the shell of water, I mean I'd read somewhere before about that, but it didn't click as to why until I saw all the water structure again. (3.9.8.50-52) [Referring to Figure 4.5 diagram #8]

The diagram helped Russell to understand why some particular ions dissolved and others did not. This particular student was reflective about his learning and the construction that was needed. Overall, there was a marked improvement observed by the researcher in the mental models of the student volunteers by the end of the course, although the students themselves were guarded about saying so or else didn't recognise it.

There are examples of students developing mental models and being aware of their learning; however, they also have the pressure of having to meet the requirements of the unit with getting practical reports and tests completed on time.

Int.:	Do you think you could write up the practical on your own? Without it being on the board?
Simon:	If I sat down and got out some books then maybe, but it'd take me a long time to do it.
Int.:	That colour chromatography is a good example. Even though it really is just a physical separation, did you have a mental picture of what the atom, or actual ions are doing?
Wally:	I think so
Simon:	Not at all, I pretty much just do what it says in the book and try and get it right.
Int.:	So what did you think when you've got one colour through and they separated out, what did you think was happening?
Wally:	I visualise it splitting apart.
Int.:	You visualise them as little round balls going through a column? Do you think of one being pulled more than another?
Wally:	Yeah
Int.:	Have you developed your mental picture over the last six months?
Wally:	I think so; I think it is mainly the visual bits, electrons and things.
Int.:	So what has helped you build up this mental picture? Any particular resources such as molecular modelling kits, or computer images, descriptions of positives and negatives being attracted?
Wally:	Well we've done this cell biology map, everything's on a microscopic level, and Kreb cycle and stuff, so we've done models; we've got through models.
Wally:	Wednesday lecture on organics, he brought in a molecular model to show us how it works and stuff.
Int.:	Did that help?
Wally:	Yeah Did he explain what they were? Yeah
Simon:	[Another] guy, used to bring in models, and say things to get everyone's attentions, would say this is just morphine, or something like that, and that would get everyone's attention because you're talking about a drug, or something you can relate to (3.9.60-70).

Towards the end of the course, 33 % (4/12) of students interviewed, still held no identifiable mental model for chemical phenomena, stating that they do learn the facts but had no mental picture of the sub-microscopic nature of chemicals. However, the other students (8/12) interviewed did provide evidence of the development of their mental models though this was not extensive. The effect of interviewing students and asking them about their mental models and the relationship they perceived between the various levels of chemical representation of matter may have influenced their perceptions and increased their awareness. Many students commented on the influence of diagrams and drawings of molecular structures on their thinking and some students referred to the importance of these diagrammatic representations in explaining why particular chemical structures looked or existed the way they did. For example, one student described how his understanding of chemical bonds became much clearer when he saw a diagrammatic representation of the electro-negativity of the atoms in a molecule helping him to understand why and how the bond occurred. This linking of representations to the sub-microscopic level indicated a more conceptual type of understanding.

When asked in the first interview about their personal mental picture of chemical atoms and compounds, most students drew or described a textbook description of the atom, reproducing what they had been taught previously. A few students reported that they had no mental picture of an atom in their mind. A mental model is a product of the students' interpretation of the images, models, and representations that they have experienced. Nevertheless, this is not an automatic learning experience; Johnstone (1991) reflects that many scientific concepts such as the electron, structures, molecules and bond energy are beyond our senses and students have no basis on which to construct an understanding. By the second interview many students (8/12) provided evidence through their laboratory activities, worksheets and interviews that their mental model of the sub-microscopic nature of matter had developed throughout the unit but each of them still considered their level of understanding to be primitive. The data from this study have shown that students often resort to a simple model and often have a preferred model. This observation is supported by the results of a study by Coll and Treagust (2001) who reported that students showed a strong preference for simple realistic mental models.

7.4.3 Summary and Response to Research Question 3.3

Research Question 3.3 asks, "How do learning strategies contribute to the development of students' personal mental models of chemical phenomena?" It is almost impossible to separate the notions of mental model and conceptual understanding since one is a reflection of the other; the results of this study show that as students' understanding improved so did their mental model. In both Studies 1 and 3, students' mental models of chemical phenomena were observed to develop despite each study adopting different learning strategies. It is hypothesised that students using strategies that promote a deeper learning would bring about more developed mental models.

When considering an individual's mental model of a chemical phenomenon, the sub-microscopic level of matter including the molecular and atomic levels is considered. When describing the movement of electrons, we are referring to subatomic particles, and in the next breadth refer to ions, which are 2000 orders of magnitude larger. Similarly, at times we will consider just one molecule – and the arrangements of the electrons in the bonds – at an instant in time, but attention to detail is necessary for the number and position of these tiny subatomic particles that only move in accordance with the forces present. So, a great deal of background knowledge is needed in order to begin to comprehend the complexities within the sub-microscopic level. It is difficult to simplify its complexity and depth to a basic level.

In comparison to the sub-microscopic level, the macroscopic level is easy to identify. The macroscopic level is real and visible whereas many students do not distinguish the symbolic representations from the sub-microscopic level because they do not perceive the sub-microscopic level to be real. This issue was discussed in Chapter 2 (Figure 2.3). Indeed, there are many ideas about atomic structure that are difficult to understand such as, the size of the atom – understanding the different orders of magnitude, the relative sizes of the parts of the atom, with the nucleus so dense and heavy, and the idea that the atom is mostly empty space, and applying this structure to solids liquids and gases, and the idea that the electrons are moving constantly and very quickly and have endless supplies of energy.

7.5 Metacognition

Data from Study 4 is used to respond to Research Question 3.4: "How does students' metacognitive awareness influence their learning of chemistry?"

The opportunity to investigate the learning of students involved in Study 4 was indeed fortuitous because these students had a metacognitive awareness. Younger students may have had some metacognitive awareness but they did not seem as aware of it nor were they willing to discuss it so freely.

7.5.1 Metacognitive Awareness

The responses to items in the SEEQ instrument (Table 7.2) and the Online Survey (Table 7.3) suggest that students did appreciate the value of various learning tasks and did have an understanding of how they learn. As already mentioned in section 7.2.2b, many students (72%, 70%) agreed that the pre-laboratory exercises helped them to learn and understand the concepts in the experiment (item 7); and 65%, 69% respectively, thought they understood the experiments better (item 14) having done the online pre-laboratory exercises. These results draw attention to the students' awareness of their own learning and the impact of specific learning strategies on their understanding. In Table 7.2 it is reported that 70% of students agreed that the online pre-laboratory exercises were useful in confirming their understanding (item 12). The consistency of the results from semester 1 to semester 2 is confirming of the results.

Representative students' written responses to the open-ended questions in the Online Survey demonstrated their reflectivity about their learning experience.

> Doing the pre-labs made me gain a better understanding of the experiments in general, but also allowed me to think about what I learned from them and apply them to the practical aspect while I'm actually doing the experiment. The questions and answers are direct so there's little confusion, which I also think, is important. (4.4.7.22)

> It has provided me with quite adequate information about the coming lab exercises but it would be much better if we could add an aim to the above, namely help students get an understanding of how the experiment works and what logical reasoning is behind the chemistry of the experiment itself. Most of the time students can do the experiment well enough to get good marks, but they don't understand how the actual experiment proves the theory behind it, or describe the logic in obtaining the steps to calculate results for an experiment such as the iodine or saponification value. If Web CT were to be able to help develop students' understanding about the logics of calculation and provide feedback of certain cases (i.e., adding excess acid), it would certainly help them, especially to those who have little understanding of chemistry. (4.4.33.22)

> It is important for the university that it helps to make students understand the concepts of the lab rather just give practicals without enough information. This way, we can understand what exactly we are doing in the lab and know what our numbers mean, how we get them, and the logical thinking in getting them. (4.4.33.27)

The metacognitive awareness expressed by some students demonstrated an appreciation of their responsibility for learning and their value of the learning resources. Further to this, students' remarks provided critical awareness about the way they wanted to learn.

> An observation I have made is that the lectures are orientated around passing the unit tests rather than 'understanding' what is happening with the chemistry. This is probably a result of the breadth of information we are encompassing this year. While this allows for students to pass the unit components fairly easily (and get good marks), it doesn't necessarily equate with an understanding of chemistry but rather an ability to remember how to do set problems. (4.4.8.26)

> The typical test solutions showing the workings has been extremely helpful in LEARNING, not only getting the answers, as each problem has been set out step by step. (4.4.39.20)

> Because of the structure of Chem 118, I have understood and enjoyed chemistry more. Being able to set my own pace with only my own pressure has meant learning it more thoroughly and more effectively. I have felt more satisfied with myself. I feel this way of learning helps you to retain what you have learnt rather than just cram and forget - This is especially true as a pre-requisite subject. Although there will only be biochemistry in my course after this year, 117 and 118 has laid a good foundation. (4.4.105.27)

> The lectures seem only aimed at passing the assessments, not actually learning any theory. But I can see the reason for this. Generally, I am very happy with the course (4.4.92.27)

With some students expressing an interest in learning as well as those expressing a desire to learn just enough to pass, the alternative motivations of the student population are revealed. Catering for these different needs is a challenge that chemical educators face.

7.5.2 The Intentional Learner

Students' responses to questions in the interviews and the written answers to the Online Survey provide evidence that many of the university students taking the introductory chemistry units were: aware of the learning processes that they were undertaking; understood the representational nature of the chemical symbols; appreciated the value of particular learning strategies; and acted intentionally and mindfully when learning. These qualities are characteristics of the intentional learner described in section 3.4.3 (Bereiter & Scardamalia, 1989). The students from Study 4 can be described as intentional learners, considering that they have chosen to study at university. However, their motivation for learning varied with some students motivated only to learn in order to pass the unit, while others were motivated to learn to understand as well as pass the unit. This is presented diagrammatically in Figure 7.2. In order to cater for all types of learners along with the connotations of a non-major unit, in Study 4 students have been provided with active learning opportunities, feedback on their understanding and practice in skill development.

The data provided examples of students making informed choices about their learning, such as the time they make available, the desired grade, and the amount of effort they are willing to offer. As presented earlier (section 7.3.2) Simon elected for a pass grade in chemistry in order to devote more time to his major subject area of study.

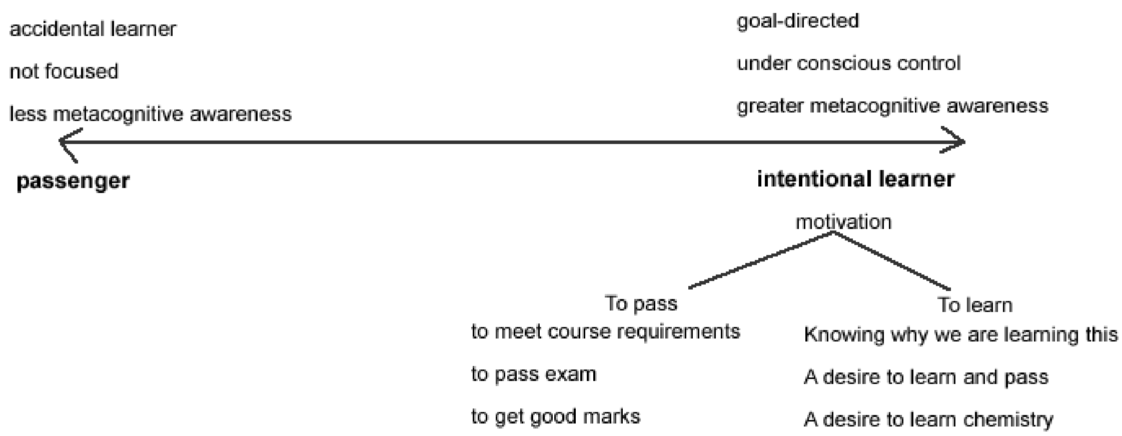

Figure 7.2 Attributes of Different Types of Learners With the Different Motivation of Students in Study 4

7.5.3 Metacognition and the Intentional Learner

As described in section 3.5, metacognition is closely related to intentional learning. Hennessey (2003) claims that "metacognitive engagement and intentional conceptual change are highly connected" (p. 125). Metacognition is the process of the learner consciously using strategies to enhance learning. Hennessey (2003) identified two levels of metacognitive thought – a representational and an evaluative level – which is consistent with Skemp's (1976) model of instrumental and relational learning described in section 3.6.2. Students with greater metacognitive awareness are better situated to have a rewarding learning experience. In this research, students who have been motivated demonstrated application and enthusiasm have improved –

irrespective of their background knowledge. A metacognitive awareness could be described as the students' understanding of their changing position in the learning process, within the ontological and epistemological boundaries.

Metacognition has emerged as a fourth perspective to learning, complementing the ontological, epistemological, and social/affective perspectives of the theoretical multidimensional framework proposed by Tyson et al. (1997)(section 3.5.2) to guide conceptual change supported by their research data (see also Harrison & Treagust, 2001; Venville & Treagust, 1998) with high school students on particular scientific concepts. The researchers were analysing the way students were learning specific chemistry and biology topics and the researchers distinguished three perspectives relevant to learning, namely ontological, epistemological and social/affective perspectives.

In Studies 3 and 4, the quantitative and qualitative responses revealed that many students had analysed their own learning and identified the same multiple perspectives as distinguished by Tyson et al. (1997). In both studies there are indications of students' motivation with written and verbal comments indicating that they want to pass the unit, and fewer students commenting on a desire to understand the chemical concepts. However, some students were critical of the assessment structure of the unit, inferring that it was not helping them to understand the concepts, as demonstrated in Margaret's comments.

Int.: How did you go about learning the topic?

Margaret: But um I got a tutor and that helped me a lot and it's coming together and I still have one now that's how I got through. I find that first year chemistry especially for people who haven't done it before there should be a tutorial involved

Int.: Not just the PSI tests?

Margaret: Not just the PSI because I mean PSI test, you learn what you have to do and then you basically forget, because you are learning something else for the next test, whereas if you have a tutorial you can understand what is happening and it would be a lot easier than what we've had. (3.9.11.5-6)

Students' responses on the VOMMS instruments provided data about their understanding of the epistemology of science, the process of science and the way scientific knowledge is built up. Many first-year university students expressed a fair understanding of the way scientific knowledge grows and changes. Laboratory tasks required students to transfer between various levels of chemical representations and students were observed successfully managing two or more levels of chemical representations simultaneously. In order to do this, students must have a schema of chemical concepts. These observations provided an insight into the students' ontological network of chemical knowledge. The data have also shown that students knowingly choose learning strategies to achieve the desired objective.

Not only does this reinforce the idea that there are multiple perspectives that influence the learning process, but more importantly that the university students are aware of their own learning and of these multiple learning influences.

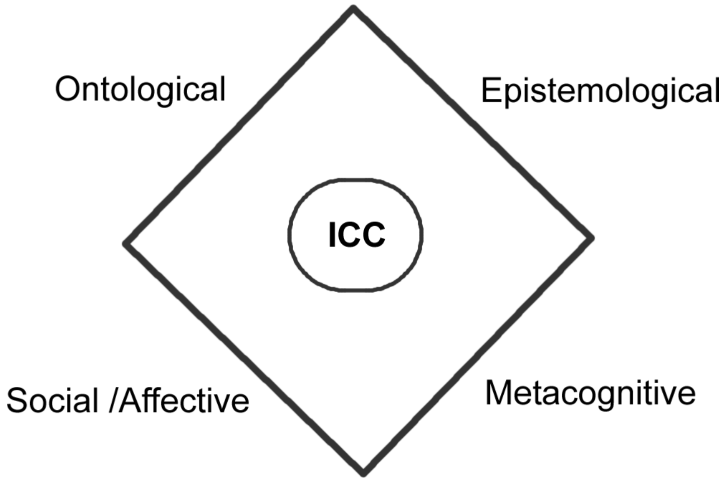

Figure 7.3 Four Dimensional Framework for Intentional Conceptual Change (ICC)

Harrison and Treagust (2001) argue that a single perspective provides only a limited view of the learning process and emphasises the importance of multiple aspects. The students' written responses coincided with the theoretical framework as described by Tyson et al. (1997). However, there is an additional perspective of learning identified by students – the metacognitive perspective in which students are aware of their own learning. With the inclusion of this additional perspective, the multidimensional framework would consist of four perspectives namely, ontological, metacognition, epistemological, and social/affective – as depicted in Figure 7.3.

7.5.4 Summary and Response to Research Question 3.4

Research Question 3.4 asked, "How does students' metacognitive awareness influence their learning of chemistry?" The data from Study 4 have shown that many students recognised the learning strategies that suited them and the factors that influenced their learning. The data suggest that students' increased awareness helps in their learning because they know what they have to do in order to achieve their objective. The corollary to this observation is the opportunity for instructors to capitalise on this attribute to improve students' learning by making more overt the metacognitive features of particular learning tasks.

7.5 Conclusion

Learning results in changes to a learners' understanding and their mental model that is a reflection of their understanding. The individualistic nature of learning highlights the diversity in the factors that can influence this process. Nevertheless, there are some commonalities identified in Studies 1, 3 and 4 that are important to learning.

The development of each student's mental model of chemical phenomena is aided by using chemical representations such as teaching models like the ball-and-stick models, diagrams and equations. Representations used in teaching are essential in helping students to develop a mental model of the sub-microscopic level of chemistry. The data here provide evidence of students' confidence and self-efficacy improving through the use of a variety of chemical representations including teaching models.

Learning strategies included the discussion of ideas, the practice and repetition of tasks, the manipulation of physical models, the transference from one type of model to another and to reality, the memorisation of chemistry content, the use of diagrams, and the use of a variety of models. The learning strategies that required the students to construct their own ideas promoted the development of the learners' mental model. The name of the learning strategy alone is insufficient to claim it will develop a students' mental model – it is the way the learning strategy is used by the learner that is important. For the high school students in Study 1, their teacher managed their instruction, providing opportunities for the students to construct new ideas. This pedagogical approach was shown to be effective in students' learning. Examples have been provided of students using the ball-and-stick model to gain an understanding of the three-dimensionality of the structures. Similarly, with the use of diagrams, students interpreted diagrams at different levels of chemical representation of matter – some at a macroscopic level and others at both the macroscopic and sub-microscopic level. So, for the particular learning strategy to promote meaningful learning, it must be used in an active, constructivist manner.

The university students in Studies 3 and 4 were directed to using learning strategies that promoted a rote-learning approach in response to the assessment demands of the unit. The learning strategies chosen were influenced by the individuals' prior knowledge, motivation, personal learning styles, in addition to the course structure, and assessment requirements. The students from Study 4 were enthusiastic to provide feedback on their learning experience in the hope of improving their learning situation. They were also thoughtful in their responses – they were serious and earnest in their criticisms. The nature of university education, with the student choosing to undertake the education, incurring the cost for the tuition, the university maintaining the academic standards, and providing an independent learning situation without the individual instruction of a school classroom generated a more disciplined attitude in the university students than in the school situation. In Studies 3 and 4, the mature students commonly displayed a disciplined and serious attitude towards their learning because they were intent on passing the unit.

With the university students involved in Studies 3 and 4, a metacognitive awareness and diligent attitude was evident in their responses. This quality is an asset that can be used to promote learning and is one that can be fostered at all levels of education. Bereiter and Scardamalia (1989) describe the intentional learner to be self-disciplined, well-organised and motivated. The responses from the university students indicated that many adopted these characteristics in order to pass the unit. Although the content of any particular unit is important, it is equally important to understand and appreciate the process of learning. The data from Studies 3 and 4 show students learning content but also show students appreciating the learning process. Any educational system in which assessment must evaluate an individuals' personal learning experience is thwart with difficulties. However, academic standards must be maintained and criteria establishing those standards need to be met. Students recognise these parameters and in this way understand the system and work to its rules. Assessment structure plays a significant role in learning in terms of motivation, expectations and direction of type of learning. The educators have a responsibility to select the most appropriate assessment techniques to achieve the desired objectives. It is up to the educators to establish the rules so that the students can attain a high academic standard in both content and process of learning.

CHAPTER 8

CONCLUSION AND IMPLICATIONS FOR FUTURE RESEARCH

Chapter Outline

The final chapter of this thesis presents a summary of the research. Section one describes the research, while section two presents the theoretical frameworks that have evolved during the research. In section three, the research findings concerning models and modelling ability are summarised. Section four presents the research results concerning the three levels of chemical representation of matter. Section five presents the research findings about the development of students' mental models. Section six summarises the limitations of the research. Section seven provides implications of the results of this research for teaching and learning. Lastly, section eight suggests areas of future educational research signalled by the research findings.

8.1 Description of The Research

This research has examined the role of representations in learning chemistry, specifically their role in the development of students' mental models of chemical phenomena. There are three objectives of this research: firstly, to understand students' perceptions of models and their modelling ability; secondly, to investigate students' perceptions of chemical representations of matter at the macroscopic, sub-microscopic and symbolic levels; and lastly, to investigate students' learning of chemical concepts in terms of the development of the learners' personal mental models.

These three objectives correspond to the three primary themes flowing through this research: models, representations and learning. Students' perceptions of general models, scientific models and chemical models have been investigated and the research has probed student learning, examining the role of representations as well as investigating other factors that influence this process. The research comprised four separate studies that occurred consecutively over a period of three and one-half years. The four studies involved students from Year 8 through to first year university and took place in high schools and a university. Study 1 took place in a senior high school, observing Year 11 chemistry students working with chemical models; Study 2 involved collecting survey data about high school students' perceptions of scientific models; Studies 3 and 4 involved investigating how first year university students, many with little or no chemical background, learnt chemistry. Qualitative and quantitative data were collected, collated, analysed and discussed. This research has attempted to draw together data about students' perceptions and understanding of the role of models and the activity of modelling in applying them to the three levels of chemical representation of matter when learning chemistry.

8.2 Theoretical Frameworks of the Research

The research developed three theoretical frameworks, which have proved to be useful in exploring and promoting ideas about the learning process. Each framework corresponds to one of the three objectives of the research:

- A theoretical framework relating the four types of models – teaching, scientific, mental and expressed models – showing their relationship to learning (Figure 5.9) corresponds to objective 1.
- The relationship between the three levels of chemical representation of matter (Johnstone, 1982) and the mental model (Figure 6.14) corresponds to objective 2.
- A four dimensional framework for learning comprised of epistemological, social/affective, ontological and metacognitive perspectives (Figure 7.3) corresponds to objective 3.

All three frameworks relate to learning. Figures 8.1, 8.2 and 8.3 show how each framework has changed and developed as a result of the analysis and interpretation of the research results. Each can be considered separately, but they are also complementary. The frameworks build on the work of other researchers including Gilbert and Boulter (1995), Johnstone (1982) and Tyson et al. (1997)**.** All three frameworks, which provide ways of thinking about the learning process, have been further developed throughout the period of the research as a result of the literature review, the research results and the analyses.

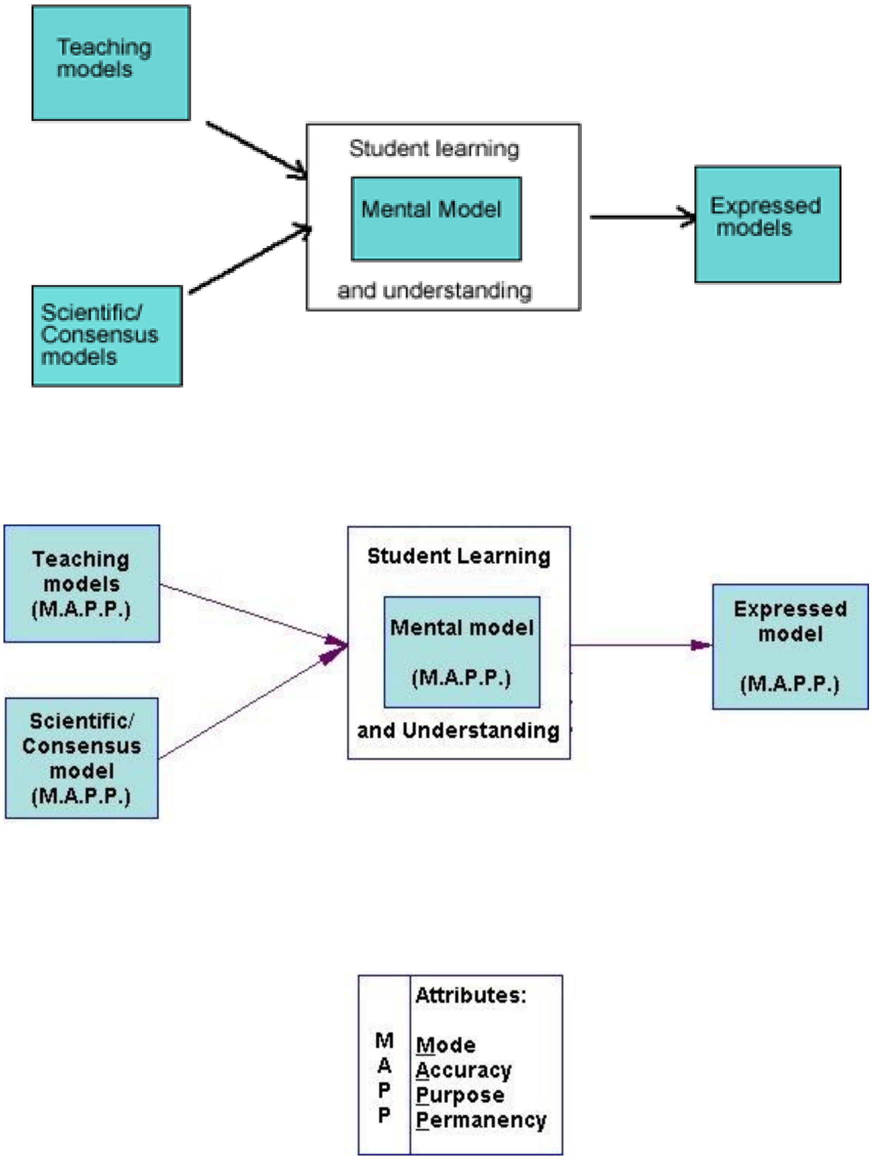

Figure 8.1 The Development of Ideas About Models and Learning

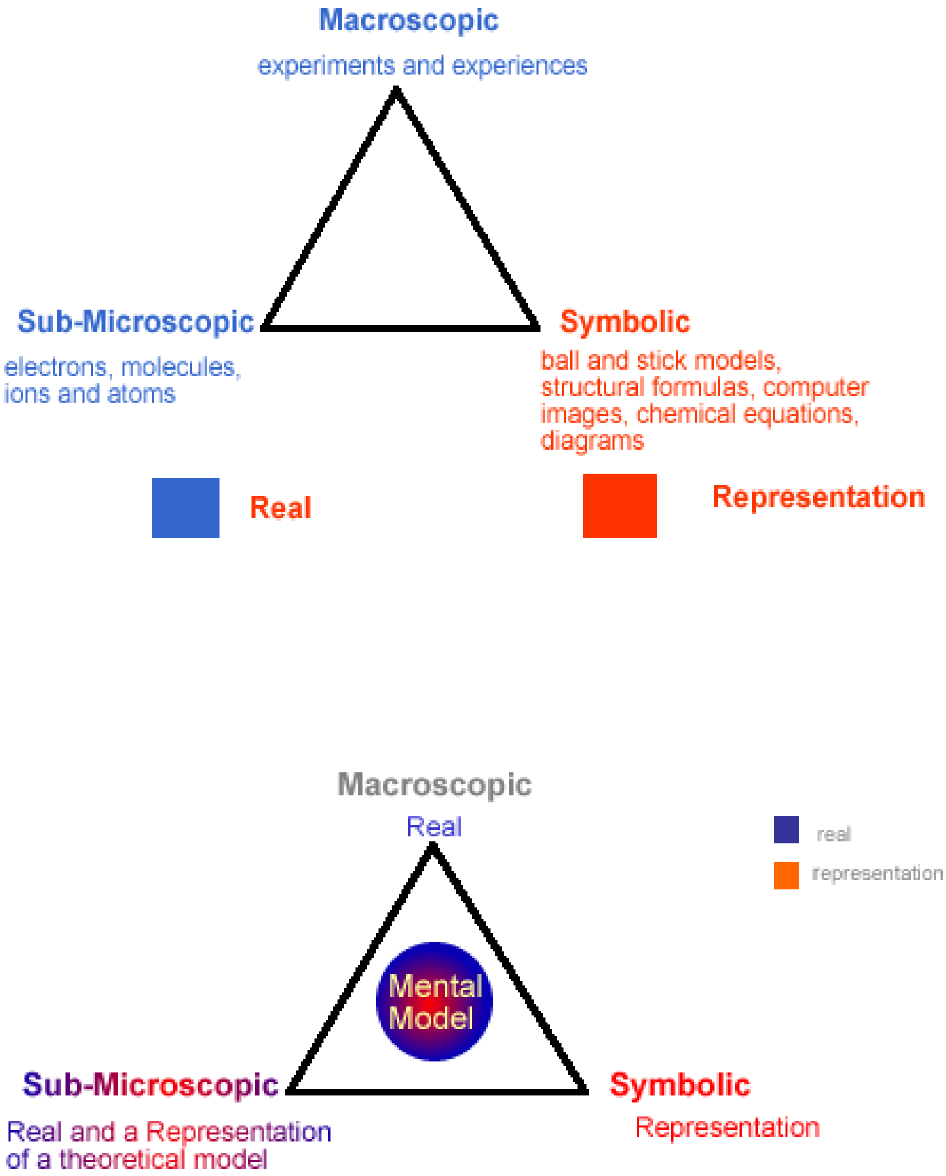

Figure 8.2 The Development of Ideas About Chemical Representations and Learning

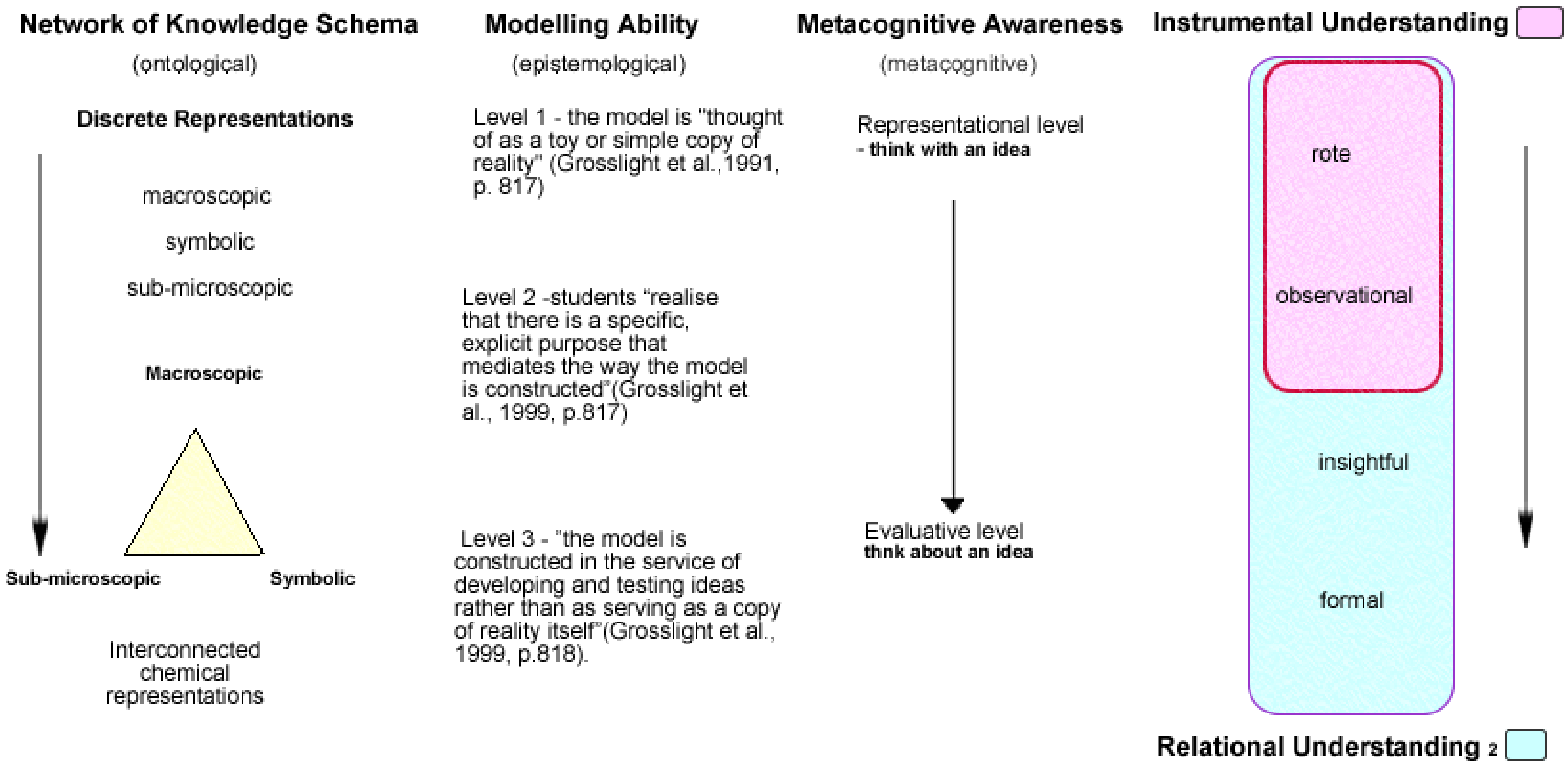

Figure 8.3 The Development of Ideas About Learning and Understanding

Data from all four studies were used to answer the research questions that pertain to each of the three research objectives. A summary of the results of the research questions for the first objective is presented in section 8.3, Models and Modelling Ability; the results of the research questions for the second objective are presented in section 8.4, The Three Levels of Chemical Representation of Matter; and the results of the research questions for the last objective are summarised in section 8.5, The Development of Personal Mental Models.

8.3 Models and Modelling Ability

Research Question 1.1 inquired, "What are students' perceptions of the role and purpose of generic models and scientific models?" Nearly all students (80%) in all studies held a good understanding of a model as a copy or replica. This traditional and narrow definition is sometimes not appropriate for scientific models. The results also indicated that only approximately 50% of high school students, but more than 75% of university students regarded abstract objects such as graphs or photos to be models. These results highlighted how sometimes a student's everyday understanding is different to the definitions or understanding assumed with a scientific view. Consequently, a student's background knowledge or previous understandings can be potentially significant to their understanding and their learning.

There was good evidence from the instruments concerning scientific models, particularly the written responses in the VOMMS instrument that many students were thinking and responding in a scientific frame of reference when asked about scientific models. For these students, the scientific models and general models were ontologically different. Most students, over 70% of those surveyed, in all four studies, were able to identify most characteristics of scientific models.

Research Question 1.2 asked, "What are the criteria that students identify as being significant when classifying scientific models?" The student responses to the research instruments were used to distinguish five distinct characteristics that students recognised as being significant in the role, nature and use of models:

- Scientific models as multiple representations
- Scientific models as exact replicas
- Scientific models as explanatory tools
- The use of scientific models
- The dynamic nature of scientific models

These characteristics of scientific models were generally well understood by all students, except for the use of scientific models. Older students expressed a greater appreciation of the predictive and testing nature of scientific models than did younger students. Similar results were obtained for chemical teaching models in which most students appreciated the descriptive nature of the teaching models but only up to approximately half the high students, and up to two-thirds of the university students recognised the predictive and testing uses of teaching models. Again the university students expressed a better appreciation of these characteristics than the high school students. The five characteristics were used to develop a typology of models, highlighting significant attributes that may be useful in teaching the skill of modelling.

Approximately half of the high school students in Study 1 who experienced the model-based instruction and used models to test ideas and make predictions failed to recognise this attribute when asked about it. This lack of awareness of the use of the models in their own learning was surprising and in contrast to their awareness of the role of models in learning the chemical content. The role of using models for predicting and testing is outside the traditional 'replica' definition while the descriptive role is within the definition; most students appreciated the descriptive role because it is consistent with the everyday definition. It is ironical that many students did not appreciate that the model-based learning was using models to target the process of science and the process of learning rather than the content.

With increasing age and maturity more students per year, from Year 8 to first year university, were able to describe the role of the scientific model in the scientific process, although the majority of students regarded models as descriptive rather than exploratory tools. The responses from many students indicated that their understanding of the process of science was based on the notion that science was based on facts, revealing a naïve, idealistic and simplistic view of the scientific process. From the data some insight of the students' epistemology of science was acquired. The epistemology of science is closely associated with the process of science, and as observed with the model-based instruction, it is not always easily understood.

Research Question 1.3 asked, "How does students' modelling ability affect their use of models and their ability to understand chemical concepts?" Students with highly developed modelling ability made better use of models and achieved a higher level of understanding of chemical concepts. Data were presented to show that students' modelling ability was observed to develop and improve through instruction and practice and mostly coincided with an improvement in understanding of chemical concepts. Chemistry is unique in that there are usually two targets for the one symbolic representation, so for example a chemical model links with two real targets – the sub-microscopic level (target 1) and the macroscopic level (target 2). Grosslight et al.'s three levels of modelling ability classification scheme provided an approximate means of evaluating students' modelling ability that was useful. Indeed, a modelling ability of at least Level 2 is needed to successfully use many chemical representations.

Research Question 1.4 examined the issue of "How and why do models help students learn?" Even though many students recognised the limitations of models in that they are abstract representations and are not accurate, they still relied on particular models to build their personal mental models. Because of this, the models that are used need to be selected carefully and limitations discussed extensively. The accuracy and the detail of the model is important – because if students are going to base their mental models on the physical model then it has to have parameters and rules, even if it is not like the real thing.

The theoretical framework (Figure 5.9) relating scientific, teaching, mental and expressed models, displays the close relationship between the various model types in the process of learning. The typology of models using the attributes of mode, accuracy, purpose and permanency were included to provide students with an ontological framework for categorising models.

8.4 The Three Levels of Chemical Representation of Matter

The research focussed on chemical models and representations using Johnstone's (1982) triplet descriptive scheme as a framework to respond to the four research questions for the second objective. Just as the students' level of understanding of chemical concepts improved as their modelling ability improved (objective 1), so did their ability to relate the three levels of chemical representation of matter (objective 2).

Building on the results of Research Question 1.1 concerning models in general, Research Question 2.1 focused on chemical representations, asking, "What are students' perceptions of the role and purpose of chemical representations, including chemical models, teaching models, chemical equations, diagrams, and pictures in learning chemistry?" Generally, the majority of students surveyed appreciated the purpose and features of different chemical teaching models. Consistently, students recognised the descriptive nature of the chemical teaching models but had a more limited appreciation of the predictive nature of the chemical teaching models.

Research Question 2.2 inquired, "What are students' understandings of each level of chemical representation of matter in relation to the chemical phenomena they experience?" Generally, most students had a good understanding of the macroscopic and symbolic levels of chemical representation of matter; however for some, their understanding of the sub-microscopic level was lacking. This conclusion is consistent across Studies 1, 3 and 4 and is corroborated by previous research. Chemical explanations rely on the sub-microscopic level of chemical representations of matter so this finding is significant to students' understanding of chemical concepts.

The confusion arising between symbolic representations of the sub-microscopic level of matter, and the reality of the sub-microscopic level are probably responsible for the sub-microscopic level being poorly understood. This research has shown that students have difficulty in drawing, describing and picturing the sub-microscopic level. This is not surprising considering the shortage of accurate and precise detail. The sub-microscopic level becomes easier to understand when the reality and the theoretical nature of the level are accepted together and understood. In chemistry education, many symbolic representations are used to help understand the sub-microscopic level of chemical representation of matter. The accuracy and detail provided by multiple symbolic representations in this research contributed towards the students' appreciation of the sub-microscopic level of chemical representation of matter.

The particulate nature of matter is real, has a theoretical basis and is represented with representations. The research data have highlighted issues that are significant to the students' understanding including being able to:

- Distinguish reality from representation
- Distinguish reality from theory
- Know what a representation is
- Understand the role of a representation in the process of science
- Understand the role of a theory in the process of science

The aspects that relate to chemical representations of the particulate nature of matter tie in closely with the students' understanding of models in the process of science discussed in section 8.3. These core principles could help teachers and students to better understand the abstract sub-microscopic level of chemical representation of matter.

Continuing on with objective 2, Research Question 2.3 asked, "How does this understanding (of each level of chemical representation) enable students to effectively transfer from one representational level to another?" Students were observed transferring among the three levels of chemical representation of matter of chemistry, thus being able to identify and distinguish the three levels. While, Studies 1, 3 and 4 have provided examples of a range of abilities, the level of understanding of chemical phenomena generally improved as their understanding of the sub-microscopic level of chemical representation of matter improved. For example, through the repeated use of chemical equations, mathematical equations and quantitative analysis, many students in the university chemistry units in Studies 3 and 4 learnt to use various representations and relate them to the macroscopic experience.

However, there were also examples of students with weak chemical background knowledge who used the macroscopic and symbolic levels independently of each other, avoiding the sub-microscopic level altogether.

As discussed in section 8.3, the accuracy and precision of models impacts on the building of mental models. This applies to chemical representations of matter where students use accurate and precise symbolic representations of the sub-microscopic level to build their own mental models, although they knew that the representation was not necessarily accurate or precise when compared to the real thing. The data provided examples of students choosing representations that they found intelligible and plausible such as the electron-dot formula, structural formulas, or polar diagrams. When students can use multiple representations in this way, they can build their personal mental model using components of various representations.

The research results are consistent with Johnstone's description of the difficulties that arise in learning chemistry because of the uncertainty of the sub-microscopic level (section 2.2.2). Learning involves the construction and manipulation of concepts in an individual's mental model. Considering that in chemistry, this construction is based on the sub-microscopic level of chemical representation of matter, then the significance of this level becomes obvious, and the need to make it more transparent a necessity.

The last question for objective 2, Research Question 2.4 inquired, "How do the variety of representational forms, which students encounter in chemistry, impact on the epistemology, ontology and social factors that have been shown to contribute to conceptual change?" The data provided examples of using chemical representations to aid learning such as providing opportunities to reorganise ones ontological framework, learning to think in a chemical way, appreciating the 'big picture' of the process of science and listening to others to gain an alternative perspective. The importance of the chemical representations is in their explanatory power.

The epistemology is the knowledge about knowing and is closely associated with the knowledge of the process of science. Through this research, the role of models and representations in the process of learning science and in particular chemistry have been shown to be important in the content they deliver as well as the process of science that they model. Nearly all students in all studies appreciated the descriptive role of models, which reflects the content, and despite nearly all students appreciating that knowledge and models will change, not all students were aware of the predictive and testing nature of models.

Most responses to the VOMMS instrument indicated a good understanding of the theoretical process of science, with the more mature students from Studies 3 and 4 having more sophisticated responses than those from Studies 1 and 2. The research has focused attention on the sub-microscopic level because this level of representation of matter is the basis of chemistry and it includes all three aspects – reality, representation and the theory upon which the explanations are based. A few students from Studies 3 and 4 displayed a well-developed understanding of the way chemical knowledge was built up, having a sub-microscopic view – spontaneously considering the sub-microscopic level simultaneously with the macroscopic or symbolic level. Most were gradually building up their understanding and were still at a rudimentary level. A few students had not accepted the need to consider the sub-microscopic level.

Because chemical knowledge can be visualised as a network of ideas at varying levels of understanding and complexity, the ontological perspective is an appropriate way to describe students' understanding. This perspective was seen in examples such as everyday references versus chemical references and linking the macroscopic, sub-microscopic and symbolic levels of chemical representation of matter. Students have existing, usually naïve understandings, situated in one ontological tree (Chi, 1992); they observe substances at the macroscopic level while they use the sub-microscopic level in order to explain and understand chemical structures and reactivity. These settings are ontologically separate. The studies provided examples of students transferring between different settings such as in the equilibrium experiment in Study 3 – transferring between numerous symbolic representations of the macroscopic and sub-microscopic levels. This transference is analogous to students linking the various trees or branches and may provide an indication of the level of understanding that the students can achieve.

Learning new ideas and concepts requires the student to be willing to consider a concept and assess its plausibility and intelligibility. There are numerous examples of this occurring in Studies 1, 3 and 4. For example in Study 1, examining isomers – compounds with the same molecular formula but different structural formula – students used molecular models and structural formula to help them understand the differences between similar compounds. The model-based instruction encouraged them to assess the compounds in multiple representational forms, helping them to assess the plausibility and intelligibility of the concept of isomerism, and then to be able to make predictions about other possible isomers, thus bearing fruit from their learning. In this way, students were able to establish the status of a concept and accept the concept as valid and true. In Study 4, the use of diagrams of chemical phenomena at the macroscopic and sub-microscopic level encouraged students to practise transferring between the two levels to develop a sub-microscopic view. Surprisingly some students were critical of some representations, experienced enough to appreciate their purpose, accuracy and value. This behaviour demonstrated students using the representations to assess the status of concepts being exemplified, in terms of their plausibility and intelligibility.

The research results show that students regard good explanations as one of the most important things to help them learn. In explaining chemical concepts there is a building of a network of knowledge that must be consistent with the students' ontological network for it to be understandable. This is consistent with the transparency of the knowledge construction process (Novak, 1990). As students assess the status of a concept their assessment of its plausibility and intelligibility is dependent on clear and concise explanations – corresponding to the responses by students in Study 4.

Motivating and engaging the students was seen to enhance the learning environment in Study 1. The students in Studies 3 and 4 were highly motivated to pass the unit, sometimes at the expense of their learning. There are examples of discussions between students and examples of laboratory experiences demonstrating a social interaction that contributed positively to students' understanding of chemical concepts.

Students recognised that receiving feedback was an important part of learning. Providing opportunities for this to occur such as with the pre-laboratory exercises and the e-mail and discussion forums proved to be beneficial to some students' learning. Promoting communication between students was achieved with the WebCT site in Study 4. This method created opportunities for students to help other students, as well as staff to help students.

A significant component of learning appears to be confidence. Some students' confidence was observed to grow, associated with understanding. This had a multiplier effect - improving motivation, building of self-esteem, understanding and learning. While some students in the research became frustrated when they could not understand concepts and their confidence was seen to wane. This affected their progress detrimentally and had a multiplier effect in the negative direction.

8.5 The Development of Personal Mental Models

Objective three focussed on how students learn and students' perceptions of their own learning. This research has been designed to include a variety of learning situations to consider and compare. Research Question 3.1 of objective 3 asked "What are the factors that influence how and why students learn chemistry?" Internal factors that influence learning included prior chemical and mathematical knowledge, modelling ability and use of chemical representations, motivation, time management, metacognitive ability and self-efficacy. External factors that influence learning identified by the first year, non-major university chemistry students included good explanations, feedback, unit organisation, structure, teaching resources and assessment. These factors were seen to affect the students' choice of learning strategies and learning style.

Research Question 3.2 explored "What learning strategies do students use in learning chemistry?" The research data included a variety of learning strategies such as: performing laboratory experiments, discussing ideas and concepts with peers, getting feedback from tutors and lecturers, using analogies, listening to others, negotiation of meanings, practice and repetition of tasks, manipulation of physical models, transference from one type of model to another and to reality, memorisation, and the use of a variety of representations such as equations and diagrams. In some instances the choice of learning strategy was made by the instructor, while in other situations, students chose the learning strategy. In either situation, the research data provided evidence of the value and impact of particular learning strategies. The assessment scheme for the first year university students in Studies 3 and 4 has been shown to direct the students to a rote style of learning by the pressures of the volume of content, the time available and the assessment regime. In light of this, the choice of assessment, irrespective of its appropriateness to this researcher, is significant because it directs the students' learning style.

Research Question 3.3 explored "How do learning strategies contribute to the development of students' personal mental models of chemical phenomena?" Mental models cannot be disputed because we all think and mentally create images and scenarios in our mind, but identifying them is complex and inexact. The relevance to chemistry occurs because of the abstract nature of the sub-microscopic level of matter and its importance in chemical explanations. The data showed some students using their personal mental model to understand chemical explanations and other students avoiding the sub-microscopic level while still managing to learn chemistry. The students who were using their personal mental model to understand chemical explanations attained a way of thinking about chemical processes referred to as the sub-microscopic view because they had a mental model for the sub-microscopic level, whereas those students who avoided the sub-microscopic level did not have this facility.

Students' mental models that are products of their personal, dynamic and responsive interpretation of experiences were observed to develop throughout the period of Studies 1, 3 and 4. Initially, a mental model may be based on one representation. But as students experience multiple models, become more knowledgeable and have more macroscopic experiences, they can evaluate and interpret these ideas constructing their own mental model. Accordingly, a holistic approach to learning chemistry would include a wide variety of resources and experiences. This learning process is consistent with the models framework (Figure 5.9) in which the internal construction of ideas from students' understanding and interpretation of multiple teaching and scientific models, results in the development of a mental model of a phenomena that is communicated through the students' expressed model.

Research Question 3.4 asked, “How does students’ metacognitive awareness influence their learning of chemistry?” The mature-aged students involved in Studies 3 and 4 provided a unique metacognitive perspective that focused on the process of learning, not the content being learnt. The students from Studies 3 and 4, who had chosen to study at university, were responsible for their own learning and made choices accordingly. Many of these students displayed a high level of metacognitive awareness, motivation, application and enthusiasm, which was important to their learning. These observations support the framework of intentional learning described by Pintrich and Sinatra (2003). Although metacognition occurred spontaneously in mature-aged students who were extremely focused, and experienced learners – just not experienced in learning chemistry – there is the possibility of introducing and developing this trait in younger students to enhance learning. Metacognition is proposed to be an important perspective of learning complementing the ontological, epistemological, and social/affective perspectives as displayed in Figure 7.3.

In 1984, Novak and Gowin addressed the issue of metacognition by stating that “learning about the nature and structure of knowledge helps students to understand how they learn, and knowledge about learning helps to show them how humans construct new knowledge” (1984, p. 9). This research has explored the ways in which students use models and chemical representations to learn chemical concepts and the results have highlighted the importance of the students having an understanding not only of the chemical concepts but also of the process of learning.

8.6 Strengths and Uniqueness of the Research

As mentioned in chapter 4, without the process of the research being robust and valid, the results on the content of the research are of no value.

8.6.1 Using a Variety of Data Sources

This research has endeavoured to address the research questions. The credibility of the research is dependent on the rigour of the research and the validity of the analysis. Throughout the research, every attempt was made to ensure that the research was robust. This included designing and validating quantitative instruments as well as ensuring that interview questions, worksheets and observations were targeting the research questions. The validity of the analysis has been justified through the reliability of data, the use of triangulation by using multiple data sources and the crosschecking of any analysis by my supervisor. Each objective of the research used quantitative and qualitative data sources from multiple studies. Overriding all these issues is the influence of my personal biases, predetermined opinions, and existing ideas that had to be considered.

8.6.2 Using a Diverse Sample

A strength of this research is in the variety of data that the four studies provide. The samples of students are diverse, with different motivations, ages and background knowledge. The learning environment in Study 1 provided a comparison to the learning environments of Studies 3 and 4. The period of Study 1 was 3 weeks whereas Studies 3 and 4 each extended over a university year. The sample size ranged from 228 students completing quantitative instruments in Study 2 to five students participating in the second set of interviews in Study 4. The data sources included both quantitative and qualitative type. There were general data sources such as the VOMMS instrument that was used in all four studies, and more specific data sources such as Worksheet 1 that related to a particular area of learning in Study 3.

8.7 Limitations of the Research

As a professional, committing a great deal of time and effort to this research, it is in my interest to make sure that the research process, already documented and unequivocal, is thorough so that the content results are accurately portrayed and are of value to researchers and teachers. Despite all these checks and balances, there are limitations to the research. As long as these limitations are recognised by the researcher, acknowledged and taken into consideration during the analysis then the research process should be incontrovertible. The limitations include the sample and sample sizes, particular learning situations and my analysis and interpretation. Each of these limitations is discussed.

8.7.1 Sample and Sample Sizes

The samples in each study are considered to be representative of the wider population for that field. Within the parameters of the research, efforts were made to ensure that the volunteer samples were representative of the larger samples in all studies. In Study 3 there were more males represented in the volunteers than in the normal population for the unit, while in Study 4 there were more females in the volunteer sample than in the normal population.

The sample sizes in this research have been restrained by the availability of subjects, time limitations and accessibility to students. Gathering data is dependent on volunteer students taking time from a busy schedule, so for example in Study 3, students had to complete worksheets and attend interview appointments outside the normal class-time. While the data are shown to be reliable, their validity in being a true representation of the whole population cannot be guaranteed. This is why the data sources that have very small sample sizes such as the worksheets and the second interview in Study 4 are corroborated with other data sources when addressing research questions.

8.7.2 Particular Learning Situations

The aspects of models, representations and learning for each unique learning situation in chemistry may not be transferable to other learning situations in other science disciplines. However, there are common characteristics of learning that can be explored. Any conclusions that are made as a result of this research are true for the particular study, situation and time. The extrapolation of the conclusions to other situations can only be hypothesised or proposed and are not validated by this research.

8.7.3 My Analysis and Interpretation

Another limitation is that the research is dependent primarily on my interpretation and analysis of the research data that are presented, although the multiple data sources and crosschecking with my supervisor guards against any major errors in my analysis.

With qualitative data sources, the results are not always definitive but rather show trends and patterns, so the significance and importance of an observation or interview response with individuals cannot always be statistically proven; however, they may still be important. The research method responded to the data exploring ideas that arose to provide corroborating or refuting evidence. For example, in this research, ideas that were identified in Study 3 through interviews where developed and tested on larger samples in the SEEQ and Online Survey in Study 4. Similarly, ideas that arose in Study 1 about the lack of awareness by students as to the predictive and testing nature of models were explored in later studies. In this way the research was dynamic – responding to the data.

8.8 Implications for Teaching and Learning of Chemistry

In chapter 1, the justification of the research (section 1.6) was described in terms of the communication of the findings and the implementation of changes – improvements – to teaching and learning as a result of the research. Endeavours to do this are documented in presentations and published papers (Appendix S). The primary outcome of the research is the need for instruction to be attentive to the three levels of chemical representation of matter at the macroscopic, sub-microscopic and symbolic levels in order to be able to generate appropriate and effective mental models for interpreting abstract chemical concepts. This section will put forward suggestions for the teaching and learning of chemistry based on the results of this research.

8.8.1 Explanatory Tools – Models and Chemical Representations

The important role of models in learning can be concealed behind their important role in the process of science. This section discusses the need to highlight the role of models in learning while section 8.7.2 discusses the equally important role of models in the process of science. It is evident from the results of this research that while students may be aware of these two roles they do not always distinguish them.

Models and chemical representations have been shown to be central to the learning of chemistry because of their explanatory power. The results in this research have shown that all students appreciate the descriptive nature of models and chemical representations that are related to learning particular content or concepts. However, the value of the models and chemical representations are in their predictive and testing roles. Understanding the value of the model and the chemical representation as an explanatory tool – that is separate from the actual chemical content or concept that it is relaying – is a significantly epistemological difference. This understanding flows onto the role of models in the process of science. Considering these implications, more overt teaching of the role of models in learning could enhance this situation.

The typology of models developed in section 5.3.6 and the framework of models (Figures 5.9) relate the important role of models in learning. This framework could be helpful to the students and the teachers or tutors in understanding the role of models in learning.

8.8.2 The Process of Science

The role of models in the process of science can be described – but more powerful are examples of the process of science, such as the changes made to the model of the atom as a result of Rutherford's experiment with the gold foil and alpha particles. The process of science is not usually taught directly but rather occurs in context with the content that is being taught – which is desirable – as long as the detail of the chemical content does not distract from the process of science that also needs to be appreciated. As a consequence, the epistemological understanding of the role of models in the process of science that students gain is sometimes not the primary objective of a curricula focussing on chemical content. Despite this discouraging picture, the students in Studies 1, 3 and 4 expressed a reasonable understanding of the process of science. Their attention to the importance of 'true' scientific facts was a concern, with some students failing to appreciate that facts and scientists' interpretation of facts can change. The position of models and chemical representations in respect of the reality, theory and facts of science and chemistry are 'big picture' ideas that may need time, experience and exposure to multiple examples to develop.

8.8.3 Modelling Skills

The research has showed that the skill of modelling can be developed through practice. Because modelling is a necessary skill in understanding chemical explanations, greater emphasis could enhance students' understanding. While the research has shown that the older and more mature students from Studies 3 and 4 expressed a better appreciation of models than the younger students in Studies 1 and 2, it does not mean that students could not be taught to appreciate models at a younger age. Instruction focussing on the role and nature of models could be advantageous to students' learning of science, especially before tackling the abstract content areas such as chemistry when this understanding is assumed.

8.8.4 Macroscopic Level of Chemical Representation

The research results have corroborated previous research results, thereby providing further support to place greater emphasis, than is evident in this research, on the macroscopic level of chemical representation of matter when teaching chemistry. This notion is reflected in the theoretical construct of the rising iceberg that provides a way of thinking about how the students are learning chemistry, as outlined in section 2.4.

Some students in Studies 3 and 4 expressed the view that chemistry was not a favoured subject; they had developed a dislike of the subject at school and now were taking chemistry as a course requirement (Stocklmayer & Gilbert, 2002). This dislike of the subject could suggest that chemistry has an image problem, especially with students who are not chemistry majors and that this image problem could be due to the way chemistry is taught. Greater emphasis on the macroscopic level, along with a more everyday approach, could possibly improve the chemical literacy of students and the image of chemistry (Hofstein & Mamlok, 2001). Educators choose what is being taught. To this end, the needs and requirements of the particular students should be considered. One chemistry curricula for all does not seem to be the solution. While the learning institution in Studies 3 and 4 offered different teaching units to major and non-major chemistry students, the content for the non-majors was a diluted and truncated version of the major chemistry content – still with a strong mathematical and theoretical emphasis – that may not be best suited to the non-major students' profile. The experiments undertaken in both units were similar due to economic and timetabling issues. Again, the philosophical change associated with a more macroscopic approach, as suggested in the rising iceberg theoretical framework, is needed to endorse the choice of chemical content.

8.8.5 Sub-microscopic Level of Chemical Representation

The sub-microscopic level of chemical representation of matter is the most important in explaining chemical theory; however, the research has shown that the sub-microscopic level is the least well understood of the three levels of representation of matter. Many students are often dependent on their teacher as their primary and often only source of chemical explanations. Through analysing students' understanding of the sub-microscopic level, this research has identified a number of characteristics that may be of pedagogical value in improving students' understanding and perceptions of this abstract level. These include distinguishing between a representation or model, theory and reality. With ambiguity about these scientific concepts that form the foundation of scientific knowledge there is need for concern (Taber, 2003). Introducing the role of the model in learning and the role of the model in the process of science is one suggestion that may help to clarify these ideas.

It is suggested that the sub-microscopic concepts are introduced simply and slowly, as they are needed to explain macroscopic features. Learning chemistry requires the learner to have a faith in the sub-microscopic level on the promise that all will become clear as his or her knowledge bank increases. Teacher awareness of these complexities means they can help to build up students' understanding slowly.

Advances in technology has seen the development of computer software such as VISCHEM (Dalton & Tasker, 2001) and ChemSense (Michalchik, Rosenquist, Kozma, Kreikemeier, & Schank, 2002) that can provide a range of visual and dynamic models of the sub-microscopic level. These technological advances now enable us to virtually see a detailed representation of the sub-microscopic level and could influence the way chemical concepts are taught in the future and hence influence students' mental models.

This technology should not be confused with the advances in technology that now enable scientists to 'see' atoms. Technology such as the scanning tunnelling microscope (STM) and atomic force microscopy (AFM) provides a visual link to the sub-microscopic level that enables the atoms on the surface of a material to be seen. With these types of experimental procedure there is no question as to the real nature of the sub-microscopic level of representation of matter.

The results of this research have shown the important role of chemical representations and models in the development of mental models of the sub-microscopic level of chemistry. For this reason, the choice of representations is important. The dynamic, interactive computer models have the potential to influence the way students perceive and think about the sub-microscopic level.

8.8.6 Symbolic Level of Chemical Representation

In considering the real versus representational matter of chemistry as well as the realisation that many symbolic representations are used to explain and describe the single macroscopic level and the single sub-microscopic level, the importance of the number and type of symbolic representations that are used in the teaching and learning of chemistry is significant. The repetitive and extensive use of representations can lead to students and teachers using representations without remembering what they represent or their role in learning.

The results of Study 3 showed that not all diagrams or models of the molecules of water are considered valuable to students. Similarly, the results from Study 4 showed that not all diagrams are of value, with students not always understanding the diagram and some diagrams leading to misunderstandings. The implication of these results suggests that the choice and number of representations is important and should take into consideration the students' background knowledge and their level of understanding of models.

While chemistry is dependent on the sub-microscopic level for explanations, it is the symbolic level that provides the representations of the sub-microscopic level. Many students in Study 4 declared clear and concise explanations to be most important to their learning. These explanations are often dependent on representations to convey intelligible and plausible concepts to the learner.

8.8.7 Background Knowledge

Comparing the students with and without background knowledge in chemistry in Studies 3 and 4 at university showed that the students' background knowledge was significant to their learning. These results imply that the foundation ideas of chemistry, primarily those associated with the sub-microscopic level including the theoretical nature of the particulate nature of matter and the use of representations, should not assumed to be understood and needs to be taught as part of the chemical content. The research showed how inexperienced students perceived chemical representations at the symbolic level only while experienced learners perceived these representations at multiple levels of representation.

8.8.8 Assessment Structure

The research results with the university students in Studies 3 and 4 indicated that the assessment structure could influence their style of learning. These data provide an opportunity for educators and teachers to direct the learning of their students by selecting appropriate assessment tasks to achieve the type of learning desired.

8.8.9 Metacognitive Aspects of Learning

The metacognitive awareness of the students in Studies 3 and 4 and their intentional approach to learning highlighted approaches that may be of value to other students. The students in Studies 3 and 4 were more self-motivated and directed learners than the high school students in Study 1. The university students had chosen to study the chemistry unit and generally had a positive attitude to learning; they were responsible for some of the costs of their education under a government subsidised fee scheme; commonly they had part-time employment and they had career aspirations that the study was directed towards. Nonetheless, the qualities of the metacognitive and intentional learner (Bereiter & Scardamalia, 1989) could be introduced to younger students with the objective of providing them with direction and insight into learning and improved self-efficacy (Pintrich, 1999).

Remembering that much of what the student knows is dependent on what and how they are taught, then greater emphasis on the macroscopic level of chemical representation of matter is suggested, and the detail of the sub-microscopic level is introduced on an 'as needed' basis. This position is consistent with the rising iceberg framework that was described in section 2.4. The selection of the content to fit in with this theoretical framework may be challenging but the concept of promoting a chemical epistemology in which students gain some general knowledge about the use and value of chemistry to become chemically literate may be worthwhile.

Following on from the research, the WebCT site for the chemistry unit including the pre-laboratory exercises has continued to be maintained and has been included in other chemistry units. I introduced a section to the WebCT site titled "So you Want to Pass this Unit!!" with eight separate parts targeting students' learning (Appendix T). The sections are titled: Past Students' Experiences; Time Management; What You Have To Do; Using WebCT; How Do I Learn Best? Learning Strategies; Diagrams; and Chemical Representations. These pages are designed to communicate some of the findings from my research to the students and include items such as feedback from other students, links to useful websites and details of the philosophy behind the PSI instructional system that they are experiencing. Consistent with the intentional learner, these resources encourage students to think about their own learning – not just the content they have to learn.

8.8.10 Feedback

The theory of learning describes a recursive process that is dependent on feedback – both positive and negative to consolidate new learning. The research illustrated this, for example, in Study 1, when time was allocated for students to experiment with the teaching models and discuss ideas with peers, gradually building up a foundation of knowledge about the sub-microscopic level. In Study 4, students received positive and negative feedback on their responses to pre-laboratory exercises. Providing opportunities to discuss concepts, play with chemical models and get feedback from instructors are some examples of a more socially constructivist approach that have been shown in this research to be valuable to the learning process and valued by the learner. However, the choice of pedagogical activities and learning approaches are influenced by the availability of staff, time, resources and the requirements of the targeted students and so opportunities for experimentation as opposed to laboratory work are not always, or often, available. It is hypothesised that students using strategies that promote a deeper learning would bring about more developed mental models.

8.8.11 Chemistry Teaching to Non-majors

The concept of chemistry being a general part of students' education is not new – Johnstone (1993) identified this need in 1993 and currently there are changes being considered to the Western Australian Chemistry curriculum aimed at improving students' chemical literacy.

At school and university, there is a need to recognise the needs of non-major chemistry students. Lagowski (2000) highlighted that the characteristics of this cohort of students is not necessarily the same as the characteristics of science students who would "succeed in science courses in spite of the instructional deficiencies of the system of science education" (p. 820). This group of students is a significant population and this research has shown that in the learning institution of Studies 3 and 4, their needs were not being met adequately. There are issues such as taking consideration of students' background knowledge in chemistry and mathematics, the relevance and application of the curriculum, teaching and learning in a contextual framework, and making links to future careers, in addition to the organisation of the unit and the assessment structure. The evidence from this research of how the non-major students are learning chemistry indicated a need for chemical educators to assess both what is being taught and how it is being taught.

The profile of students in Studies 3 and 4 is probably characteristic of most non-major units: the students have diverse backgrounds and there is a range of learner-types from intentional learners – goal-directed and focused, with their learning under conscious control and usually having a degree of metacognitive awareness, to the more accidental learner – not so focused, more a passenger and with less metacognitive awareness. This situation describes the dilemma for instructors, catering for all students is difficult and demands learning tasks that challenge and support all students.

8.9 Areas for Future Research

While this research has provided some insight into the development of students' mental models of chemical phenomena, it has also highlighted the difficulties and limitations of trying to understand the process of learning chemistry. The results of this research may provide direction for future research. Particular areas of research that obviously warrant future research are expanded on.

8.9.1 Using Technology to better investigate mental model development

The integration of technology into teaching and learning of science and chemistry, so that the technology provides a means of accessing a better model is a most obvious area of research (J. K. Gilbert & Justi, 2002). Because the model that the teacher or student selects is prominent in establishing the students' mental model, then the use of, for example, a better, animated, precise, accurate, computer model could be most advantageous. Hardwicke (1995b) is guarded about the use of computer technology in modelling, but with the rapid advances in this area the extension to the classroom seems inevitable. However, adopting more technologically advanced models means that students may miss out on the sifting, sorting, and mapping they would have previously done – both physically and mentally – in their evaluation of any model. With a very accurate and precise model that closely replicates reality, students may not map the model at all but accept the model as a replica of the real thing. The question arising is: Would it matter if they did this, considering that the 'new' models will be so accurate and precise? The use of only one model would mean that the value of multiple models might be lost. The task of constructing personal mental models where the learner draws on attributes from multiple models may be redundant; yet these active mental and physical processes have been shown to be an important part of the learning process.

8.9.2 Teaching and Evaluating Modelling as a Skill

While modelling is already part of the science curriculum, it could be further developed so that modelling is taught as a skill – separate from the content to which it may be relating. Similarly to the skill of critical analysis where students are taught how to compare and contrast, evaluate and distinguish, in the skill of modelling students can be taught how to map the components of a model with its target, evaluate the attributes of the model, distinguish reality, theory and representations and appreciate the role of the model in learning and in the process of science. Gilbert and Justi (2002) recommend a similar area of investigation with a "model of modelling framework" (p. 62) which provides students with a map with which to evaluate models.

There is potential to evaluate the value of more extensive education about modelling with younger age groups. There has already been educational research demonstrating the value of modelling with primary and lower secondary students. And while teachers are encouraged to use modelling in the Western Australian outcomes–based science curricula, the actual extent to which it is done and its educational value has not been determined. This use could be examined in conjunction with exploring ways of integrating modelling with new technology – thus refreshing the modelling concept.

8.9.3 Integrating Modelling with the Three levels of Chemical Representation of Matter

All chemistry students model but the research could focus further on having students identify and use the three levels of chemical representation of matter overtly – as is done in the Silberberg (2000) textbook – where all three levels are regularly represented.

Another possible area of research is that of modelling in chemistry and the change in modelling from one target to two targets. As students are introduced to the sub-microscopic level of matter and the symbolic representations that are epitomized, students' appreciation of the two targets of the model could be explored.

8.9.4 More Focus on Chemical Literacy

At the secondary school level, developing one chemical curriculum that satisfies the needs of both the generalists and the future chemistry specialists has limitations. However, by focussing on promoting chemical literacy with a context-based approach, it is intended that both types of students can be accommodated (Bennett & Holman, 2002; *ChemCom: Chemistry in the community*, 2002; Hofstein

& Mamlok, 2001). This holistic approach to learning the context–based curricula is consistent with the rising iceberg framework. Opportunities exist for educational researchers to develop detailed learning outcomes and teaching strategies for a new context-based curriculum.

8.9.5 Developing Teachers' Philosophy of Chemical Education

Providing teachers with the opportunity to examine Johnstone's three levels of chemical representations and the rising iceberg approach, and consider how and why chemistry is taught, could challenge teachers about their philosophy of teaching. Consequently, these considerations may help teachers to reflect upon the content that they are teaching.

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Appendix A

List of Abbreviations

List of Abbreviations

CNM	The changing nature of models
ER	Models as exact replicas
ET	Models as explanatory tool
ID	Identification number
ICC	Intentional conceptual change
LEAP	Learning Effectiveness Alliance Program
MAPP	Mode, Accuracy, Purpose and Permanency
MCR	Molecular Chemical Representations
MR	Models as multiple representations
PSI	Personalised Student Instruction
SUMS	Students' Understanding of Models in Science
USM	Uses of scientific models
VOMMS	My Views of Models and Modelling in Science

Appendix B

Permission Slips for Studies 2, 3 and 4

Study 2

6/12/99

Science and Mathematics Education Centre
Curtin University of Technology
GPO Box U1987, Perth,
Western Australia 6845

Number/Name________________

School _______________________

Year/Class ____________________

Male / Female

Dear Student,

We are doing an investigation into the use of scientific models in science lessons. We are interested to find out about your views on scientific models and how they relate to your understanding of science. Please read each statement carefully and choose the answer that best represents your views.

Thank you for taking the time to complete this questionnaire.

Professor David Treagust, Gail Chittleborough and Thapelo Mamiala,

Science and Mathematics Education Centre,
Curtin University of Technology
Perth, WA

Study 3

Curtin University of Technology
Science and Mathematics Education Centre
March, 2001

Project: Representations in chemistry: Investigations of students' mental models of chemical phenomena.

My PhD studies are investigating the way students use chemical representations to construct their own personal mental models.

In order to complete this investigation, I would like to observe you in the chemistry laboratory throughout this semester. The observations will not be intrusive nor will they interfere with the teaching or learning. In addition, I would like to conduct confidential interviews with some members of the class. The interviews may be conducted individually or in small groups. The date and time of interviews will be organised at the students' convenience. Only the researcher will know the identity of the participants, and your identity will be protected at all times. In any reporting of the outcomes of the interviews, the names of the interviewees will be replaced by pseudonyms.

If you would like to know more about the project please feel free to contact me personally or by phone or e-mail. If you are willing to be involved in the research, please complete the consent form and return it to me.

Thank you,

Gail Chittleborough
Research Assistant
Phone 92663791
Email: chittleg@smec.curtin.edu.au

Study 3

CONSENT FORM

I, ____ currently enrolled in first year Chemistry at Curtin University of Technology, confirm that:

I have read the information sheet and the nature and the purpose of the research project has been explained to me. I understand and agree to take part.

I understand that I may not directly benefit from taking part in the study.

I understand that while information gained during this study may be published, I will not be identified and my personal results will remain confidential.

I understand that I may withdraw from the study at anytime and this will not affect my status now or in the future.

Signed ____

Date ________________

Study 4

Science and Mathematics Education Centre
Curtin University of Technology
Perth, WA
March 2002

Project: Representations in chemistry: Investigations of students' mental models of chemical phenomena.

My PhD studies looks at the way students use chemical representations to construct their own personal mental models and hence learn chemistry concepts.

In order to complete this investigation, I would like to conduct confidential interviews, which may be conducted individually or in small groups. The date and time of interviews will be organised at the students' convenience. Only the researcher will know the identity of the participants, and your identity will be protected at all times. In any reporting of the outcomes of the interviews, the names of the interviewees will be replaced by pseudonyms.

If you would like to know more about the project please feel free to contact me personally or by phone or e-mail. If you are willing to be involved in the research, please complete the consent form and return it to me.

Thank you,

Researcher: Gail Chittleborough

Phone 92663791
Email: G.Chittleborough@curtin.edu.au

Study 4

CONSENT FORM

I, ____ currently enrolled in first year Chemistry unit at Curtin University of Technology, confirm that:

I have read the information sheet and the nature and the purpose of the research project has been explained to me. I understand and agree to take part.

I understand that I may not directly benefit from taking part in the study.

Interviews may be audio-taped and transcribed. Transcripts will be made available to me prior to analysis to check their accuracy. I have the right to decline or approve part or all of this data.

I understand that while information gained during this study may be published, I will not be identified and my personal results will remain confidential.

I understand that I may withdraw from the study at anytime and this will not affect my status now or in the future.

Signed ____Date ______

Student Profile

Gender: male female
Age: 17-20 21-25 26-35 over 35
E-mail address:
Number of years at university:
Previous chemistry education and experience:
University Course:

Appendix C

Syllabus for Study 1– Learning Introductory Organic Chemistry in Secondary School

Appendix C

CHEMISTRY (YEAR 11) – D403

Subject Objectives

6. Organic chemistry

Cognitive objectives:

6.1 Describe the bonding capacity of carbon and hydrogen, and the covalent nature of the bonding between atoms of these elements.

6.2 Describe the ability of carbon to form strong covalent bonds with other carbon atoms which results in a large number of chain and cyclic carbon-containing compounds.

6.3 Identify alkanes as saturated hydrocarbons which contain only single bonds between carbon atoms.

6.4 Identify alkenes as unsaturated hydrocarbons which contain a double covalent bond.

6.5 Identify alkynes as unsaturated hydrocarbons which contain a triple covalent bond.

6.6 Use the general formula for the following homologous series to classify hydrocarbons:

alkanes C_nH_{2n+2}

cycloalkanes C_nH_{2n}

alkenes C_nH_{2n}

alkynes C_nH_{2n-2}

6.7 Describe as an 'alkyl group' a monovalent group derived from an alkane.

6.8 Write the IUPAC names and structural formula of:

straight and branched chain alkanes (C_1 to C_8)

simple cycloalkanes (C_3 to C_6)

*straight and branched chain alkenes (C_2 to C_8)

*simple cycloalkenes (C_3 to C_6)

*straight and branched chain alkynes (C_2 to C_8)

straight chain alkyl groups (C_1 to C_8)

halogen-substituted alkanes (C_1 to C_8).

*Note: It is not expected that students will be able to name such compounds as dienes, diynes, trienes, triynes etc. given their formula, nor write structural formula given their names.

6.9 Identify and write structures for structural isomers.

6.10 Identify and write structures for *cis*/*trans* geometric isomers of alkenes.

6.11 Identify and write equations for the substitution reactions of alkanes with halogens.

6.12 Identify and write equations for the addition reactions of alkenes and alkynes with hydrogen and halogens.

6.13 Relate the chemical reactivity of alkenes and alkynes to the presence of double and triple covalent bonds, respectively.

6.14 Write equations for the combustion of hydrocarbons in air or oxygen. Specify the major hydrocarbon constituents of petrol, kerosene, natural gas, LPG and LNG.

Laboratory work objectives:

6.L.1 Distinguish between saturated and unsaturated hydrocarbons by their reaction with aqueous bromine solution.

Appendix D

Quantitative Data Sources for Study 1 – Learning Introductory Organic Chemistry in Secondary School

There are three quantitative data sources used in Study 1:

- Models
- Molecular Chemical Representations (MCR)
- My Views of Models and Modelling in Science (VOMMS)

Models

The Role of Models in Science

1. TYPES OF MODELS

Models are often used in Science lessons.

For each of the items listed below decide if the item is a model? YES/NO

If it is a model describe the qualities of the model from the list below: (Tick each letter that accurately describes the model. More than one box can be ticked)

ITEM	IS IT A MODEL? YES /NO		Best way to describe the model?							
			A static model	Works the same as the real thing	Looks the same, but different size	Diagram or map or plan	Descript-ion in symbols /numbers	Descript-ion with words	Descript-ion using pictures/d iagrams	Simulat-ion
A toy car										
A model of the ear										
A living animal e.g. a wombat										
An experiment of a metal in acid										
A photograph of a cell taken with an electron microscope										
A chemical equation										
A diagram of the inside of an atom										
A computer image of a rat dissection										
A graph showing the energy changes in a reaction										

Molecular Chemical Representations (MCR)

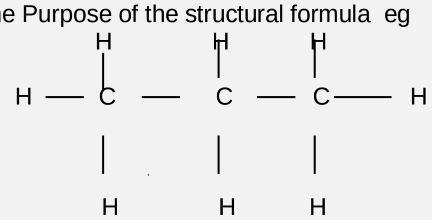
2. PURPOSE OF MODELS

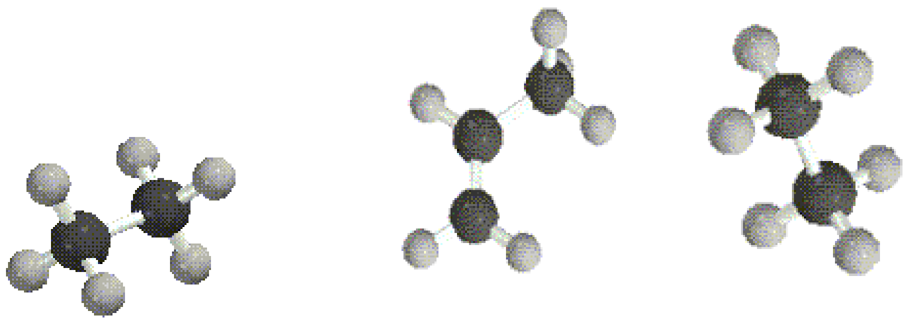
Models are used to help you understand new ideas or develop a more scientific way of looking at an idea.

Consider the different models you have been using in chemistry: the structural formula, the ball-and-stick model, the space-filling model and the computer model.

Tick the box, which most accurately reflects your opinion for each statement about each particular model.

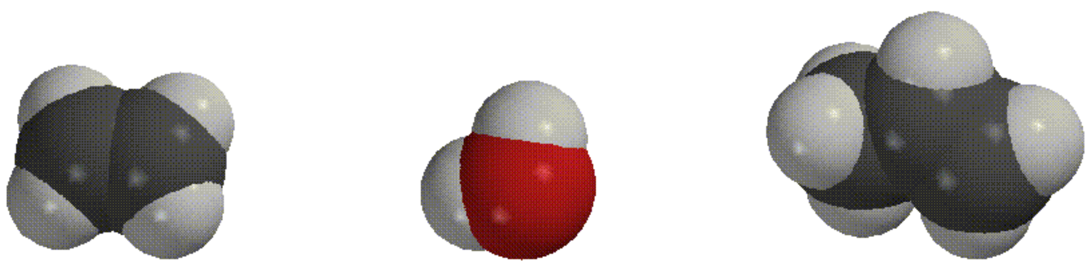
2a

The Purpose of the structural formula eg  is to:	Strongly Disagree	Disagree	Don't Know	Agree	Strongly Agree
show what the molecule looks like.					
show how the molecule behaves.					
show the shape and structure of the molecule.					
show the existence of chemical bonds.					
help understand the idea of chemical bonds.					
help generate a picture in your mind.					
touch and manipulate something which is like the real thing.					
show accurate detail of the molecule.					
make and test predictions.					
solve intellectual problems.					
test ideas.					

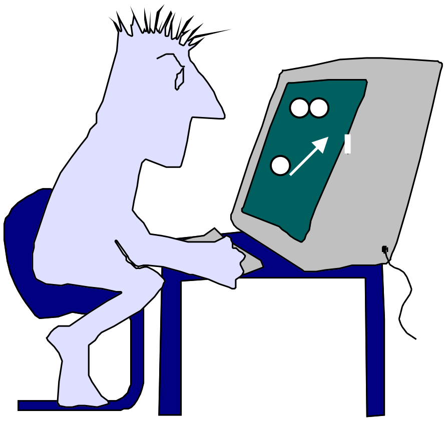


2b

The purpose of the ball-and-stick model is to:	**Strongly Disagree**	**Disagree**	**Don't Know**	**Agree**	**Strongly Agree**
show what the molecule looks like.					
show how the molecule behaves.					
show the shape and structure of the molecule.					
show the existence of chemical bonds.					
help understand the idea of chemical bonds.					
help generate a picture in your mind.					
touch and manipulate something which is like the real thing.					
show accurate detail of the molecule.					
make and test predictions.					
solve intellectual problems.					
test ideas.					



The Purpose of the space filling (spatial) model is to:	**Strongly Disagree**	**Disagree**	**Don't Know**	**Agree**	**Strongly Agree**
show what the molecule looks like.					
show how the molecule behaves.					
show the shape and structure of the molecule.					
show the existence of chemical bonds.					
help understand the idea of chemical bonds.					
help generate a picture in your mind .					
touch and manipulate something which is like the real thing .					
show accurate detail of the molecule.					
make and test predictions.					
solve intellectual problems.					
test ideas.					



2d

The Purpose of a computer-generated model is to:	Strongly Disagree	Disagree	Don't Know	Agree	Strongly Agree
show what the molecule looks like.					
show how the molecule behaves.					
show the shape and structure of the molecule.					
show the existence of chemical bonds.					
help understand the idea of chemical bonds.					
help generate a picture in your mind.					
touch and manipulate something which is like the real thing.					
show accurate detail of the molecule.					
make and test predictions.					
solve intellectual problems.					
test ideas.					

My Views of Models and Modelling in Science (VOMMS)

MY VIEWS ON MODELS AND MODELLING IN SCIENCE

In your chemistry classes you have been using chemical models (e.g., ball-and-stick, computer models) to represent molecules. The use of models is a common practice in science. For each of the six items you are given two statements, circle the number that you think most closely represents your view on models and modelling in science. Explain your choice in the space provided below each item.

1.Models and modelling in science are important in understanding science. Models are:

a) representations of ideas or how things work.

b) accurate duplicates of reality.

Evidence from your classwork:

………………………………………………………………………………

2. Scientific ideas can be explained by:

a) one model only, - any other model would simply be wrong.

b) one model, - but there could be many other models to explain the ideas.

Evidence from your classwork:

………………………………………………………………………………

3. When scientists use models and modelling in science to investigate a phenomenon, they may:

a) use only one model to explain scientific phenomena.

b) use many models to explain scientific phenomena.

Evidence from your classwork:

………………………………………………………………………………

4. When a new model is proposed for a new scientific theory, scientists must decide whether or not to accept it. Their decision is:

a) based on the facts that support the model and the theory

b) influenced by their personal feelings or motives.

Reason:

………………………………………………………………………………

5. The acceptance of a new scientific model:

a) requires support by a large majority of scientists .

b) occurs when it can be used successfully to explain results.

Reason:

…………………………………………………………………………………………………

6. Scientific models are built up over a long period of time through the work of many scientists, in their attempts to understand scientific phenomenon. Because of this scientific models:

a) will not change in future years.

b) may change in future years.

Reason:………………………………………………………………………

Appendix E

Quantitative Data Sources for Study 2 – Secondary School Students' Views on Models

There are three quantitative sources used in Study 2:

- Scientific Models (SM)
- Students' Understanding of Models in Science (SUMS)
- My Views of Models and Modelling in Science (VOMMS)

Scientific Models

6/12/99
Number/Name____________
School__________________
Year / Class _____________
Male / Female

Dear Student,

We are doing an investigation into the use of scientific models in science lessons. We are interested to find out about your views on scientific models and how they relate to your understanding of science. Please read each statement carefully and choose the answer that best represents your views.
Thank you for taking the time to complete this questionnaire.

Professor David Treagust, Gail Chittleborough and Thapelo Mamiala,
Science and Mathematics Education Centre, Curtin University of Technology, Perth.

Scientific Models

Questionnaire A
Part One

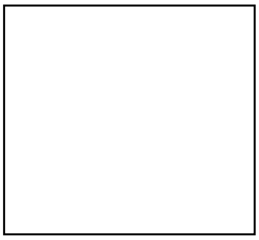
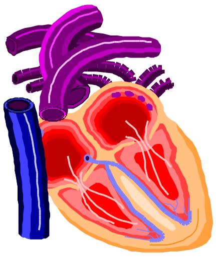
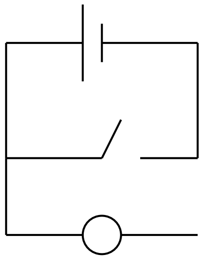
Please indicate your opinion on the following statements about scientific models. Circle the number that most accurately reflects your opinion

	Strongly Disagree	Disagree	Don't Know	Agree	Strongly Agree
The word model is associated with:					
A smaller version of the real thing.	1	2	3	4	5
Something you can use to show an example of something.	1	2	3	4	5
A 3-D picture of an object.	1	2	3	4	5
A visual representation of how something works.	1	2	3	4	5
Duplicate of reality.	1	2	3	4	5
A visual way to show how ideas are connected.	1	2	3	4	5
Anything that gives a clearer picture of a scientific idea.	1	2	3	4	5

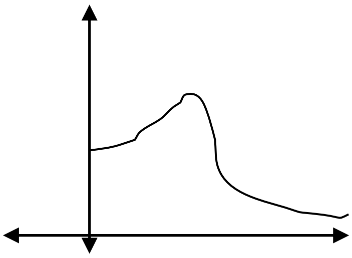
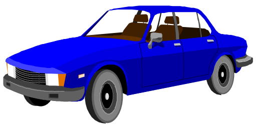
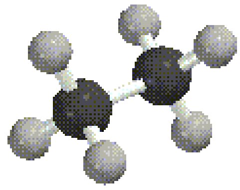
Please turn over and continue the questionnaire. Do not return and change your answers.

Questionnaire A
Part Two

The items below are scientific models.

A B C

F G H

For each item circle one statement that BEST describes the model.

Scientific Models	**Helps visualise how the real thing works**	**Looks the same, but different size**	**Description using numbers or symbols**	**Description using pictures or diagrams**	**Simulation**
A diagram of the inside of an atom	1	2	3	4	5
A plastic model of the heart	1	2	3	4	5
An electric circuit	1	2	3	4	5
A chemical equation e.g. Carbon +Oxygen ⟶ Carbon Dioxide	1	2	3	4	5
A computer image of a rat dissection	1	2	3	4	5
A graph showing the energy changes in a chemical reaction	1	2	3	4	5
A model car	1	2	3	4	5
A ball-and-stick model of a chemical such as ethane.	1	2	3	4	5

Students' Understanding of Models in Science (SUMS)

Questionnaire A

Part Three

		Strongly Disagree	Disagree	Don't Know	Agree	Strongly Agree
Models are used to:						
1	Show an idea.	1	2	3	4	5
2	Explain scientific phenomena.	1	2	3	4	5
3	Physically or visually represent something.	1	2	3	4	5
4	Show a smaller scale size of something.	1	2	3	4	5
5	Show or demonstrate how something works.	1	2	3	4	5
6	Make and test predictions about a scientific event.	1	2	3	4	5
7	Help formulate ideas and theories about scientific events.	1	2	3	4	5
8	Show how they are used in scientific investigations.	1	2	3	4	5
9	Help create a picture in your mind of the scientific happening.	1	2	3	4	5
A model may be changed if:						
10	The idea is changed.	1	2	3	4	5
11	There are changes in data or beliefs.	1	2	3	4	5
12	There are new findings.	1	2	3	4	5
13	New theories or evidence prove otherwise	1	2	3	4	5
A model needs to be close to the real thing by:						
14	Being very exact, so nobody can disprove it.	1	2	3	4	5
15	Being very exact in every way except for size.	1	2	3	4	5
16	Being as close as it can be to the real thing.	1	2	3	4	5
17	Giving the correct information and showing what the object/thing looks like.	1	2	3	4	5
18	Being able to show the relationship of ideas clearly.	1	2	3	4	5

	Strongly Disagree	Disagree	Don't Know	Agree	Strongly Agree
The features of a model are as follows:					
19. It should be an exact replica	1	2	3	4	5
20. Everything about it should be able to tell what it represents	1	2	3	4	5
21. It shows what the real thing does and what it looks like.	1	2	3	4	5
22. Has what is needed to show or explain a scientific phenomenon.	1	2	3	4	5
23. It is something you can handle and touch, which you can't do with the real thing.	1	2	3	4	5
24. It can be a diagram or a picture, a map, graph or a photo.	1	2	3	4	5
Many models may be used to express features of a science phenomenon by showing:					
25. Different versions of the phenomenon	1	2	3	4	5
26. Different sides or shapes of an object.	1	2	3	4	5
27. Different parts of an object or showing the object differently.	1	2	3	4	5
28. Different perspectives to view an object.	1	2	3	4	5
29. How different information is used.	1	2	3	4	5
30. How it depends on individuals different ideas on what things look like or how they work.	1	2	3	4	5

Students' Views of Models and Modelling in Science (VOMMS)

For each of the six items you are given two statements, circle the number that you think most closely represents your view(s) on models and modelling in science.

1. Models and modelling in science are important in understanding science. Models are:

a) representations of ideas or how things work.

b) accurate duplicates of reality.

2. Scientific ideas can be explained by:

a) one model only, - any other model would simply be wrong.

b) one model, - but there could be many other models to explain the ideas.

3. When a new model is proposed for a new scientific theory, scientists must decide whether or not to accept it. Their decision is:

a) based on the facts that support the model and the theory.

b) influenced by their personal feelings or motives.

4. The acceptance of a new scientific model:

a) requires support by a large majority of scientists.

b) occurs when it can be used successfully to explain results.

5. Scientific models are built up over a long period of time through the work of many scientists, in their attempts to understand scientific phenomenon. Because of this scientific models:

a) will not change in future years.

b) may change in future years.

6. When scientists use models and modelling in science to investigate a phenomenon, they may:

a) use only one model to investigate the scientific phenomena.

b) use many models to investigate the scientific phenomena.

Appendix F

PSI (Personalised Student Instruction) Learning Program

Information on the Self-Paced Learning Program is from the website for Curtin University of Technology: http://chemistry.curtin.edu.au/teaching/portfolio/innovation.html (Curtin University of Technology, 2003c)

Self-Paced Learning Program

The Self Paced Learning or PSI method of teaching is used extensively at the first year level. Some 60 topics have been developed in this teaching program and its modular nature allows for devising groupings of appropriate packages of topics for a wide range of courses. These units have been designed to cater for a wide range of student intakes. Students with no TEE* Chemistry background may enrol in the PSI program and, if required, sit for the appropriate number of units to advance to receiving credit for the equivalent of a full first year chemistry unit. Packages of units have been designed to cater for students in: Aquaculture, Biomedical Science, Engineering, Environmental Health, Environmental Biology, Foundation Studies, Geology, Geophysics, Horticulture, Nutrition and Food Science and Viticulture.

The flexible teaching nature of the PSI system is widely accepted by students from the Schools for which we carry out service teaching. By way of example, a survey of graduates of the Environmental Health degree course found that the satisfaction with the PSI Chemistry units was well above that for other service units and the course satisfaction as a whole.

PSI teaching is a mastery-learning program where students study the workbook prior to submitting themselves for a weekly mastery test, for which a mark of at least 80% is required for a pass. Strict quality guidelines in the Unit Outlines ensure that students meet their obligations within sensible time frameworks. A computerised system has been installed to monitor the administration of the PSI program including test selection and student records.

PSI teaching is a human system with no penalty being given for failing a test. Tests are marked in the students' presence immediately at the conclusion of the test, ensuring maximum feedback and explanations of errors where appropriate. There is also a back-up weekly lecture presented for each course group where further advice may be obtained. The tests also give students practice in answering examination-standard questions, and a feel for the level of understanding required for the end-of-semester examination.

The School has resisted the temptation to proceed to a computerised system since the cost of such packages is prohibitive. The use of CAL packages would enhance the process by filtering out students who do not necessarily require feedback.

The flexibility of the PSI mode of delivery is important for both staff and students. Most academic staff have a two hour slot on their timetable as back-up personnel who may be contacted on demand to assist with marking tests when the need arises. Staff involved with first year teaching are also available for personal tuition and problem solving.

Trials were carried out in 1998 to replace mainstream Chemistry tutorials with the PSI mode of teaching. Students received one semester of tutorials and one semester of PSI teaching, and were surveyed as to their preference. The overwhelming support for the PSI method resulted in all Chemistry 101/102/115/116 tutorial classes being replaced by the PSI method in the year 2000.

*Note: TEE refers to the Tertiary Entrance Examination - an assessment of students' ability occurring the final year of schooling comprising continued assessment in the classroom and examination that is used to determine entrance to tertiary institutions.

Appendix G

Unit Outlines for Chemistry 117 and Chemistry 118

Curtin University of Technology
SCHOOL OF APPLIED CHEMISTRY

07230 CHEMISTRY 117

2001

SUBJECT INFORMATION

Chemistry 117 is taught using PSI and is designed for those students who:

a) have NEVER taken any formal chemistry courses
b) are now attempting chemistry at tertiary level and have a non standard entry to this course.

Chemistry 117 is a significant unit.

The syllabus content has been organised into topics which are contained in this unit's Chemistry PSI Study Notes, obtainable from the Curtin Bookshop.

PSI PROGRAM

The PSI program is a "Mastery Learning" program in the form of a continuous learning/assessment process. Study material is divided into topics and various courses use the PSI approach for their chemistry component use selected topics to make up the appropriate subject. Students will be required to pass short tests on each topic throughout the semester.

The PSI approach:

- introduces the concept of "Mastery learning" with each topic of material in the course,
- allows students to work at their own pace (within specified time constraints),
- allows students to study material in the order of their choosing,
- increases the availability of non structured tutorials in the form of individual tutorial assistance,
- reduces the formal structured lectures to a minimum as students purchase a set of detailed lecture notes (viz: one lecture per week),
- eliminates the formal structural tutorials

COURSE CONTENT

The syllabus for the course assumes no prior knowledge of chemistry. It covers those parts of the secondary chemistry course which are essential for a sound basis in chemistry plus relevant portions of the first year chemistry course offered by the School of Applied Chemistry.

The selected topics (shown as C compulsory, or O optional) are contained in Chemistry 117 PSI Study Notes. The order in which they are covered is outlined in the Lecture/Laboratory Schedule.

Topic 01 (c)	Components of Matter (Part A)
Topic 02 (c)	Components of Matter (Part B)
Topic 03 (c)	Chemical Equations and Stoichiometry
Topic 04 (c)	Solutions, Concentration of Solutions, and Volumetric Analysis
Topic 05 (c)	Oxidation-Reduction Reactions
Topic 07 (c)	Introduction to Chemical Bonding
Topic 08 (o)	Shapes and Polarity of Molecules
Topic 09 (o)	States of Matter and Intermolecular Forces

Topic 11 (o)	Periodic Trends
Topic 17 (c)	Properties of Gases
Topic 31 (c)	Alkanes, Cycloalkanes
Topic 32 (c)	Alkenes
Topic 33 (c)	Polymers, Alkynes
Topic 34 (c)	Benzene And Derivatives

TEXTBOOKS AND OTHER ITEMS

Texts Zumdahl, *Chemistry*, latest or 3rd Ed. D C Heath. (Recommended text)
First Year Practical Chemistry Manual 2001. Curtin
Chemistry 117 PSI Study Notes. Curtin

- Safety glasses (you will not be allowed into the laboratory without suitable eye protection).
- Laboratory coat (you will not be allowed into the laboratory without suitable protective clothing).
- Scientific calculator.
- Metal or Plastic Spatula.

COURSE REQUIREMENTS

As the minimum requirement, students are required to complete the material outlined in the lecture notes for the compulsory topics, and to pass the mastery tests of these topics with a mark of 80% or better in each topic. There is no limit to the number of attempts at each topic. Students may then choose to complete the optional topics and then the optional review exam.

STUDENTS WHO WISH TO SIT THE REVIEW EXAM MUST COMPLETE ALL COMPULSORY TOPICS BY END OF WEEK 15.

COURSE ORGANISATION

One Lecture	1 hr/week	See Timetable on Noticeboard in Chemistry Foyer Bldg 305
One Lab (305:101)	3 hrs/week	
PSI Tests (303:209)	various times	

PSI Testing

Attendance at any or all of these sessions is at the students discretion. **It is not compulsory to attend all sessions, HOWEVER YOU MUST ATTEND when you have nominated to sit for a test.** The student should make sure that the rate of completion of topics is adequate to meet the course deadlines.

Students should have mastered six topics by April 20th.

A separate timetable, for testing sessions to be conducted in the study break and the formal exam period (i.e. weeks 16,17, and 18) will be posted on the PSI Noticeboard. During this period students will be allowed to **ATTEMPT** a maximum of 3 topics and, if they meet the requirements, sit the review exam.

Laboratory Classes

It is compulsory for all students to attend all laboratory sessions and have a laboratory exercise marked each week. Absences will only be permitted when supported by documentary evidence (eg a medical certificate), otherwise a mark of 0 will be recorded. It is the duty of the student to make sure they are familiar with the topic material required for successful completion of the laboratory exercise.

ASSESSMENT

(i) On completion of the compulsory topics:

Mark Awarded = 45% + (lab mark)% **max 55%**

(ii) Having completed all the compulsory topics, each completed optional topic increases the awarded mark by 4%:

Mark Awarded = [as per (i)] + 4 x (# of optional topics passed)% **max 67%**

(iii) Completion of **all** topics **plus** a pass in the **OPTIONAL REVIEW EXAM** generates a mark of:

Mark Awarded = 0.5 x (average topic mark)%
+ 0.4 x (exam review mark)%
+ 0.1 x (lab mark)% **min 65% - max 100%**

(iv) A failure in the final review exam will result in an assessment as outlined in (ii) above + 10% of the review exam mark:

Mark Awarded = as per (ii) above + 0.1 x (review exam mark)% **min 58% - max 72%**

(v) Failure to complete the compulsory topics by the 22 June will record a result of:

Mark Awarded = 50% - 4 x (# of topics incomplete)% **max 46%**

TIMETABLE FOR SUPPLEMENTARY EXAMINATIONS

All students are advised that their eligibility for a supplementary exam will be determined at the BOARD OF EXAMINERS. Students awarded a supplementary will be advised if possible, by phone, after the meeting and in writing by the earliest possible mail. No allowances will be made for students who are not available at this time.

Unit Coordinator
Chris Taylor
Room 303-206
Telephone 9266-3016
email ntaylorc02@cc.curtin.edu.au

LECTURE /LABORATORY SCHEDULE

Week (#) Commencing	Lecture	Experiment - Page No
(1) February 19	Topic 1	Introduction to the laboratory - Qualitative Inorganic Analysis *(pp 27)* • Formulae, Equation Writing, And The Colours Of Hydrated Cations
(2) February 26	Topic 2	Qualitative Inorganic Analysis *(pp 31)* • Solubility And Precipitation Of Inorganic Compounds
(3) March 5	Topic 3	Quantitative Inorganic Analysis *(pp 47)* • Titration Of Approx 0.1 M Hydrochloric Acid Against 0.1 M Sodium Hydroxide
(4) March 12	Topic 7	Quantitative Inorganic Analysis *(pp 51)* • Titration Of Approx 0.1 M Sodium Hydroxide Against Standard 0.1 M Hydrochloric Acid • Determination Of Acetic Acid In Vinegar Using Standardised Sodium Hydroxide Solution
(5) March 19	Topic 4	Quantitative Inorganic Analysis *(pp 55)* • Standardisation Of Approx 0.1 M Hydrochloric Acid With Borax
(6) March 26	Topic 5	Quantitative Inorganic Analysis *(pp59)* • Preparation Of A Standard Solution Of 0.05 M Sodium Carbonate • Standardisation Of Approx 0.1 M Hydrochloric Acid Using The Standard Sodium Carbonate From Exercise 5(a)
(7) April 2	Topic 17	Quantitative Inorganic Analysis *(pp 67)* • Standardisation Of Approx 0.01 M Potassium Permanganate With Ar Ammonium Iron(II) Sulfate • Determination Of The % w/v Oxalate In An Oxalate Solution
(8) April 9	Topic 31	Quantitative Inorganic Analysis *(pp 71)* • Standardisation Of Approx 0.05 M Sodium Thiosulfate Solution • Analysis Of Vitamin C (Ascorbic Acid)
(9) April 16		Week Free From Class 16 - 20 April
(10) April 23	Topic 32	Quantitative Inorganic Analysis *(pp 77)* • Gravimetric Determination Of Nickel As Oxinate
(11) April 30	Topic 33	**PRACTICAL EXAM** - Quantitative Inorganic Analysis *(pp 57)* • Standardisation Of Approx 0.25 M Sodium Hydroxide With Potassium Hydrogen Phthalate
(12) May 7	Topic 34	Organic Chemistry *(pp 175- 177)* • Identification Of Food Colouring Dyes • Identification Of Red Dye In Frankfurter Skin • Identification Of Phenol Mixture
(13) May 14	Topic 8	Repeat practical test (if necessary)
(14) May 21	Topic 9	No practical
(15) May 28	Topic 11	No practical
(16) June 4		Week free from class contact 4 - 8 June
(17) June 11		Examinations commence 11 - 22 June

Curtin University of Technology
SCHOOL OF APPLIED CHEMISTRY

7231 CHEMISTRY 118

2001

SUBJECT INFORMATION

Chemistry 118 is taught using PSI and is designed for those students who:

- have passed Chemistry 117

Chemistry 118 is a significant unit.

The syllabus content has been organised into topics which are contained in this unit's Chemistry PSI Study Notes, obtainable from the Curtin Bookshop.

PSI PROGRAM

The PSI program is a "Mastery Learning" program in the form of a continuous learning/assessment process. Study material is divided into topics. Various courses use the PSI approach for their chemistry. Each unit uses selected topics to make up the subject. Students will be required to pass short tests on each topic throughout the semester.

The PSI approach:
- introduces the concept of "Mastery learning" with each topic of material in the course,
- allows students to work at their own pace (within specified time constraints),
- allows students to study material in the order of their choosing,
- increases the availability of non structured tutorials in the form of individual tutorial assistance,
- reduces the formal structured lectures to a minimum as students purchase a set of detailed lecture notes (viz: one lecture per week),
- eliminates the formal structural tutorials

COURSE CONTENT

The selected topics (shown as C compulsory, or O optional) are contained in Chemistry 118 PSI Study Notes. The order in which they are covered is outlined in the Lecture/Laboratory Schedule.

Topic 18 (o)	Colligative Properties Of Solutions
Topic 19 (o)	Thermodynamics and Equilibrium
Topic 20 (c)	Molecular Equilibria
Topic 21 (c)	Chemical Kinetics
Topic 22 (c)	Applications Of Equilibrium Constants
Topic 23 (c)	Acids and Bases
Topic 24 (c)	Salts and Buffers
Topic 28 (o)	Principles and Practice Of Chromatography
Topic 37 (c)	Optical Isomerism, Alkyl Halides
Topic 38 (c)	Alcohols, Phenols, Ethers
Topic 39 (c)	Aldehydes, Ketones, Grignard Reagents
Topic 40 (c)	Carboxylic Acids And Derivatives, Amines

TEXTBOOKS AND OTHER ITEMS

Texts Zumdahl, *Chemistry,* latest or 3rd Ed. D C Heath. (Recommended text)
First Year Practical Chemistry Manual 2000. Curtin
Chemistry 118 PSI Study Notes. Curtin

- Safety glasses (you will not be allowed into the laboratory without suitable eye protection).
- Laboratory coat (you will not be allowed into the laboratory without suitable protective clothing).
- Scientific calculator.
- Metal or Plastic Spatula.

COURSE REQUIREMENTS

As the minimum requirement, students are required to complete the material outlined in the lecture notes for the compulsory topics, and to pass the mastery tests of these topics with a mark of 80% or better in each topic. There is no limit to the number of attempts at each topic. Students may then choose to complete the optional topics and then the optional review exam.

STUDENTS WHO WISH TO SIT THE REVIEW EXAM MUST COMPLETE ALL COMPULSORY TOPICS BY END OF WEEK 15.

COURSE ORGANISATION

One Lecture	1 hr/week
One Lab (305:101)	3 hrs/week
PSI Tests (303:209)	various times

PSI Testing

Attendance at any or all of these sessions is at the students discretion. **It is not compulsory to attend all sessions, HOWEVER YOU MUST ATTEND when you have nominated to sit for a test.** The student should make sure that the rate of completion of topics is adequate to meet the course deadlines.

A separate timetable, for testing sessions to be conducted in the study break and the formal exam period (i.e. weeks 16,17, and 18) will be posted on the PSI Noticeboard. During this period students will be allowed to **ATTEMPT** a maximum of 3 topics and, if they meet the requirements, sit the review exam.

Laboratory Classes

It is compulsory for all students to attend all laboratory sessions and have a laboratory exercise marked each week. Absences will only be permitted when supported by documentary evidence (eg a medical certificate), otherwise a mark of 0 will be recorded. It is the duty of the student to make sure they are familiar with the topic material required for successful completion of the laboratory exercise.

Exemptions from laboratory courses, First Year Laboratory Classes

The following guidelines apply to the granting of exemptions from laboratory courses in first year.

- The granting of an exemption is a privilege and not a right.
- An exemption may be granted to a student repeating a failed unit if the lab assessment for the failed unit is 60% or above.

- An exemption will not be granted if there is an unsatisfactory record of missed or late submissions.
- An exemption is only valid for the year following the failed unit and cannot be carried over to subsequent years.
- No exemption will be granted if the unit has been failed more than once.

All requests for exemptions must be made in writing to the first year coordinator.

ASSESSMENT

(i) On completion of the compulsory topics:

Mark Awarded = 45% + (lab mark)% **max 55%**

(ii) Having completed all the compulsory topics, each completed optional topic increases the awarded mark by 4%:

Mark Awarded = [as per (i)] + 4 x (No of optional topics passed)% **max 67%**

(iii) Completion of **<u>all</u>** topics **plus** a pass in the **OPTIONAL REVIEW EXAM** generates a mark of:

Mark Awarded = 0.5 x (average topic mark)%
+ 0.4 x (exam review mark)%
+ 0.1 x (lab mark)% **min 65% - max 100%**

(iv) A failure in the final review exam will result in an assessment as outlined in (ii) above + 10% of the review exam mark:

Mark Awarded = as per (ii) above + 0.1 x (review exam mark)% **min 58% - max 72%**

(v) Failure to complete the compulsory topics by the 23November will record a result of:

Mark Awarded = 50% - 4 x (No of topics incomplete)% **max 46%**

TIMETABLE FOR SUPPLEMENTARY EXAMINATIONS

All students are advised that their eligibility for a supplementary exam will be determined at the BOARD OF EXAMINERS. Students awarded a supplementary will be advised if possible, by phone, after the meeting and in writing by the earliest possible mail. No allowances will be made for students who are not available at this time.

Unit Coordinator
Chris Taylor
Room 303-206
email C.Taylor@curtin.edu.au
Telephone 9266-3016

LECTURE /LABORATORY SCHEDULE

Week (No) Commencing	Lecture	Experiment - Page No
(1) July 23	Topic 20	NORMAL DISTILLATION • Distillation of ethanol *(pp 156)* FRACTIONAL DISTILLATION • Fractionation of methanol water solution *(pp 159)* BOILING POINT DETERMINATION • Determination of boiling points *(pp 161)*
(2) July 30	Topic 20	CRYSTALLISATION • Crystallisation of crude benzoic acid *(pp 166)* MELTING POINT DETERMINATION • Determination melting points *(pp 169)*
(3) August 6	Topic 22	COLUMN CHROMATOGRAPHY • Separation Of Permanganate And Dichromate *(pp 181)*
(4) August 13	Topic 37	DETERMINATION OF EQUILIBRIUM CONSTANT • Equilibrium Constant For The Iodine/Tri-Iodide System *(pp 109)*
(5) August 20	Topic 37	FREEZING POINT DEPRESSION • Determination Of The Apparent Molecular Weight Of Acetanilide In Naphthalene Solution *(pp 135)*
(6) August 27	Topic 18	ANALYSIS OF VEGETABLE OILS • Saponification Value *(pp 250)* • Refractive Index *(pp 251)*
(7) Sept 4	Topic 38	ANALYSIS OF VEGETABLE OILS • Iodine Value *(pp 251)* • Acid Value *(pp 253)*
(8) Sept 10	Topic 23	TITRATION CURVES *(pp 127)*
(9) Sept 17	Topic 24	INDICATORS, HYDROLYSIS OF SALTS, AND BUFFER SOLUTIONS • Colours Of Indicator Solutions *(pp 117)* • Hydrolysis Of Salts *(pp 119)* • The Acetic Acid-Acetate Ion Buffer System *(pp 120)*
(10) Sept 24		Week free from class contact 24 – 28 September
(11) Oct 1	Topic 39	ALCOHOLS AND PHENOLS • Alcohols And Phenols *(pp 207)* • Reactions Of Alcohols And Phenols *(pp 211)*
(12) Oct 8	Topic 39	ALDEHYDES AND KETONES • Aldehydes And Ketones *(pp 221)* • Reactions Of Aldehydes And Ketones *(pp 225)*
(13) Oct 15	Topic 40	CARBOXYLIC ACIDS AND DERIVATIVES • Carboxylic Acids And Derivatives *(pp 243)* • Reactions Of Carboxylic Acids, Salts, Esters, Acid Chlorides, Anhydrides, And Amides *(pp 244)* AMINES • Reactions Of Amines *(pp 247)*
(14) Oct 22	Topic 21	No Practical
(15) Oct 29	Topic 19	No Practical
(16) Nov 5		Week free from class contact 5 – 9 November
(17) Nov 12		Examinations commence 12 - 23 November

Appendix H

Quantitative Data Sources for Study 3 – Learning Introductory Chemistry for Non-majors

There are several quantitative data sources used in Study 3

- Initial Questionnaire comprising:
    - A questionnaire about the role and use of models in science – an abridged version of the SUMS instrument.
    - My Views on Models and Modelling in Science (VOMMS) questionnaire.
    - The use of particular chemical models – an abridged version of the MCR instrument.
    - A question about the appearance of the atom and two requests to draw concept maps using chemical terms.
- SUE – Student Unit Experience Questionnaire.

Students' Understanding of Models in Science (SUMS)

Name: ________________

Tutorial __________

Department of Applied Chemistry and Science and Mathematics Education Centre

QUESTIONNAIRE ABOUT THE ROLE AND USE OF MODELS IN SCIENCE

For each statement tick the box which most accurately reflects your opinion.

	Strongly Disagree	Disagree	Don't Know	Agree	Strongly Agree
Various models represent different versions of a phenomenon.					
Models can show the relationship of ideas clearly.					
A range of models caters for different learning styles					
Numerous models are used to show different parts of an object or show the objects differently.					
A model has what is needed to show or explain a scientific phenomenon.					
A model is an exact replica.					
A model needs to be close to the real thing by being very exact in every way except for size.					
A model shows what the real thing does and what it looks like.					
Models show a smaller scale size of something.					
Models are used to represent abstract objects or ideas for which the real appearance or behaviour is not certain					
A model is always like the real thing					
Models are used to physically or visually represent something.					
Models help create a picture in your mind of the scientific happening.					
Models are used to explain scientific phenomena.					
Models are used to show an idea.					
A model can be can be a diagram or a picture, a map, graph or a photo.					
Models are used to help formulate ideas and theories about scientific events.					
Models are used to show how they are used in scientific investigations.					
Models are used to make and test predictions about a scientific event.					
A model can change if new theories or evidence prove otherwise.					
A model can change if there are new findings.					
A model can change if there are changes in data or belief.					

My Views on Models and Modelling in Science (VOMMS)

MY VIEWS ON MODELS AND MODELLING IN SCIENCE

- For each of the five items you are given two statements, circle the number that you think most closely represents your view on models and modelling in science.
- Explain your choice in the space provided below each item.

1. Models and modelling in science are important in understanding science. Models are: a)representations of ideas or how things work.

b) accurate duplicates of reality.

Reason……………………………………………………………………………………

2. Scientific ideas can be explained by:

a) one model only, - any other model would simply be wrong.

b) one model, - but there could be many other models to explain the ideas.

Reason:…………………………………………………………………………

4. When a new model is proposed for a new scientific theory, scientists must decide whether or not to accept it. Their decision is:

a) based on the facts that support the model and the theory.

b) influenced by their personal feelings or motives.

Reason:…………………………………………………………………………

5. The acceptance of a new scientific model:

a) requires support by a large majority of scientists .

b) occurs when it can be used successfully to explain results.

Reason:……………………………………………………………………………………

6. Scientific models are built up over a long period of time through the work of many scientists, in their attempts to understand scientific phenomenon. Because of this scientific models:

a) will not change in future years.

b) may change in future years.

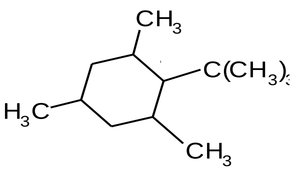
Reason:…………………………………………………………………………

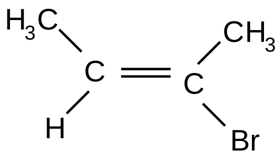
Molecular Chemical Representations (MCR)

THE USE OF PARTICULAR CHEMICAL MODELS

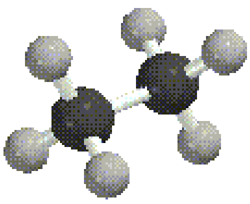
Particular chemical models are often used to help explain chemical concepts. For each type of chemical model, tick the box that most closely reflects your opinion.

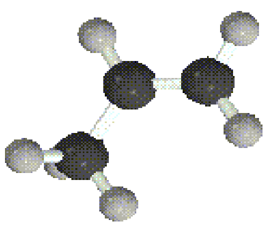
SD =- Strongly Disagree
D = Disagree
DK = Don't Know
A = Agree
SA = Strongly Agree



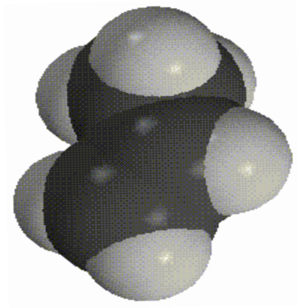


The purpose of the structural formula is to:	SD	D	DK	A	SA
show the shape and structure of the molecule.					
show the existence of chemical bonds.					
help understand the idea of chemical bonds.					
help generate a picture in your mind.					
be able to touch and manipulate something which is like the real thing.					
show accurate detail of the molecule.					
show how the molecule behaves.					
make and test predictions.					

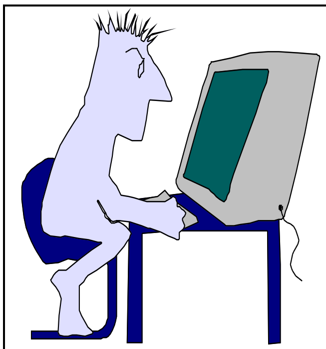




The purpose of the ball-and-stick model formula is to:	SD	D	DK	A	SA
show the shape and structure of the molecule.					
show the existence of chemical bonds.					
help understand the idea of chemical bonds.					
help generate a picture in your mind.					
be able to touch and manipulate something which is like the real thing.					
show accurate detail of the molecule.					
show how the molecule behaves.					
make and test predictions.					



The purpose of the space-filling model is to:	SD	D	DK	A	SA
show the shape and structure of the molecule.					
show the existence of chemical bonds.					
help understand the idea of chemical bonds.					
help generate a picture in your mind.					
be able to touch and manipulate something which is like the real thing.					
show accurate detail of the molecule.					
show how the molecule behaves.					
make and test predictions.					



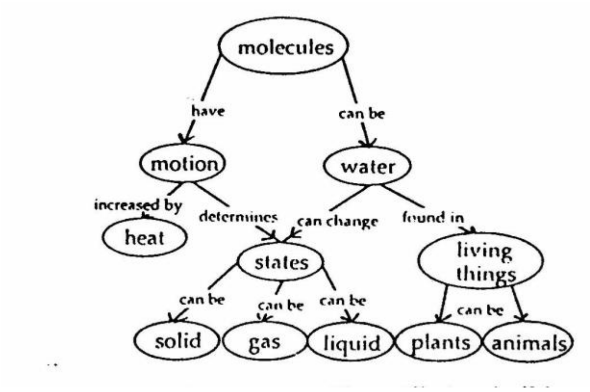
The purpose of the computer-generated model is to:	SD	D	DK	A	SA
show the shape and structure of the molecule.					
show the existence of chemical bonds.					
help understand the idea of chemical bonds.					
help generate a picture in your mind.					
be able to touch and manipulate something which is like the real thing.					
show accurate detail of the molecule.					
show how the molecule behaves.					
make and test predictions.					

The Atom

What do you think the atom looks like? (use drawings and/or text)

Concept Mapping

A concept map links ideas/concepts using sentences that make sense and are read in the direction of the arrow, for example:



Use the following terms (you can add your own if you like) to build concept maps

Concept Map 1 – Atom, compound, element, proton, isomer, liquid, compound, metal, nucleus, charge, ions.

Concept Map 2 – limiting reagent, concentration, volume titration, diffusion, acid, neutralisation, indicator, moles, equation.

Student Unit Experience Questionnaire (SUE)

STUDENT UNIT Feedback Questionnaire

INSTRUCTIONS:

- Use a blue/black biro or 2B pencil
- Do not use red pen or felt tip pen
- Do not fold or bend
- Erase mistakes fully
- Please MARK LIKE THIS:
- Make no stray marks

Unit Name: ______ Semester: ______

Have you taken this unit before? Yes ○ No ○ Sex: Female ○ Male ○

This questionnaire gives you the opportunity to express your views about this unit. Your responses will be totally anonymous. The results will be used as part of an overall assessment of the effectiveness of this unit and for course improvement.

Please answer all questions, and for each one FILL IN the oval closest to your view.

UNIT CONTENT

1 Background knowledge assumed	Too little	○○○○○	Too much
2 The amount of material covered	Too little	○○○○○	Too much
3 I found the unit	Too easy	○○○○○	Too difficult
4 The unit content followed a logical progression	Very logical	○○○○○	Not logical

UNIT ORGANISATION

5 The unit outline (ie. the document detailing aims, content, reading, organisation of teaching, assignments, assessment, etc.) was	Easy to understand	○○○○○	Hard to understand
6 The statement of unit objectives was	Very clear	○○○○○	Very vague
7 Unit expectations (ie. what was expected of you) were	Very clear	○○○○○	Very vague
8 The unit activities (eg. lectures, seminars, lab, tutorials, etc.) were	Well organized	○○○○○	Poorly organized

TEACHING AND LEARNING

9 The teaching staff were	Very helpful	○○○○○	Very unhelpful
10 The availability of unit material (eg. reading lists, handouts, etc.) were	Readily available	○○○○○	Not available
11 The unit materials were	Very clear	○○○○○	Very vague
12 The feedback I received on my progress was	Very helpful	○○○○○	Of little help
13 The assessment weightings were	Very appropriate	○○○○○	Not appropriate
14 My interest in the subject as a result of the unit has	Increased significantly	○○○○○	Decreased significantly

SIDE ONE

STUDENT UNIT Feedback Questionnaire

LABORATORY CLASSES (Respond only if relevant)

15	The organisation of the laboratory class was	Very good	5 4 3 2 1	Very poor
16	In terms of helping me understand the unit content, the laboratory experiments were	Very helpful	5 4 3 2 1	Of little help
17	The clarity of laboratory manual/notes was	Very clear	5 4 3 2 1	Very unclear
18	The lab reports were returned promptly	Always	5 4 3 2 1	Never
19	I read the laboratory notes **before** the lab session	Always	5 4 3 2 1	Never

TUTORIAL CLASSES (Respond only if relevant)

20	The organisation of the tutorial class was	Very good	5 4 3 2 1	Very poor
21	In terms of helping me understand the unit content, the tutorials were	Very helpful	5 4 3 2 1	Of little help
22	I attended the tutorials	Always	5 4 3 2 1	Never

OVERALL EVALUATION

		Very good	Good	Fair	Poor	Very poor
23	Overall, the unit was	5	4	3	2	1
24	Overall, the organisation of the unit was	5	4	3	2	1
25	In comparison to other units this unit was	5	4	3	2	1

26 Good features of this unit are:

27 My suggestions for improving this unit are:

Appendix I

Worksheets 1 – 4

There were four worksheets used in Study 3:

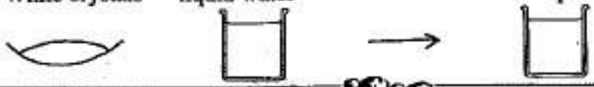
- Worksheet 1 - Solutions and Ions
- Worksheet 2 - Moles
- Worksheet 3 - Symbolism
- Worksheet 4 - Equilibrium

Worksheet 1- Solutions and Ions

Solutions and Ions

Name:______________________

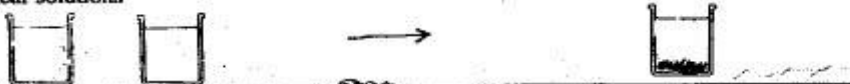
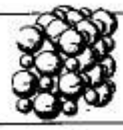
1.Sodium nitrate crystals are dissolved in water

Macro- what you see	White crystals	liquid water →	clear liquid
			
Micro- atomic level			
Symbolic	$NaNO_{3\,(s)}$	$\longrightarrow$	$Na^{+}_{(aq)} + NO_3^{-}{}_{(aq)}$

Please circle the number that most accurately reflects your confidence with the statement being correct:

	1 not at all confident	2	3 Confident	4	5 Very Confident	Don't Know
The white crystals have no net charge	1	2	3	4	5	X
Sodium nitrate consists of positively charged parts and negatively charged parts which are attracted to each other	1	2	3	4	5	X
When the salt dissolves, it breaks down into very small microscopic particles consisting of one or a few atoms.	1	2	3	4	5	X
When the salt dissolves the ions in the salt are attracted to each other and stay bonded to each other.	1	2	3	4	5	X
When the salt dissolves the ions are mixing with the water at a microscopic level	1	2	3	4	5	X
Particles held in suspension are not broken down into ions.	1	2	3	4	5	X
The water molecules help to drag the charged atoms away from the solid crystal thus dissolving it.	1	2	3	4	5	X
The dissolved ions cannot be seen with the eye.	1	2	3	4	5	X
The ions are mixing in the water, but they are not reacting.	1	2	3	4	5	X

2 Consider the mixing of two solutions: sodium chloride and silver nitrate.

Macro- what you see	Clear solutions	→	white solid in solution
			
Micro- atomic level			
Symbolic	$NaCl + AgNO_3$	$\longrightarrow$	$Na^{+}_{(aq)} + NO_3^{-}{}_{(aq)} + AgCl_{(s)}$

Please circle the number that most accurately reflects your confidence with the statement being correct:

	1 not at all confident	2	3 Confident	4	5 Very Confident	Don't Know
When a precipitate forms a chemical reaction has occurred.	1	2	3	4	5	X
Some ions stay in solution and do not react.	1	2	3	4	5	X
An insoluble substance can be seen with your eye.	1	2	3	4	5	X
In a precipitation reaction, one ion gives electrons to another ion to form a chemical bond	1	2	3	4	5	X
The dissolved ions cannot be seen but they can react to form an insoluble substance which can be seen	1	2	3	4	5	X
The soluble ions can be separated by filtering.	1	2	3	4	5	X

Worksheet 2: Moles

Q1. In a practical lesson you prepared a 0.05 M solution of sodium carbonate

Macro- what you see	Weighed out 1.325g of Na_2CO_3 white crystals	dissolved the crystals in water	made the solution up to 250ml - clear liquid
Micro-	atomic level		
Symbolic	$Na_2CO_{3\ (s)} \longrightarrow 2\ Na^{+}_{(aq)} + CO_3{}^{2-}_{(aq)}$		

Please circle the number that most accurately reflects your confidence with the statement being correct:

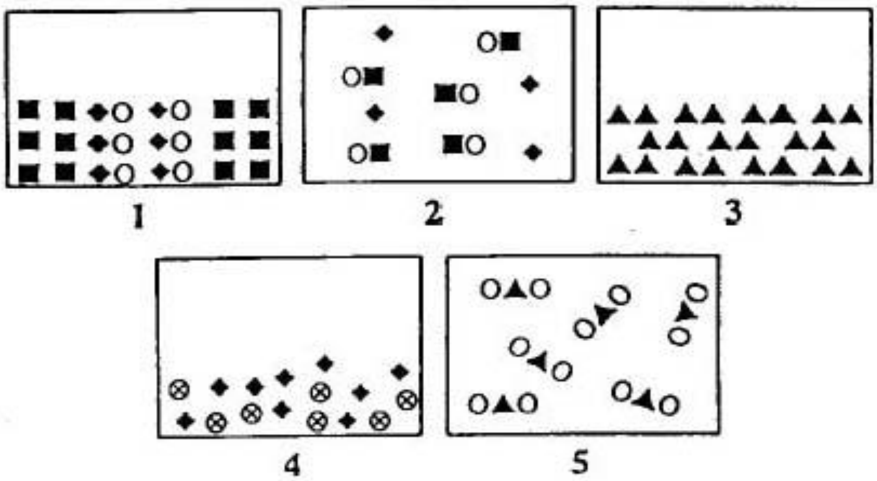
1=Not at all confident 3=Confident 5=Very Confident

		1 Not at all confident	2	3 Confi-dent	4	5 Very Confi-dent	Don't Know
1	1.35 grams of Na_2CO_3 contains (0.05x .25x 6.022 x10^{23}) ie 7.53 x 10^{21} molecules	1	2	3	4	5	X
2	A standard solution has a known number of particles that is indicated by the molarity of the solution.	1	2	3	4	5	X
3	The mole is the unit of measure; the items being measured can be anything eg atoms, molecules, units, particles, entities, jellybeans.	1	2	3	4	5	X
4	The mole is a unit of measure which is most suitable for very small entities	1	2	3	4	5	X
5	A mole of any element contains the same number of atoms but its mass will vary.	1	2	3	4	5	X
6	In a 1 molar solution there are 6.02x 10^{23} particles dissolved into the water	1	2	3	4	5	X
7	The molecular weight of Na_2CO_3 is 105.988g. 1 mole of Na_2CO_3 weighs 105.988g	1	2	3	4	5	X
8	The mass of 1 molecule of Na_2CO_3 is 105.988 amu.						
9	1 mole of Na_2CO_3 contains the same number of particles as there are in exactly 12 grams of Carbon-12	1	2	3	4	5	X
10	Scientists have assigned a single atom of ^{12}C a mass of exactly 12 amu.	1	2	3	4	5	X
11	The mass of all elements in the periodic table have a mass relative to Carbon 12	1	2	3	4	5	X
12	The value 12 for the mass of a single carbon atom in amu is the same as the mass of a mole of carbon- 12 atoms in grams	1	2	3	4	5	X
13	The number of particles in 1 mole is 6.02 x10^{23}	1	2	3	4	5	X
14	The mass of a molar quantity is in direct proportion to the mass of an individual particle.	1	2	3	4	5	X
15	In the lab we use molar quantities because they are can be handled easily because amu quantities are too small to be handled.	1	2	3	4	5	X
16	The Mole is a unit of measure, measuring a particular quantity, similar to a dozen.	1	2	3	4	5	X
17	The amu is a unit of measure, measuring the mass of a particle/atom/unit etc.	1	2	3	4	5	X
18	The mole is a measure of the number of	1	2	3	4	5	X

	'particles'. One mole of any substance contains 6.022×10^{23} particles						
19	One amu equals 1.66×10^{-24} grams and is a unit of mass	1	2	3	4	5	X
20	1 mole of Na_2CO_3 means 1 mole of Na_2CO_3 molecules	1	2	3	4	5	X
21	The molar mass of Na_2CO_3 in grams is the sum of the masses of the component atoms	1	2	3	4	5	X
22	If the number of moles is known then the mass can be computed and vice versa.	1	2	3	4	5	X

Worksheet 2 Question 2

The following drawings contain representations of atoms and molecules. Classify each of these drawings (labeled 1–5) according to the three characteristics listed below. You should classify all five drawings for each category.



State of matter

______	______	______
solid	liquid	gas

Physical composition of matter

______	______	______
pure substance	heterogeneous mixture	homogeneous mixture

Chemical composition of matter

______	______	______
elements	compounds	both

Worksheet 3: Symbolism Used in Chemistry

For each of the following chemical symbols choose the meaning which **best** fits your understanding.

1. In a reaction equation A + B $\longrightarrow$ C + D

The arrow $\longrightarrow$ means

A) reacts to form
B) gives
C) are converted to
D) are equal to
E) go to

2. In the same reaction equation the sign **+** on the **left hand side** of the equation means:

A) reacts with
B) is added to
C) combines with
D) plus
E) and

3. In the same reaction equation the sign **+** on the **right hand sid**e of the equation means:

A) reacts with
B) is added to
C) combines with
D) plus
E) and

4. In the notation [NO_2], the square brackets mean:

A) volume of concentration of NO_2
B) mass of NO_2
C) number of moles of NO_2 per litre
D) number of moles of NO_2
E) quantity of NO_2

5. In the reaction equation $N_2O_{4(g)} \rightleftarrows 2NO_{2(g)}$

The double arrow here means:

A) that equilibrium has not been reached yet
B) the rate of the forward reaction is equal to the rate of the reverse reaction
C) a relatively large amount of product is formed
D) the amount of reactants is equal to the amount of products.
E) that equilibrium has not been reached yet

6. The notation $2NO_2$ represents:

A) 2 atoms of NO_2
B) a total of six atoms altogether
C) two molecules of nitrogen combined with two oxygen molecules O_2
D) two molecules of NO_2
E) two atoms of nitrogen combined with four atoms of oxygen

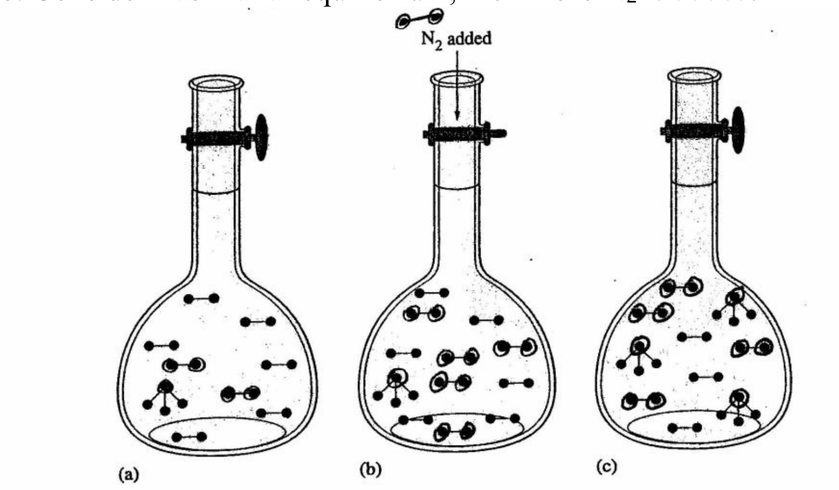
Worksheet 4 Equilibrium

Consider the reaction:

Nitrogen gas +	Hydrogen gas	$\rightleftharpoons$	Ammonia gas
(colourless gas)	(colourless gas)		(strong smelling gas)
N_2 (g) +	$3H_2$ (g)		$2NH_3$ (g)

a. What does the arrow indicate?

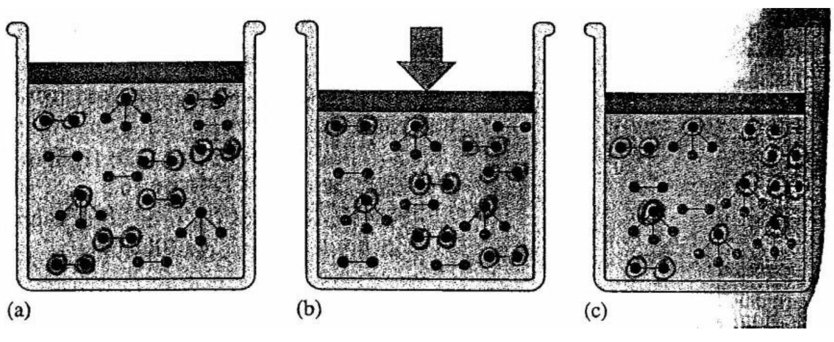
b. Consider flask 'a' at equilibrium, then more N_2 is added.



a) initial equilibrium b) N_2 added c)

Predict and explain what happens to the volumes of H_2, N_2 and NH_3 at the new equilibrium position c)

1.2 Consider the same equilibrium, but now the volume is suddenly decreased. Explain what happens and why?

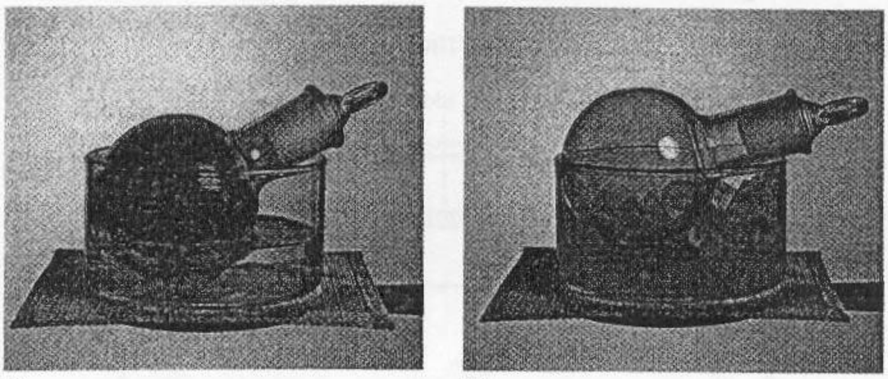


2. Consider the equilibrium:

$$\text{Energy} + N_2O_4\,(g) \rightleftharpoons 2NO_2\,(g)$$

(Colourless gas shown in b) (Reddish brown gas shown in a)

Complete the table - does the reaction shift to the right, left or no shift?



(a) (b)

TABLE 16.2

Shifts in the Equilibrium Position for the Reaction Energy + $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

Change	Shift
addition of $N_2O_4(g)$	
addition of $NO_2(g)$	
removal of $N_2O_4(g)$	
removal of $NO_2(g)$	
decrease in container volume	
increase in container volume	
increase in temperature	
decrease in temperature	

Can you draw a diagram to represent this equilibrium situation?

Appendix J

Interview Questions for Study 3

Two series of interviews conducted in Study 3:

- 1st interview
- 2nd interview

Study 3 – 1st Interview

The focus cards are shown in Figures 4.4 and 4.5

Elements, Compounds and Matter

Matter includes everything around us and everything is made up of atoms. What is the difference between the atoms in 'everything' e.g. the table, or the air, and the atoms in an element?

Given a sample of an element e.g. copper, sulfur, describe the arrangement of atoms in this sample. Do you know the chemical symbol for this substance? What do you think of the atoms themselves?

Are your ideas from what you have learnt or have you developed any of your own ideas?

1 Given a sample of a compound e.g. sodium chloride (common salt), water, describe the arrangement of atoms in a) sodium chloride and b) water. Do you know the chemical symbol for these substances?

2 Which diagram on Focus Card 1 represents an element?

3 Which diagram on Focus Card 1 represents a compound?

Structure of the Atom

Look at the diagrams of atomic structure on Focus Card 2

4 What information do you get from these diagrams?

5 Which representation do you prefer?

6 Look at the representations of water on the Focus Card 3

Which representation do you prefer? Why?

Formation of Ions

7 What charges are found in atoms?

8 How does an atom become charged?

In the lab, you looked at cobalt sulfate solution.

$CoSO_4 \longrightarrow Co(aq) + SO_4(aq)$

9 It is a clear red solution. How do you visualise the contents of the beaker at the atomic level?

10 Do you think the 'charge' factor has helped you understand what's happened?

Study 3 – 2nd Interview

Learning Chemistry

1 What is your opinion about the chemistry module this year/semester, do you find it to be easy or difficult? Explain your answer.

2 Which section in particular did you find easy to learn? Give reason(s).

3 How did you go about learning the section/topic? What strategies did you use?

4 Which section did you find difficult to learn? Why was it difficult?

5 Have you been able to get assistance/clarification on the difficult sections?

6 What you already know affects what and how you learn. Has this applied to you? Explain.

7 Which one of the following activities did you find to be helpful in your learning of this unit? Give reason(s) for your choice.

- A - Working with other students
- B – Practicing problems.
- C – Reading the PSI chemistry notes.
- D – Studying worked solutions
- E – Using other resources ie chemistry books, videos?

8 When learning concepts in chemistry:

8.1 Can you make links to other areas of chemistry? Give example

8.2 Is the chemistry relevant to you? Give an example

Labwork – Macroscopic Representation

9 What is your opinion about the chemistry lab work this year/semester, do you find it to be easy or difficult? Explain your answer.

10 Can you recall any lab session/practical that you found to have been significant in your learning? Explain.

11 Can you recall any lab session/practical that you found to have been difficult in your learning? Explain.

12 In laboratory work, we perform experiments and use equations to do calculations.

13 Can you relate the equation to the experiment?

14 Do you fill in the blanks in the calculations?

15 Do you have a mental picture of the reaction occurring?

Symbolic and Sub-microscopic Representations

16 Last time I interviewed you we talked about the mental picture you have of a chemical phenomenon. Can you give me an example of a chemical phenomenon?

17 Has your mental picture of this phenomenon developed/changed?

18 Models are frequently used in chemistry teaching and learning, can you recall any chemical model that you have learnt in your chemistry module? What are its strengths and limitations?

19 You are currently learning about equilibrium. If you are asked to explain equilibrium to a friend how will you do it? Consider changes in temperature, pressure and concentration?

20 Ways of learning: Do any of these methods apply to you?

- I learn best listening in lectures
- Laboratory work helps me understand the lectures
- I learn best with visual aids eg tables, graphs, diagrams
- I start to understand the lab only when I start writing up the report
- When I listen to the lecture I think about the concepts being discussed.
- I don’t really think about the concepts when I solve problems
- When I solve problems I find pictures are useful
- When I learn chemistry I try to figure out a real world application
- When I learn chemistry concept I think about what the molecules might be doing

Appendix K

Learning Effectiveness Alliance Program (LEAP) – Grant Application

Division of Engineering and Science

Title:

Using Web-CT as a forum for improving flexibility and providing feedback for pre-laboratory exercise

SUMMARY

Laboratory work is fundamental to the teaching and learning of chemistry and this is reflected in the assessment of Chemistry 117 and Chemistry 118 in which a compulsory attendance record and satisfactory written reports are required to pass the course. This course assumes no prior knowledge of chemistry, however the results of a preliminary study last year revealed that students' prior experiences and knowledge in chemistry had a significant influence on their approach, attitude and perception of chemistry. The study also indicated that although students received help from tutors after tests and from demonstrators in laboratory sessions, the majority of students worked in isolation - there being no formal provision for collaborative discussions as part of the teaching program - and only 20% of the students interviewed obtained help from peers. The laboratory manual is detailed and thorough but lacks illustrations and diagrams. Evidence from the preliminary study showed that some students had difficulty writing up laboratory reports and made use of a laboratory-help web page provided later in semester two. Students come to the laboratory session apprehensively, but soon develop confidence in what they are doing and learn new skills. Despite their ability to follow written instructions, students' understanding of the aim of an experiment is sometimes obscured by the tasks required to conduct the experiment. It is proposed that a more thorough preparation

for the laboratory class would improve this situation.

In this project the Web-CT site will be expanded to include pre-laboratory exercises corresponding to the laboratory classes, which students will have to access, complete and submit electronically prior to the laboratory class each week. The exercise items will be straightforward and uncomplicated, endeavouring to help the students understand the practical and theoretical aspects of the experiment. The students' responses are recorded by the Web-CT facility. Last year a voluntary Web-CT site was initiated for Chemistry 117 and 118 at a preliminary level but student access was sporadic. The results of other LEAP projects in Chemistry have shown that a compulsory assessment component is necessary to encourage students to log-on, after which they have been shown to make use of other aspects of Web-CT, were needed.

The aim of this project is to engage students so that they are better prepared to maximise the benefits of the class and provide basic information for students with little or no chemical background. The web-based assessment will provide students with some immediate feedback on their understanding, correct answers will be positively reinforced and in the case of incorrect answers, correct answers will be given so students can identify any misconceptions. Diagrammatic and illustrative resources that help students to identify apparatus and techniques will, were possible, be included on the Web-CT site. In addition the Web-CT facility allows students and staff to communicate via e-mail - encouraging students to help each other as already experienced in previous LEAP projects in Chemistry and Statistics. The exchange of ideas is a most desired outcome because it is proposed that this will encourage students to express their current personal understanding, improve their understanding and promote meaningful learning of chemical concepts. It is proposed that with a better understanding of the laboratory classes, the links between the theoretical chemistry being taught in the lectures and the practical chemistry being taught in the laboratory will be improved.

OUTCOMES:

Summarise the expected **outcomes** of this initiative and explain why these are anticipated. Also indicate how many units and students the initiative will impact.

The primary objective of the pre-laboratory exercises is to improve the students' understanding of the laboratory work

All students will be expected to do the exercises in their own time, at their home or university computer through access to Web-CT over a two-week period. The pre-laboratory exercises will earn the students 20% of their weekly laboratory mark- i.e. 2 marks out of the weekly 10. It is envisaged that students will spend approximately 20 minutes on the pre-laboratory exercises.

Students will be better prepared for the laboratory sessions having read, answered and received feedback on items such as the aim of the experiment, the equipment being used and how they do the calculations.

Students will be better able to write-up their laboratory reports using guidelines from the exercises.

The Web-CT site provides a means of communicating between students and staff, allowing for greater flexibility and accessibility.

This proposal will be undertaken with students of Chemistry 117 in semester 1 and Chemistry 118 in semester 2. The anticipated number of students is approximately 150.

EVALUATION:

Before implementation items in the pre-lab exercises will be assessed and modified by team members for appropriateness and impact. A written survey of students' perceptions of the importance and value of pre-laboratory exercises in learning chemistry will be administered at the beginning of semester and again at the end of semester.

Interviews with student volunteers in the latter part of the semester – examining their evaluation of the format of the pre-laboratory exercises and the Web-CT site.

Interview with demonstrator volunteers about their perceptions of the impact of the Web-CT pre-laboratory exercises system on students' learning and their ability to carry out experiments.

Results of pre-laboratory exercises and results of laboratory reports.

Both quantitative and qualitative data will be analysed to generate and support any assertions and conclusions.

DISSEMINATION:

At the end of semester 1, the data will be collated and incorporated into a report on the assessment of the value of the pre-laboratory exercises administered through the Web-CT forum as part of Chemistry 117. In light of this report modifications may be made to this initiative to improve its implementation in semester 2 for Chemistry 118. At the end of the year, all data will be collated and a second report generated summarising the results of the implementation of the initiative. Both reports will be presented at internal university forums as well as appropriate conferences.

TIMELINE:

Please indicate specifically what/how the initiative will be conducted within its development phase (Feb-Oct 2002).

Month	Planned Activities
Feb	Expand the Web-CT site for Chemistry 117 to include a *pre-laboratory exercises* component. The exercises will be of multiple choice, matching or single word answers as suggested in the web-CT online assessment manual. Student responses will be computer marked and feedback will be provided through the marking. Testing and trialling will be required. Exercises will be written to match the practical classes for semester 1. The exercises will need to correspond to the laboratory classes and discussion among team members will ensure that the exercises are appropriate and suitable.
Feb cont'd	The pre-laboratory exercises for each class will be available for 2 weeks, a week prior to the class and the week of the class. Survey students about their perceptions of the importance and value of pre-laboratory exercises in learning chemistry and on their appreciation and understanding of the value of a web-CT site.
March to May	Weeks 2-10, continued development of laboratory exercises in advance of the laboratory classes. Monitoring of the web-CT site biweekly by staff throughout the semester.
April	Begin interviewing students and demonstrators; continue through to the end of semester.
May	Re-survey students about their perceptions of the importance and value of pre-laboratory exercises in learning chemistry and on their appreciation of the value of a web-CT site. 31st Submission of initiative progress report
June	Assessment of the semester 1 project

July	After evaluation of the first semester scheme – make modifications and then implement the pre-laboratory exercise scheme to Chemistry 118 for semester 2. Expansion of the Web-CT site for Chemistry 118 to include a pre-laboratory exercises component as in semester 1. The degree of student monitoring (e.g. survey and interview) will have to be determined at that time depending on the results of the semester 1 study. Prepare and write the laboratory exercises for semester 2 to correspond to the practical activities.
July to October	Implementation of scheme throughout semester 2 as for semester 1. Continuation of Web-CT site monitoring
November	Collation of data and written report LEAP EXPO Wednesday, 6 November 2002 31st Submission of initiative final report
December	Final Meeting and review

FUNDING FOR TIME RELEASE

Team member	School funded	LEAP funded	Total
Chittleborough, G.		1	
Mocerino, M.	1	1	
Treagust, D.	1	1	
Taylor, C.		1	
TOTALS*	2 hours	4 hours(b)	6 hours(a)

Additional information you may want the Selection Panel to be aware of – e.g. evidence of the need for the project, previous work done related to teaching and learning, participants track record in improving teaching and learning, team members expertise etc

In 2001, I approached Dr Mocerino with the desire to make some preliminary observations of students learning chemistry. I worked as a demonstrator throughout the year, collecting data, mainly in the form of surveys and interviews with a small group of students undertaking Chemistry 117 and Chemistry 118. Encouraged by my interest in computer-assisted learning I introduced a preliminary Web-CT site for Chemistry 117 and 118, exploring the suitability of this forum to enhance the channels of communication. The students' access to the site was sporadic, despite this, some interest was shown by students towards the *solutions to typical tests,* otherwise only available through the library and *laboratory help*, outlining how to do calculations. Both these resources were closely aligned with assessment tasks and were difficult to obtain, so students were motivated to make use of them via Web-CT. This background information provided some support for the needs of students and has helped with the generation of this proposal.

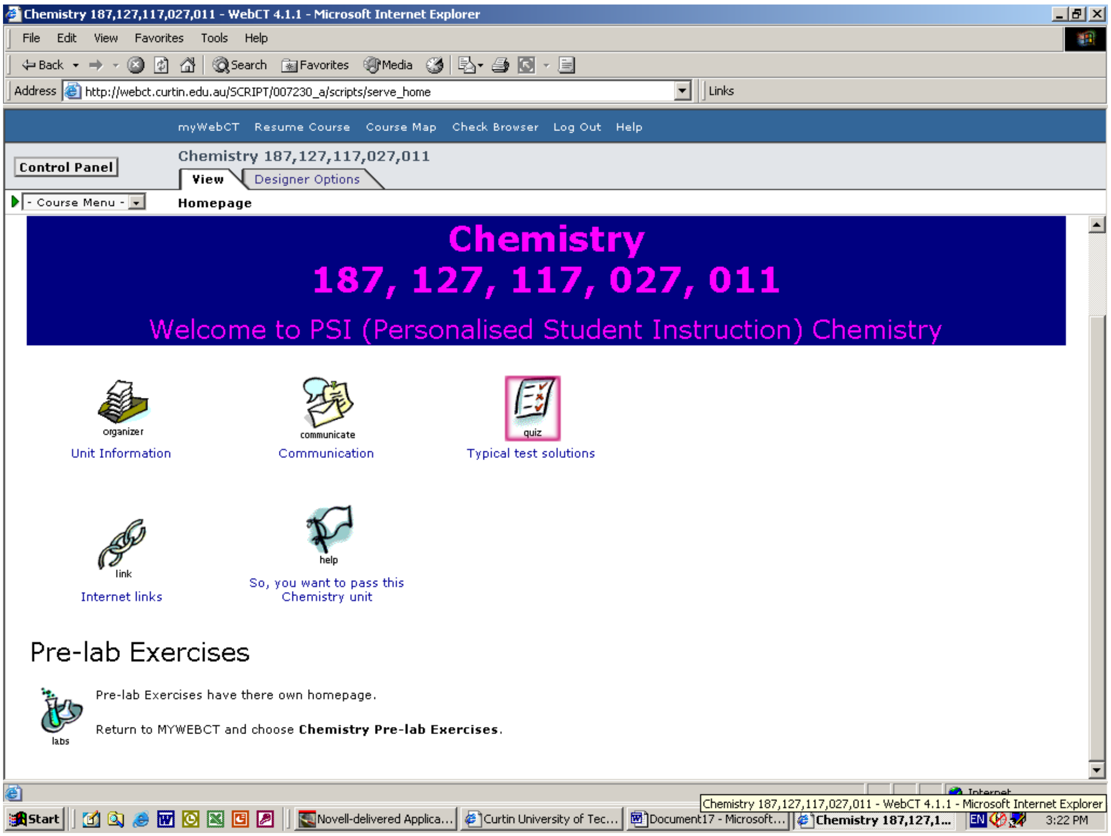
Gail Chittleborough

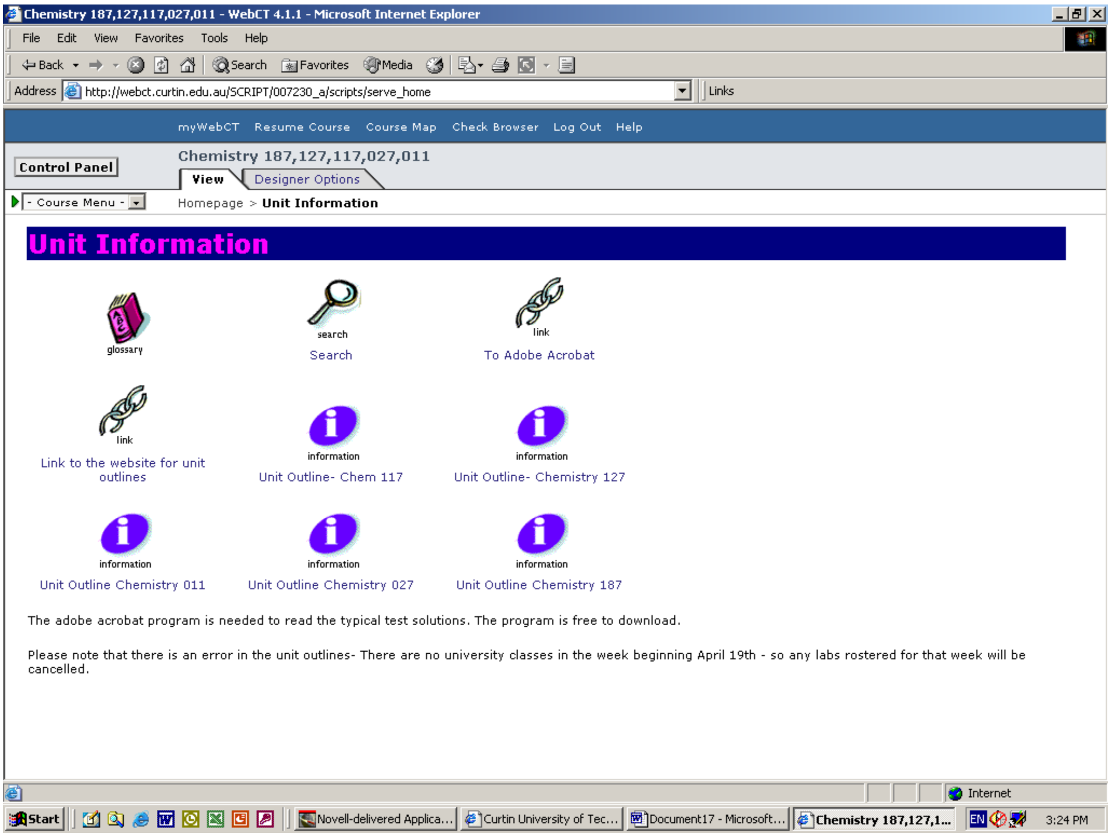
Appendix L

Websites for Chemistry 117 and 118

Images of the web-pages comprising the website available to students undertaking Chemistry 117 are provided as typical examples of the online resources. They include:

- Chemistry 117
- Homepage
- Unit information
- Communication Tools
- Typical Test Solutions
- Internet links
- So, You want to pass this unit!!
- Pre-lab exercises
- Pre-lab exercises
- Checking my marks


Chemistry 187,127,117,027,011 - WebCT 4.1.1 - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Address http://webct.curtin.edu.au/SCRIPT/007230_a/scripts/serve_home
myWebCT Resume Course Course Map Check Browser Log Out Help
Control Panel
Chemistry 187,127,117,027,011
View Designer Options
Homepage
Chemistry
187, 127, 117, 027, 011
Welcome to PSI (Personalised Student Instruction) Chemistry
Unit Information
Communication
Typical test solutions
Internet links
So, you want to pass this Chemistry unit
Pre-lab Exercises
Pre-lab Exercises have there own homepage.
Return to MYWEBCT and choose Chemistry Pre-lab Exercises.


Chemistry 187,127,117,027,011 - WebCT 4.1.1 - Microsoft Internet Explorer
File Edit View Favorites Tools Help
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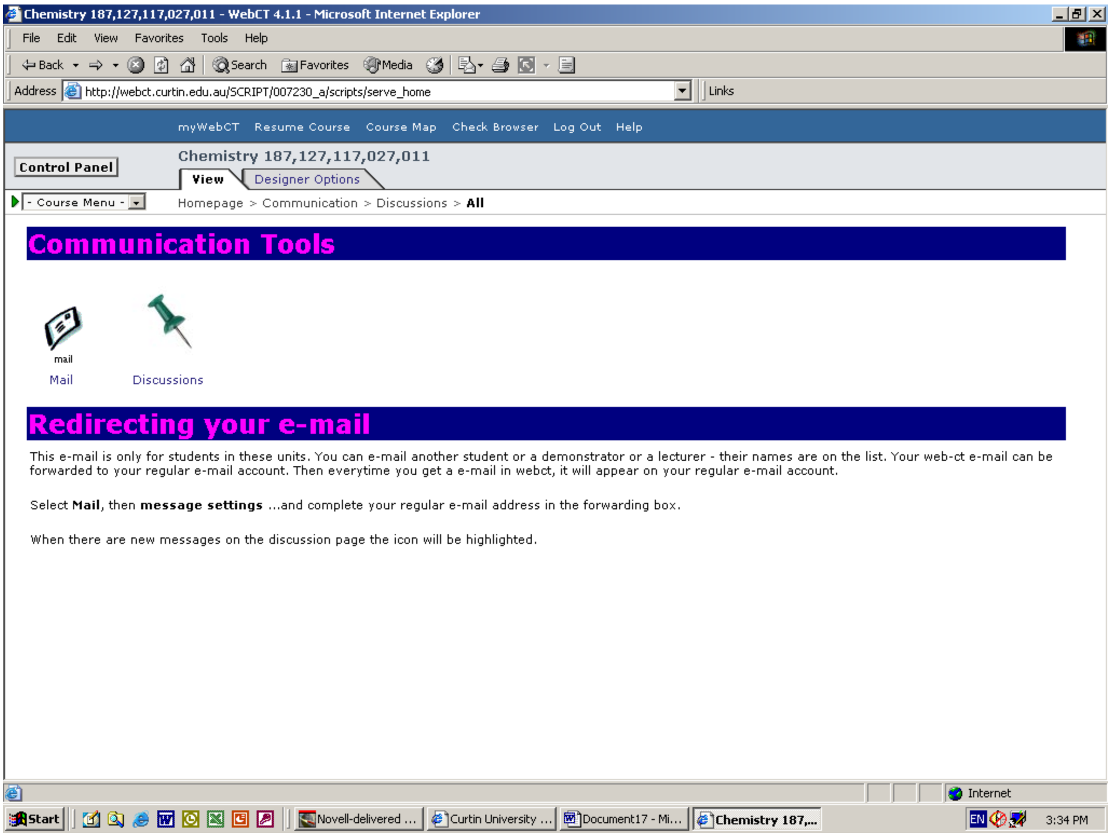
myWebCT Resume Course Course Map Check Browser Log Out Help
Control Panel
Chemistry 187,127,117,027,011
View Designer Options
Homepage > Unit Information
Unit Information
Search
To Adobe Acrobat
Link to the website for unit outlines
Unit Outline- Chem 117
Unit Outline- Chemistry 127
Unit Outline Chemistry 011
Unit Outline Chemistry 027
Unit Outline Chemistry 187
The adobe acrobat program is needed to read the typical test solutions. The program is free to download.
Please note that there is an error in the unit outlines- There are no university classes in the week beginning April 19th - so any labs rostered for that week will be cancelled.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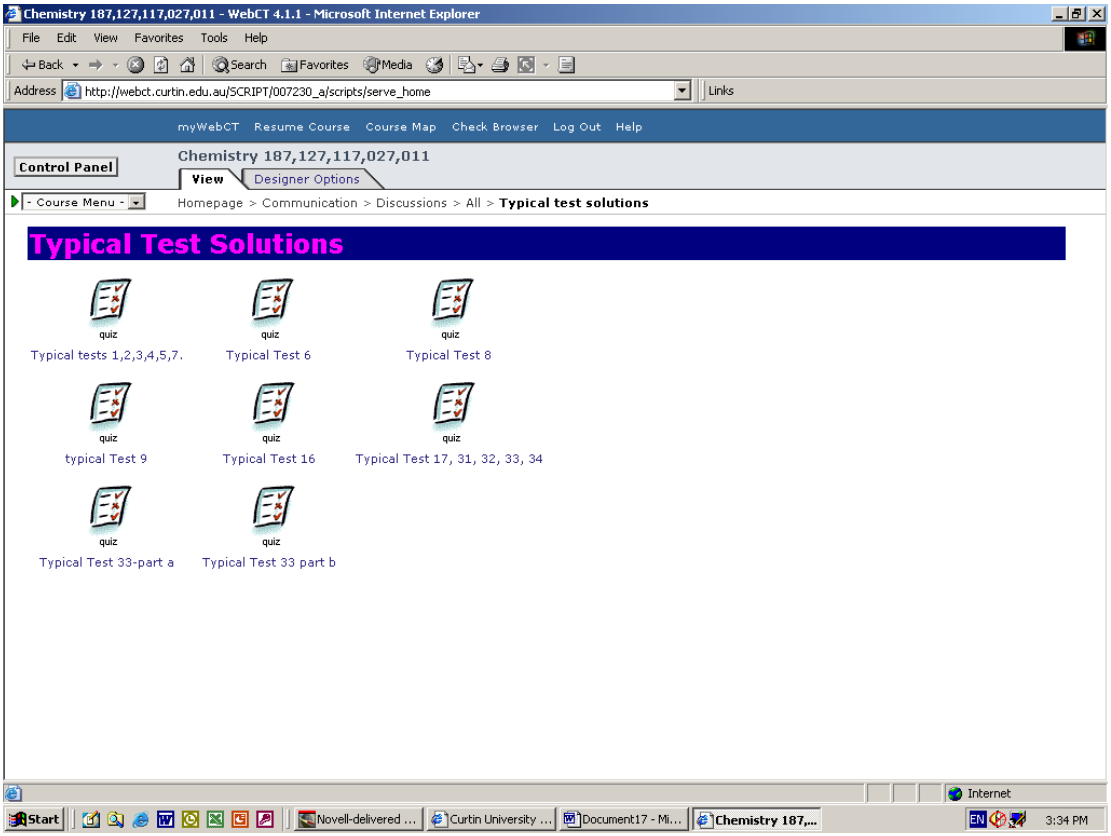
Redirecting your e-mail
This e-mail is only for students in these units. You can e-mail another student or a demonstrator or a lecturer - their names are on the list. Your web-ct e-mail can be forwarded to your regular e-mail account. Then everytime you get a e-mail in webct, it will appear on your regular e-mail account.
Select Mail, then message settings ...and complete your regular e-mail address in the forwarding box.
When there are new messages on the discussion page the icon will be highlighted.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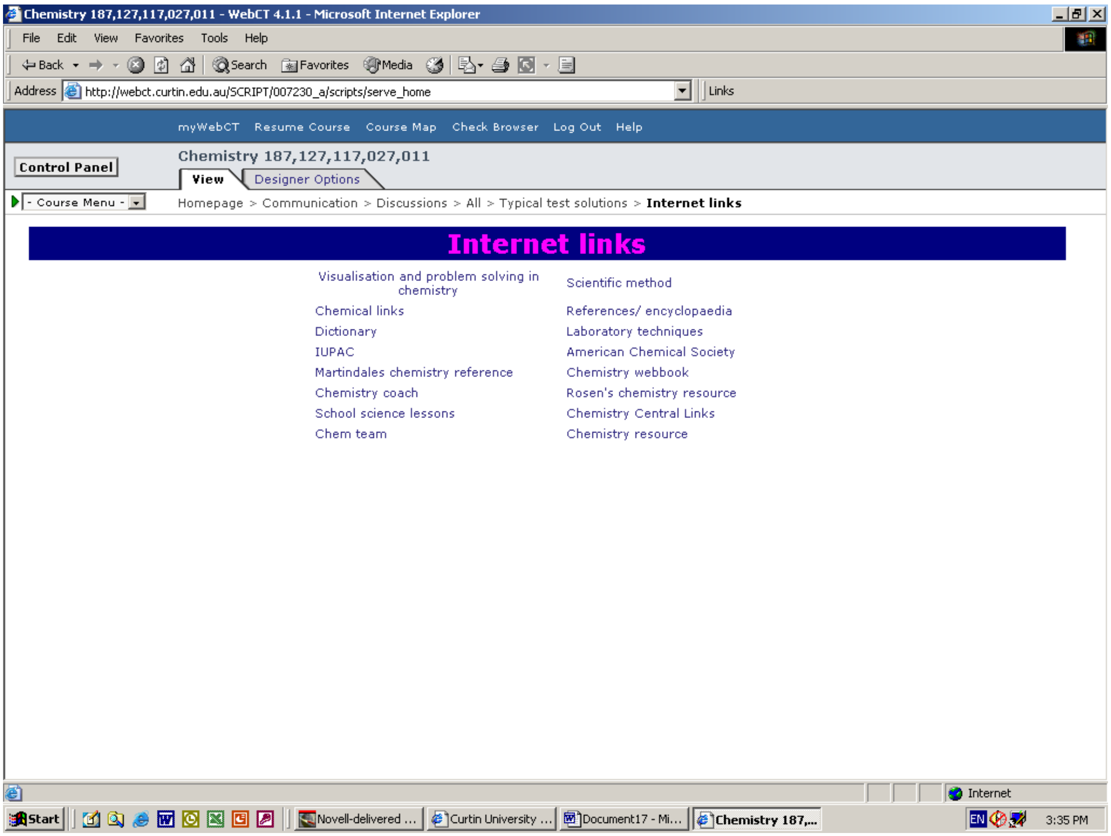
View Designer Options
Course Menu
Homepage > Communication > Discussions > All > Typical test solutions
Typical Test Solutions
Typical tests 1,2,3,4,5,7.
Typical Test 6
Typical Test 8
typical Test 9
Typical Test 16
Typical Test 17, 31, 32, 33, 34
Typical Test 33-part a
Typical Test 33 part b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Homepage > Communication > Discussions > All > Typical test solutions > Internet links
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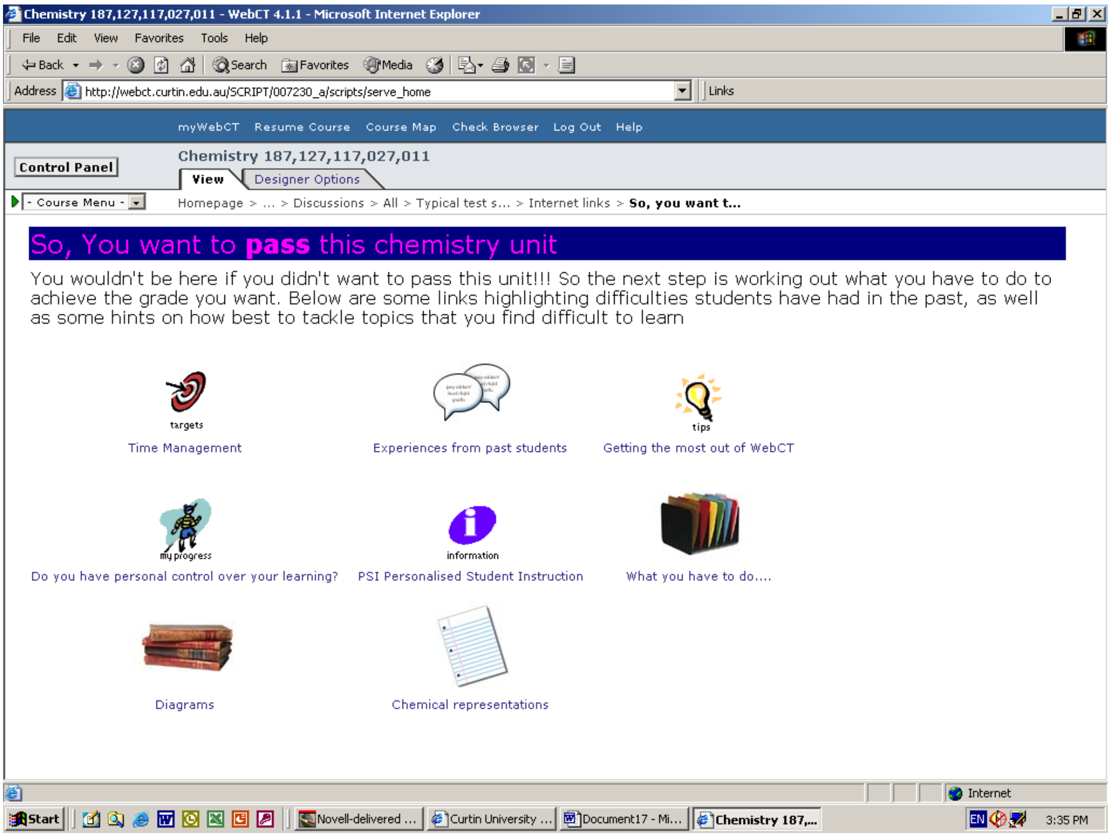
Visualisation and problem solving in chemistry
Scientific method
Chemical links
References/ encyclopaedia
Dictionary
Laboratory techniques
IUPAC
American Chemical Society
Martindales chemistry reference
Chemistry webbook
Chemistry coach
Rosen's chemistry resource
School science lessons
Chemistry Central Links
Chem team
Chemistry resource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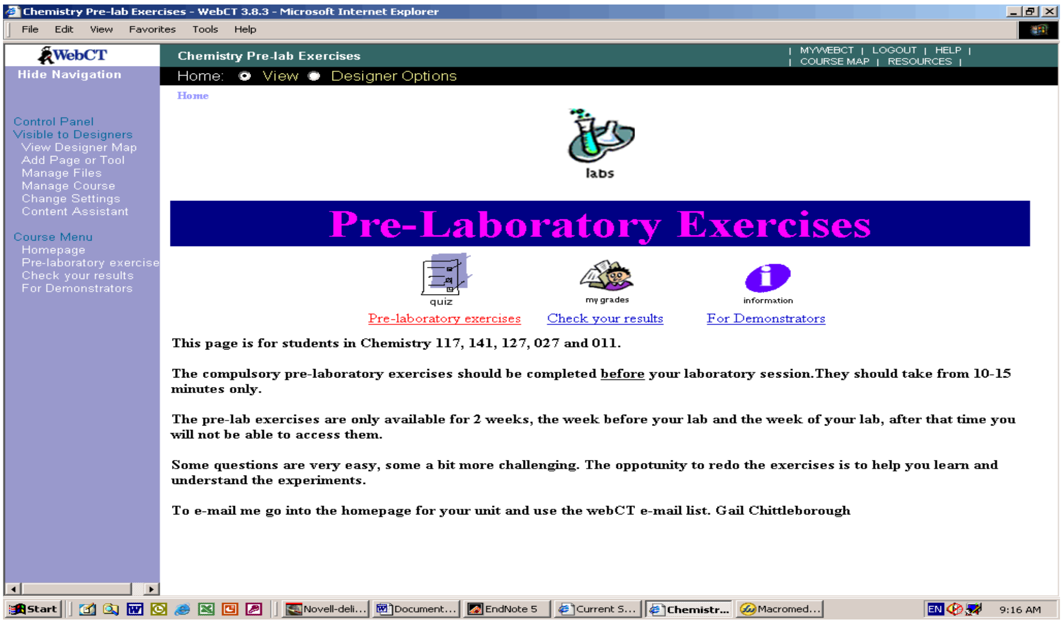
myWebCT Resume Course Course Map Check Browser Log Out Help
Control Panel
Chemistry 187,127,117,027,011
View Designer Options
Homepage > ... > Discussions > All > Typical test s... > Internet links > So, you want t...
So, You want to pass this chemistry unit
You wouldn't be here if you didn't want to pass this unit!!! So the next step is working out what you have to do to achieve the grade you want. Below are some links highlighting difficulties students have had in the past, as well as some hints on how best to tackle topics that you find difficult to learn
targets
Time Management
Experiences from past students
tips
Getting the most out of WebCT
my progress
Do you have personal control over your learning?
information
PSI Personalised Student Instruction
What you have to do....
Diagrams
Chemical representations



Chemistry Pre-lab Exercises - WebCT 3.8.3 - Microsoft Internet Explorer

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WebCT | Chemistry Pre-lab Exercises | MYWEBCT | LOGOUT | HELP | COURSE MAP | RESOURCES

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Home

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Manage Files
Manage Course
Change Settings
Content Assistant

Course Menu
Homepage
Pre-laboratory exercise
Check your results
For Demonstrators

labs

Pre-Laboratory Exercises

quiz | my grades | information

Pre-laboratory exercises | Check your results | For Demonstrators

This page is for students in Chemistry 117, 141, 127, 027 and 011.

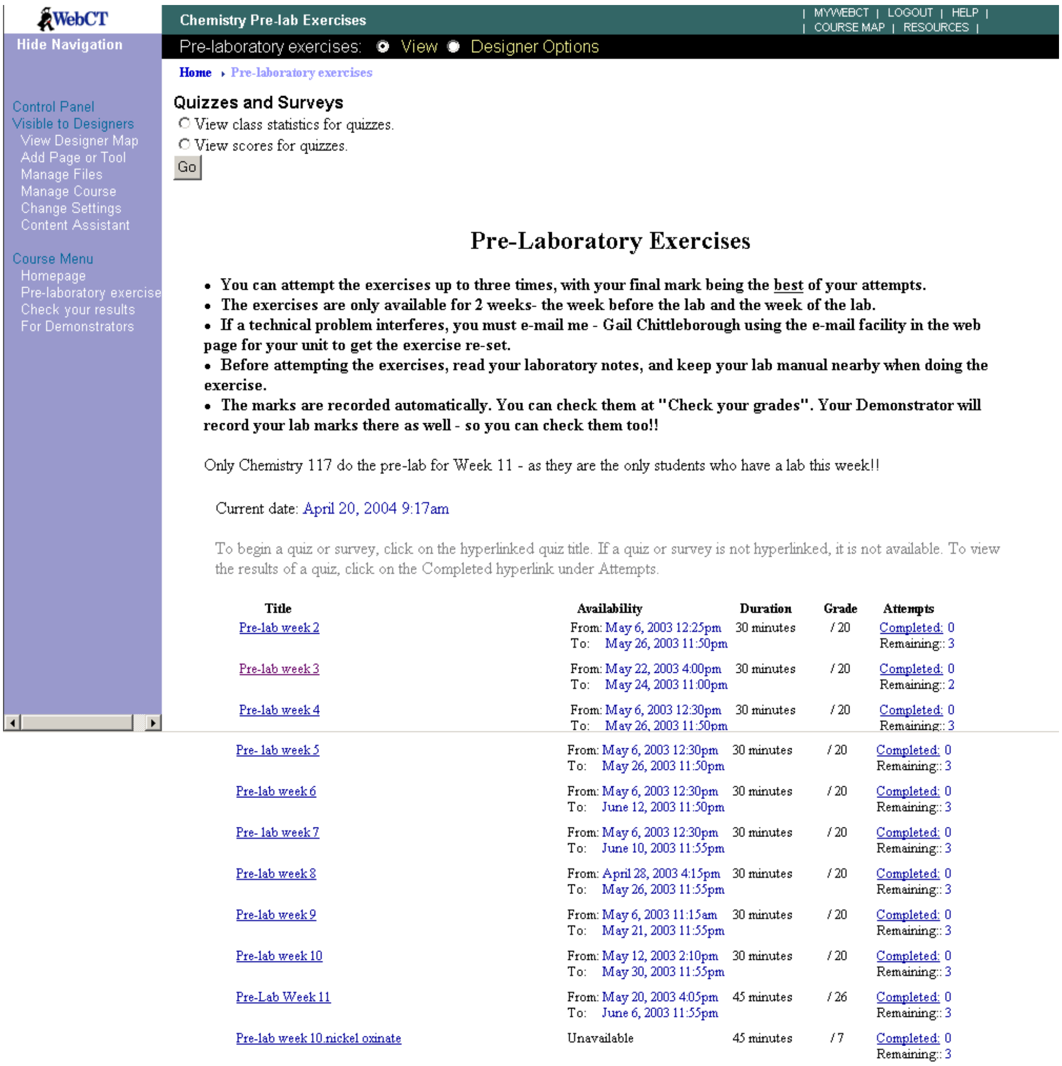
The compulsory pre-laboratory exercises should be completed before your laboratory session.They should take from 10-15 minutes only.

The pre-lab exercises are only available for 2 weeks, the week before your lab and the week of your lab, after that time you will not be able to access them.

Some questions are very easy, some a bit more challenging. The oppotunity to redo the exercises is to help you learn and understand the experiments.

To e-mail me go into the homepage for your unit and use the webCT e-mail list. Gail Chittleborough

Start | Novell-deli... | Document... | EndNote 5 | Current S... | Chemistr... | Macromed... | EN | 9:16 AM



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Pre-laboratory exercises: View Designer Options

Home › Pre-laboratory exercises

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Change Settings
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Course Menu
Homepage
Pre-laboratory exercise
Check your results
For Demonstrators

Quizzes and Surveys

- View class statistics for quizzes.
- View scores for quizzes.

Go

Pre-Laboratory Exercises

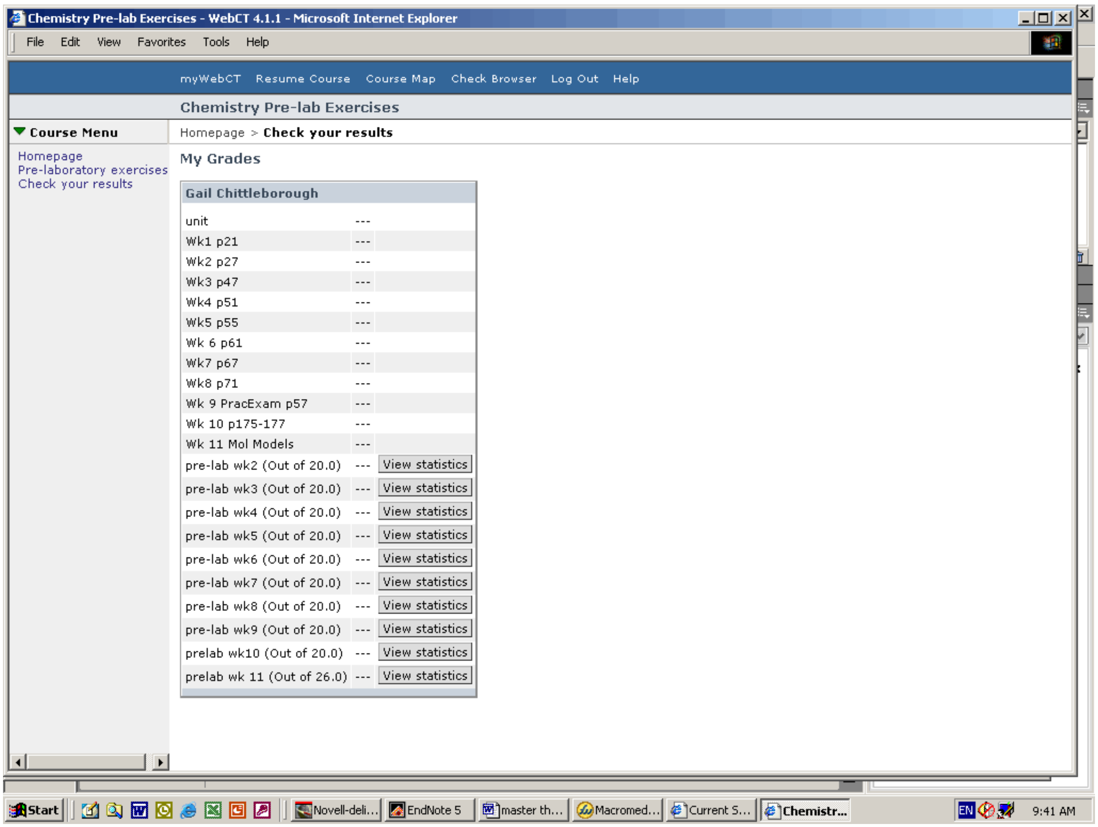
- **You can attempt the exercises up to three times, with your final mark being the best of your attempts.**
- **The exercises are only available for 2 weeks- the week before the lab and the week of the lab.**
- **If a technical problem interferes, you must e-mail me - Gail Chittleborough using the e-mail facility in the web page for your unit to get the exercise re-set.**
- **Before attempting the exercises, read your laboratory notes, and keep your lab manual nearby when doing the exercise.**
- **The marks are recorded automatically. You can check them at "Check your grades". Your Demonstrator will record your lab marks there as well - so you can check them too!!**

Only Chemistry 117 do the pre-lab for Week 11 - as they are the only students who have a lab this week!!

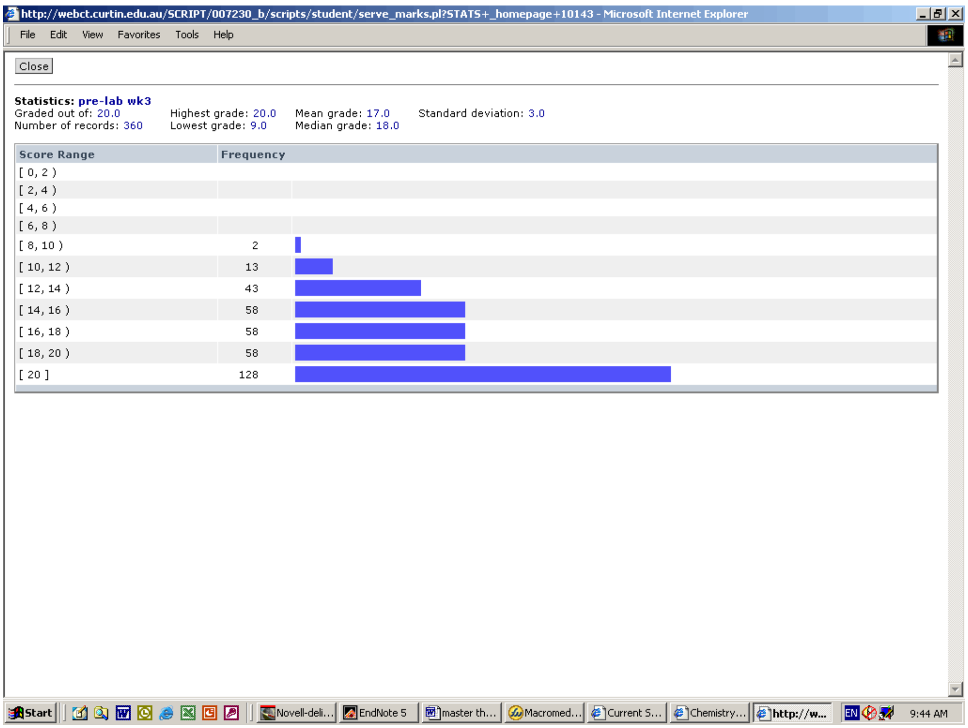
Current date: April 20, 2004 9:17am

To begin a quiz or survey, click on the hyperlinked quiz title. If a quiz or survey is not hyperlinked, it is not available. To view the results of a quiz, click on the Completed hyperlink under Attempts.

Title	Availability	Duration	Grade	Attempts
Pre-lab week 2	From: May 6, 2003 12:25pm To: May 26, 2003 11:50pm	30 minutes	/ 20	Completed: 0 Remaining:: 3
Pre-lab week 3	From: May 22, 2003 4:00pm To: May 24, 2003 11:00pm	30 minutes	/ 20	Completed: 0 Remaining:: 2
Pre-lab week 4	From: May 6, 2003 12:30pm To: May 26, 2003 11:50pm	30 minutes	/ 20	Completed: 0 Remaining:: 3
Pre- lab week 5	From: May 6, 2003 12:30pm To: May 26, 2003 11:50pm	30 minutes	/ 20	Completed: 0 Remaining:: 3
Pre-lab week 6	From: May 6, 2003 12:30pm To: June 12, 2003 11:50pm	30 minutes	/ 20	Completed: 0 Remaining:: 3
Pre- lab week 7	From: May 6, 2003 12:30pm To: June 10, 2003 11:55pm	30 minutes	/ 20	Completed: 0 Remaining:: 3
Pre-lab week 8	From: April 28, 2003 4:15pm To: May 26, 2003 11:55pm	30 minutes	/ 20	Completed: 0 Remaining:: 3
Pre-lab week 9	From: May 6, 2003 11:15am To: May 21, 2003 11:55pm	30 minutes	/ 20	Completed: 0 Remaining:: 3
Pre-lab week 10	From: May 12, 2003 2:10pm To: May 30, 2003 11:55pm	30 minutes	/ 20	Completed: 0 Remaining:: 3
Pre-Lab Week 11	From: May 20, 2003 4:05pm To: June 6, 2003 11:55pm	45 minutes	/ 26	Completed: 0 Remaining:: 3
Pre-lab week 10 nickel oxinate	Unavailable	45 minutes	/ 7	Completed: 0 Remaining:: 3



The students only have access to their own results. There is provision for the laboratory grades to be entered. The statistics (e.g. mean, range, frequencies, standard deviation etc.) for weekly pre-laboratory exercises are available so students can compare their efforts with the whole class. The results for week 3 are displayed below.

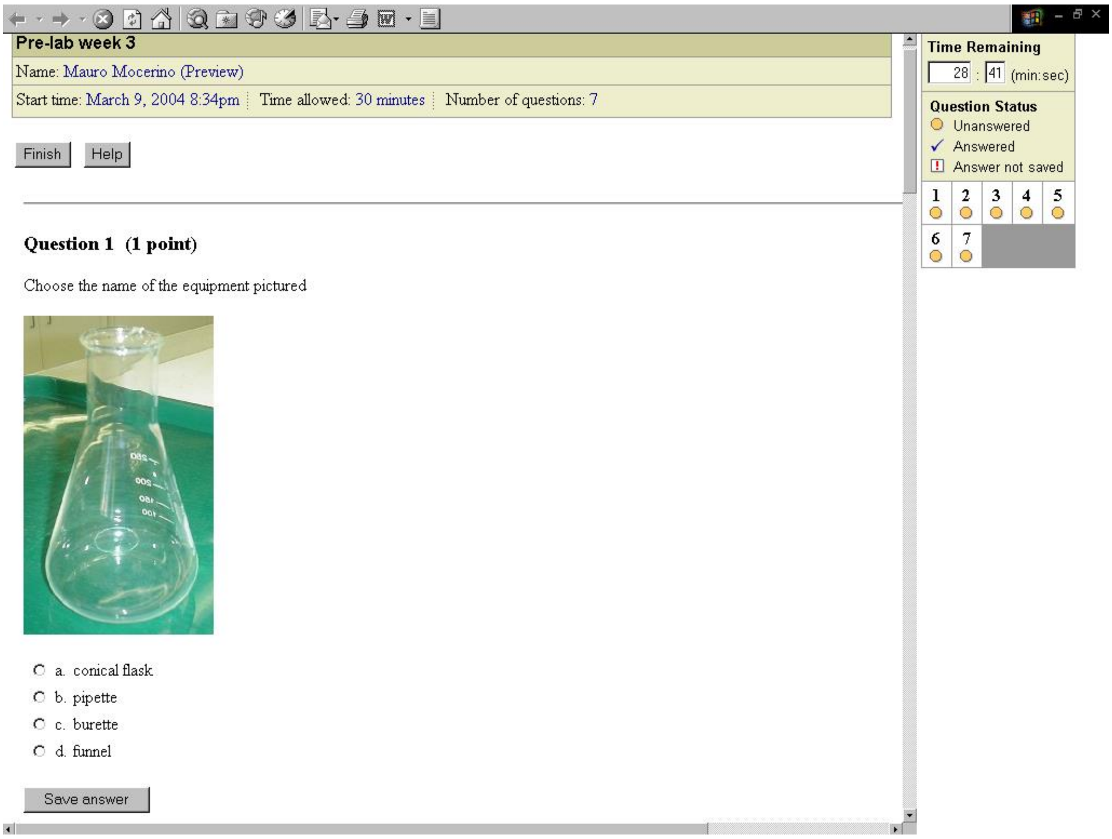


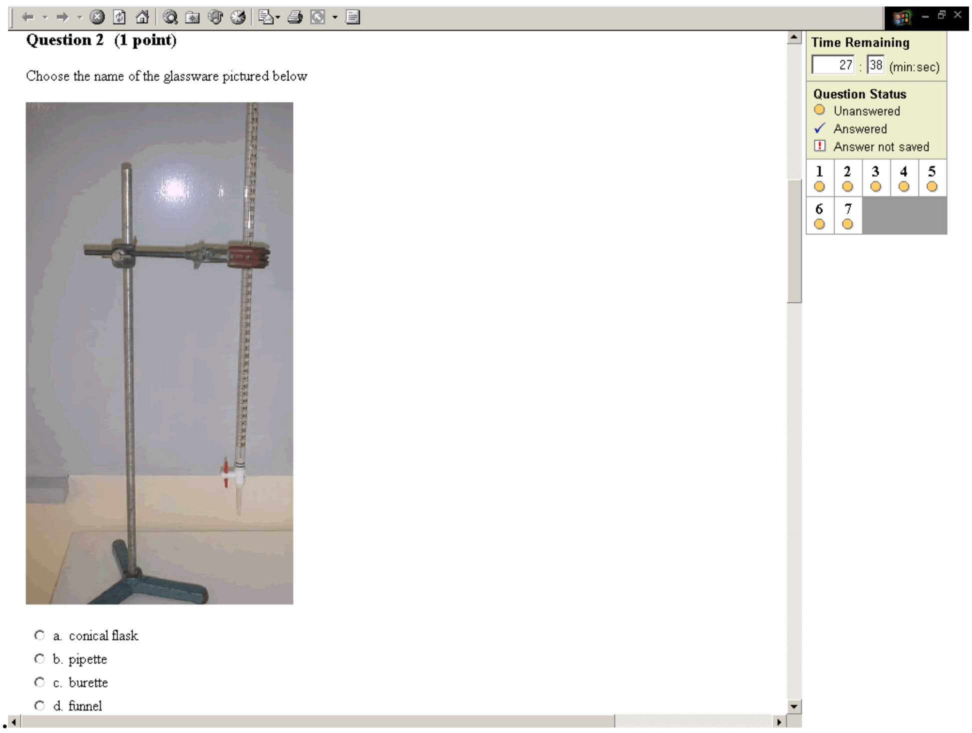
Appendix M

Example of Pre-laboratory Exercises

Example of the Pre-laboratory Exercises – Semester 1, Week 3

Questions 1-7 are shown here as they appear to the students on the screen.





Question 3 (1 point)

Why must the burette be thoroughly rinsed with tap water and finally deionised water after the Sodium hydroxide (NaOH) has been use

- a. To remove any contaminents
- b. To ensure that the next set of results are not affected
- c. Chemicals in ordinary water, present as ions, can affect the results of any titration, so deioinised water must be used.
- d. All of the above

Save answer

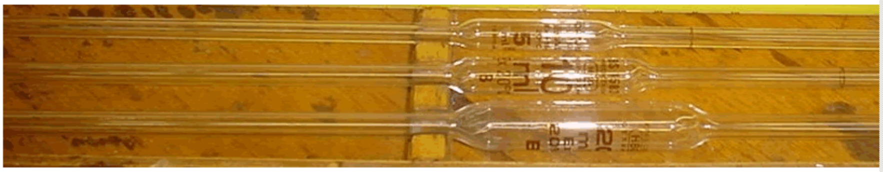
Time Remaining
26 : 50 (min:sec)

Question Status
Unanswered
Answered
Answer not saved

1	2	3	4	5
6	7			

Question 4 (8 points)

The pipette pictured below is used to measure exact volumes of liquids. For the volume to be accurate the pipette must be used properl correct order from 1 to 10.



1 a. Allow the liquid to drip out slowly until the bottom of the meniscus just reaches the graduation mark.
2 b. Hold the jet in contact with the side of the vessel for 15 secs
3 c. Allow the liquid to run into the vessel.
4 d. Clean the pipette- wash thoroughly then rinse with tap water and then deionised water
5 e. Insert the pipette into the chuck of the pi-pump.
6 f. Wipe away any adhering liquid from the outside of the pipette
7 g. Draw the liquid up until it is above the graduation mark.
8 h. Rinse the pipette 2 or 3 times with a small amount of the liquid, tilting to ensure the whole inner surface is rinsed.

1 --> Choose match
2 --> Choose match
3 --> Choose match
4 --> Choose match
5 --> Choose match
6 --> Choose match
7 --> Choose match
8 --> Choose match

Save answer

Time Remaining
26 : 15 (min:sec)

Question Status
Unanswered
Answered
Answer not saved

1	2	3	4	5
6	7			

Time Remaining
25 : 41 (min:sec)

Question Status
Unanswered
Answered
Unanswered question

1	2	3	4	5
6	7			

Question 5 (1 point)

In an acid-base titration, acid and base are combined until they reach the equivalence point or endpoint.

If the concentration of the acid and the base are the same then at the endpoint there will be:

- a. equal volumes of acid and base
- b. more acid than base
- c. less base than acid
- d. Less acid than base

Save answer

Question 6 (7 points)

Collecting data requires measurement. Match the correct unit with the physical quantity in the list below.

temperature -->	Choose match
length -->	Choose match
time -->	Choose match
volume -->	Choose match
mass -->	Choose match
concentration -->	Choose match
density -->	Choose match

Save answer

6	7

Question 7 (1 point)

Volume (V) refers to the amount of space something occupies.

For liquids, the term volume refers to the amount of liquid. In the laboratory we use the units litre (L) and millilitre (mL).

1mL = 1cm^3 that is 1 milllitre = 1 cubic centimetre

1L = 1 dm^3 , that is , 1 litre = 1 cubic decimetre

What fraction of 1 litre is 1 millilitre?

- a. 1mL is a tenth (1/10) of a litre
- b. 1mL is one thousandth (1/1000) of a litre
- c. 1mL is one hundredth (1/100) of a litre
- d. 1 mL is a thousand times bigger than a litre.

Save answer

Appendix N

Quantitative Data Sources for Study 4 – Learning Introductory Chemistry and the Implementation of Online Pre-laboratory Exercises for Non-majors

There are three quantitative sources used in Study 4

- Introductory Questionnaire-
  - Students' Understanding of Models in Science (SUMS)
  - My Views of Models and Modelling in Science (VOMMS)
- SEEQ Questionnaire
- Online Survey

Students' Understanding of Models in Science (SUMS)

Name: _________________

Tutorial __________

Department of Applied Chemistry and Science and Mathematics Education Centre

QUESTIONNAIRE ABOUT THE ROLE AND USE OF MODELS IN SCIENCE

For each statement tick the box which most accurately reflects your opinion.

	Strongly Disagree	Disagree	Don't Know	Agree	Strongly Agree
Various models represent different versions of a phenomenon.					
Models can show the relationship of ideas clearly.					
A range of models caters for different learning styles					
Numerous models are used to show different parts of an object or show the objects differently.					
A model has what is needed to show or explain a scientific phenomenon.					
A model is an exact replica.					
A model needs to be close to the real thing by being very exact in every way except for size.					
A model shows what the real thing does and what it looks like.					
Models show a smaller scale size of something.					
Models are used to represent abstract objects or ideas for which the real appearance or behaviour is not certain					
A model is always like the real thing					
Models are used to physically or visually represent something.					
Models help create a picture in your mind of the scientific happening.					
Models are used to explain scientific phenomena.					
Models are used to show an idea.					
A model can be can be a diagram or a picture, a map, graph or a photo.					
Models are used to help formulate ideas and theories about scientific events.					
Models are used to show how they are used in scientific investigations.					
Models are used to make and test predictions about a scientific event.					
A model can change if new theories or evidence prove otherwise.					
A model can change if there are new findings.					
A model can change if there are changes in data or belief.					

My Views of Models and Modelling in Science (VOMMS)

MY VIEWS ON MODELS AND MODELLING IN SCIENCE

- For each of the five items you are given two statements, circle the number that you think most closely represents your view on models and modelling in science.
- Explain your choice in the space provided below each item.

1. Models and modelling in science are important in understanding science. Models are:

a) representations of ideas or how things work.

b) accurate duplicates of reality.

Reason :………………………………………………………………………………

2. Scientific ideas can be explained by:

a) one model only, - any other model would simply be wrong.

b) one model, - but there could be many other models to explain the ideas.

Reason:…………………………………………………………………………………

3. When a new model is proposed for a new scientific theory, scientists must decide whether or not to accept it. Their decision is:

a) based on the facts that support the model and the theory.

b) influenced by their personal feelings or motives.

Reason:……………………………………………………………………………………….

4. The acceptance of a new scientific model:

a) requires support by a large majority of scientists.

b) occurs when it can be used successfully to explain results.

Reason:……………………………………………………………………………………….

5. Scientific models are built up over a long period of time through the work of many scientists, in their attempts to understand scientific phenomenon. Because of this scientific models:

a) will not change in future years.

b) may change in future years.

Reason:…………………………………………………………………………………………

SEEQ Questionnaire

This survey used a generic form (SEEQ) supplied by the university, however I supplied additional questions, which the students had to respond to on the 9 point scale.

I am requesting your help in completing this survey to get feedback on the pre-laboratory exercises, both online and in the laboratory manual. Please complete the name of instructor, Unit and Date only – Do not answer the questions on the front page.

Then turn over the page and place your responses to the additional items (items 1-17 below) in the appropriate boxes.

For each item indicate the extent of your agreement/disagreement with the statement by colouring in the appropriate number 1-9 on the answer sheet.

1=Strongly Disagree 3=Disagree 5=Neutral 7=Agree 9=Strongly Agree

Lecturer Supplied Questions - Additional Items

Items 1-17 Online pre-laboratory exercises on Chemistry 117 website

1. I have accessed the online pre-laboratory exercises weekly
2. I had difficulty accessing the website from home
3. I had difficulty keeping the website up and running.
4. I had difficulty navigating the website for the unit.
5. The online pre-laboratory exercises allowed me greater flexibility with my time.
6. The online pre-laboratory exercises provided feedback on my understanding.
7. The online pre-laboratory exercises helped me to learn and understand the concepts in the experiment.
8. Getting immediate feedback on the online pre-laboratory was valuable.
9. The online pre-laboratory exercises were challenging.
10. Being able to try an exercise more than once helped me learn from my mistakes.
11. I had to read the laboratory notes in order to do the online pre-laboratory exercises.
12. The online pre-laboratory exercises were useful in confirming my understanding
13. The online pre-laboratory exercises provided me with valuable feedback on my progress.
14. I understood the experiments better having done the online pre-laboratory exercises.
15. The pictures in the online pre-laboratory exercises were valuable.
16. The online pre-laboratory exercises should be worth more marks.
17. I used the solutions to typical tests on the website regularly.

Please complete the background information too.

Thank you for your help

Gail Chittleborough

Online Survey

This survey was accessed through the website for the chemistry unit. It appeared to the students in a similar format to the weekly pre-laboratory exercises. The survey consisted of 19 multiple-choice questions and some open-ended questions.

Multiple-choice questions

The questions 1-19 were multiple-choice items with students required to select a response from the following list:

Strongly Disagree, Disagree Neutral, Agree, Strongly Agree

1. My computer skills are good enough to use the Web CT program effectively
2. Without good computer skills I could not use the pre-lab exercises effectively
3. I had difficulty accessing the website from home
4. I had difficulty keeping the website up and running.
5. I had difficulty navigating the website for the unit.
6. The online pre-laboratory exercises allowed me greater flexibility with my time
7. The online pre-laboratory exercises provided feedback on my understanding.
8. The online pre-laboratory exercises helped me to learn and understand the concepts in the experiment
9. Getting immediate feedback on the online pre-laboratory was valuable
10. Being able to try an exercise more than once helped me learn from my mistakes
11. I had to read the laboratory notes in order to do the online pre-laboratory exercises
12. I understood the experiments better having done the online pre-laboratory exercises
13. The pictures and diagrams in the online pre-laboratory exercises were valuable
14. I use the solutions to the typical tests on the website regularly
15. I monitor the discussion page on the website regularly
16. I find the e-mail facility useful
17. I usually completed the pre-lab exercises before the laboratory session
18. I find the calendar useful
19. The website has directed me to relevant Internet sites

Open Ended Questions

For Q20 - Q27 students were required to type their written response in the answer box provided.

20. What aspects of the Web-CT site for Chemistry 118 have been valuable?

21.What aspects of the Web-CT site for Chemistry 118 have NOT been of value?

22.The aim of the pre-lab exercises is to:

- better prepare students for labs
- provide basic information for students with little or no chemical background.
- provide students with some immediate feedback on their understanding,
- use diagrammatic and illustrative resources to enhance explanations
- improve links between theory and practical work
- use other Web-CT facilities eg e-mail, discussion, test solutions etc

Do you think it is achieving these objectives? Please support your answer

23. What aspects of the pre-laboratory exercises are helpful to your learning of chemistry?

24. What aspects of the pre-laboratory exercises are NOT helpful to your learning of chemistry?

25. Some examples of strategies used in learning chemistry include

- underlining; highlighting; copying out notes
- memorising, reading,
- working out problems; practising problems; using solutions to understand the problems,
- working with friends; asking friends for help; asking tutors/demonstrators
- for help,
- looking up other texts; using the course notes; using the web-site,
- drawing concept maps; drawing diagrams,

List any strategies you make use of in learning chemistry.

26 Many things can influence your learning of chemistry. For example

- Good explanations - easy to follow.
- Using a variety of diagrams/models to represent the chemicals.
- Your background knowledge in chemistry.
- Your background knowledge in mathematics.
- Your motivation for learning chemistry? Perseverance? Discipline?
- A desire to learn chemistry or a need to pass the exam in order to meet course requirements.
- The pace of the course; the content of the course; the assessment of the course .
- Links between the practical work and the theoretical work.

List any - from the list or any others, that are especially important to you.

27 There is room below for any other comments

Appendix O

Interview Questions for Study 4

Two series of interviews were conducted in Study 4 concerning the diagrams used in the pre-laboratory exercises:

- Weeks 1 – 5 of pre-laboratory exercises.
- Weeks 6 – 12 of pre-laboratory exercises.

Interview Questions for Study 4

For both sets of interviews, the written interview questions were given to students on paper as well as asked verbally. During the interviews, copies of the interview questions were used in conjunction with copies of the pre-laboratory exercises to which the questions were referring. All students had completed the pre-laboratory exercises and so were familiar with the diagrams that they were being questioned about. Since it is too cumbersome to include all the pre-laboratory exercises here in the appendix, copies of the relevant diagrams have been included with the questions.

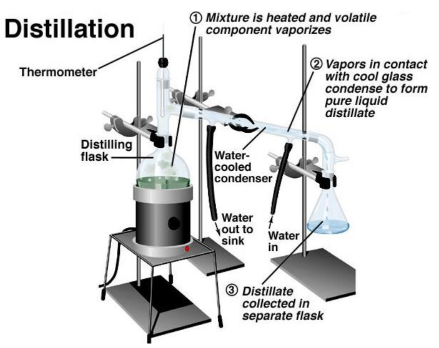
Interview Questions – Diagrams and Explanations Week 1-5

Week 1– Distillation

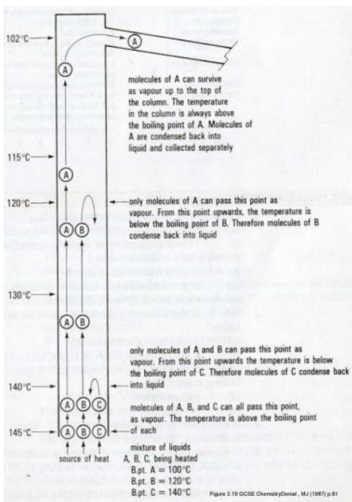
Look at Q1 distillation diagram
1.1 What does the diagram show?
In what ways does the diagram help you understand:
1.2 The experimental method, the technique?
1.3 What is happening to the mixture in the distilling flask?
1.4 Changes that are occurring at the molecular level?
1.5 In what ways has diagram helped you to understand the concept of distillation?
1.6 Has the image supported what you already know?
1.7 Has it added to your understanding?
1.8 Does the image 'makes sense' to you – based on your previous understandings.
1.9 Has the image highlighted some erroneous ideas?

Look at Q5 the fractional distillation diagram

2.1 What does the diagram show?
In what ways does the diagram help you understand:
2.2 The experimental method, the technique?
2.3 What is happening to the mixture in the fractionating column?
2.4 Changes that are occurring at the molecular level?
2.5 In what ways has diagram helped you to understand the concept of fractional distillation?
2.6 Has the image supported what you already know?
2.7 Has it added to your understanding?
2.8 Does the image 'makes sense' to you – based on your previous understandings?
2.9 Has the image highlighted some erroneous ideas?
2.10 Is there any other image, model, representation etc that you have found helpful in understanding the distillation process?



Distillation



Fractional Distillation

Week 2 – Crystallisation practical – *dissolving, filtering, vacuum filtering, crystallising*

Gravity Filtration

Vacuum filtration

Both gravity filtration and vacuum filtration were introduced in week 2’s pre-lab exercises.

3.1 Describe what is occurring with the filtration process.

3.2 What is happening at the molecular level?

3.3 Is a chemical change occurring?

3.4 Would you classify filtration as a physical or chemical process? Explain

3.5 In what ways has your lab work helped you to understand the process?

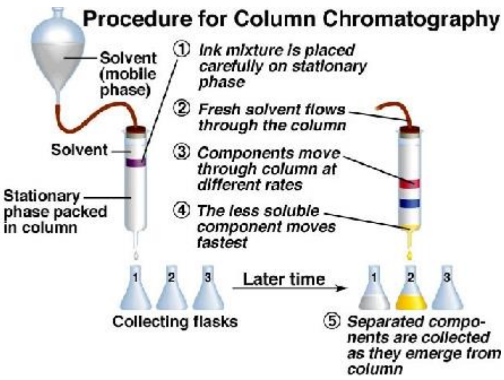
3.6 You probably had some ideas about filtration before starting this unit. Has your experience in the lab supported what you already knew?

3.7 Has it added to your understanding?

3.10 Has the lab experience highlighted some erroneous ideas?

3.11 Is there any other image, model, representation etc that you use to help you to understand filtering?

Week 3 – Column Chromatography



Column Chromatography

The diagram shows the equipment for column chromatography – very similar to that we used in the lab.

4.1 Describe the diagram?

In what ways does the diagram help you understand:

4.2 The experimental method, the technique?

4.3 What is happening to the mixture in the column?

4.4 Changes that are occurring at the molecular level?

4.6 In what ways has diagram helped you to understand the concept of column chromatography?

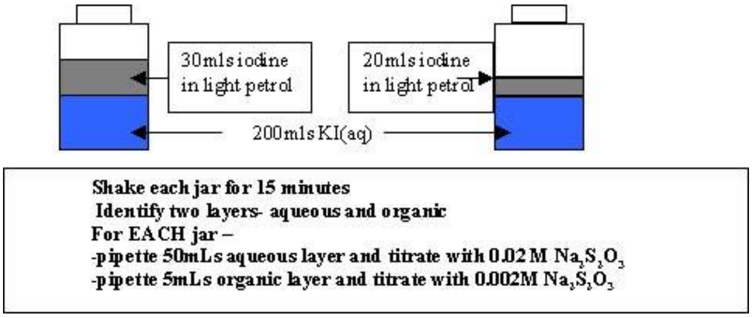
4.7 Has the image supported what you already know?

4.8 Has it added to your understanding?

4.9 Does the image 'makes sense' to you – based on your previous understandings.

4.10 Has the image highlighted some erroneous ideas?

Week 4 – Equilibrium Constant



Potassium iodide (I^-) is in solution, it doesn't dissolve in light petroleum.

Iodine (I_2) is dissolved in light petroleum, it doesn't dissolve in water.

The aqueous solution and the organic solvent (light petroleum) don't mix.

There are two equilibriums occurring

- in the aqueous layer
- between the aqueous and organic layers

In the aqueous layer:

$$I_{2\ (aq)} + I^-_{(aq)} \longleftrightarrow I_{3(aq)}$$

(From Iodine in light petrol) + (from KI)

At the organic / aqueous interface:

$$I_{2(org)} \longleftrightarrow I_{2(aq)}$$

Question 3 shows a sketch of method used in the equilibrium experiment

5.1 What does the diagram show?

In what ways does the diagram help you understand:

5.2 The experimental method, the technique?

5.3 What is happening to the mixture in the bottles?

5.4 Changes that are occurring at the molecular level?

5.6 Question 6 uses equations to represent the equilibrium systems.

Explain what these equations mean.

In what ways do the symbols and equations help you understand

5.8 The experimental method, the technique?

5.9 What is happening to the mixture in the bottles?

5.10 Changes that are occurring at the molecular level?

5.11 In what ways has diagram helped you to understand the concept of equilibrium?

5.12 Has the image, equations and experimental work supported what you already know?

5.13 Has it added to your understanding?

5.14 Does this data (the image, equations and experimental work) 'makes sense' to you – based on your previous understandings.

5.15 Has it (the image, equations and experimental work) highlighted some erroneous ideas?

5.16 How would you explain the idea of chemical equilibrium and the equilibrium constant to a friend?

Have a go! (Are there any models, analogies, tools which could help?)

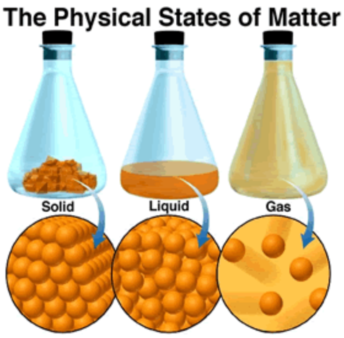
5.17 Can you comment on the equilibrium state in terms of the:

- *experiment*
- *molecules in the system*
- *chemical equation*

5.18 What is the significance of the arithmetic constant – the equilibrium constant?

Week 5 – Freezing point

Diagrams as simple as that shown in question 1 helps to remind us of the molecular nature of chemistry



6.1 Do you think the representation here is accurate?

6.2 Do you think the representation here is real?

6.3 Do you think the representation here is useful?

6.4 What is good about it?

6.5 What is bad about it?

6.6 Do you think of atoms as the round balls as drawn here?

6.7 Remember the naphthalene- in the test tube. What would the atoms of naphthalene look like?

a) Colour?

b) Size?

c) Density?

During the experiment you melted and solidified pure naphthalene and melted and solidified a mixture of naphthalene and acetanilide.
6.8 What did it look like?

6.9 Can you describe what was happening at the molecular level?

6.10 Does the representation of solids, liquids and gases as round balls help you to understand the changes of state?

6.11 Is there any other image, model, representation etc that you use to help you to understand the changes of state?

6.12 Has the representation of solids, liquids and gases as round balls supported what you already know?

6.13 Has it added to your understanding?

6.14 Does the image 'makes sense' to you – based on your previous understandings?

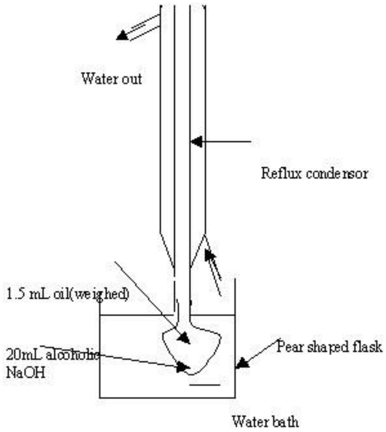
6.15 Has the representation of solids, liquids and gases as round ball highlighted some erroneous ideas?

Interview Questions – Diagrams and Explanations Week 6-12

Week 6 – Oil Identification

The aim of this experiment was to determine the amount of fatty acids (carboxylic acids) produced by the hydrolysis of the oil (triglyceride ester).

Q1 shows a sketch of the reflux apparatus used in the experiment to determine the saponification value.



Sketch of the reflux equipment

1. *In what ways is the sketch useful to you?*

This experiment was performed 'with oil' and 'without oil'. The 'without oil' is referred to as a blank titration; Q2 describes a blank titration.

2 What do you understand about a blank titration?

Question 3 states that fats and oils are triglyceride esters, which contain carboxylic acid parts.

3. *How did you determine the correct answer?*
4. *What do these structural formulas mean to you?*

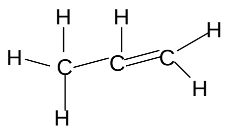
Question 7 and 8 describe some quantitative results from which you have to calculate some values. This type of calculation is similar to that which you have to do in the experiment.

5. *Does the calculation help you understand what you have to do in the experiment?*
6. *Does the calculation help you understand what you are measuring in the experiment?*
7. *Does the calculation help you understand what you is occurring at the molecular level?*

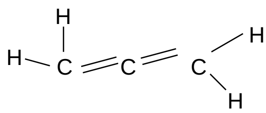
Week 7 – Oil Identification

The aim of the experiment was to measure the Iodine value that is the degree of unsaturation of a substance.

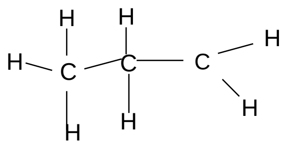
Question 1 shows the structural formula of some compounds.



A



B



C

8. Does this question help you to understand what saturation means?

Question 7 describes what happens in the experiment. Some of the ICl reacts with the unsaturated oil.

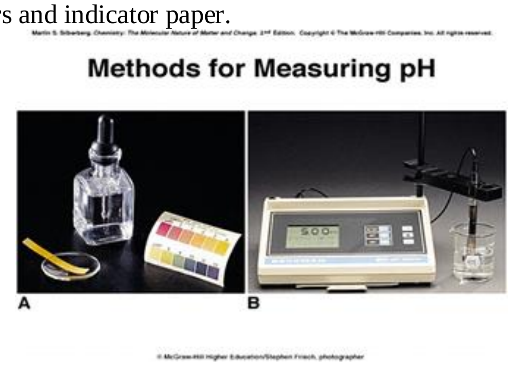
9. Can you describe what happens at a molecular level in this reaction?

Question 7 describes how the remaining unreacted ICl is measured. Again a blank titration is needed.

10. Can you explain why?

Week 8 – Titration curves

Q1 shows pH meters and indicator paper.



Tools for measuring Ph as shown in Q1

11. Were the pictures useful in understanding the experimental method?

In Q5 the diagram shows the difference between strong and weak acids.

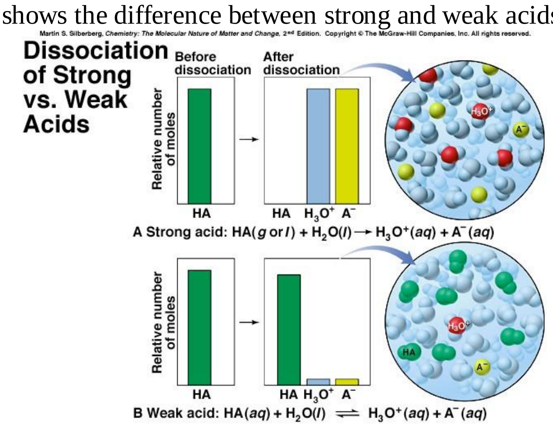
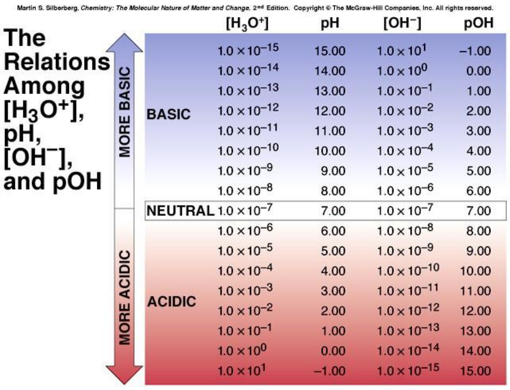


Diagram from Q5 **-** strong and weak acids

12. How does the diagram help you understand:

a) The difference between strong and weak acids?

b) Changes that are occurring to the chemicals at the molecular level?



	$[H_3O^+]$	pH	$[OH^-]$	pOH
BASIC	1.0×10^{-15}	15.00	1.0×10^{1}	−1.00
	1.0×10^{-14}	14.00	1.0×10^{0}	0.00
	1.0×10^{-13}	13.00	1.0×10^{-1}	1.00
	1.0×10^{-12}	12.00	1.0×10^{-2}	2.00
	1.0×10^{-11}	11.00	1.0×10^{-3}	3.00
	1.0×10^{-10}	10.00	1.0×10^{-4}	4.00
	1.0×10^{-9}	9.00	1.0×10^{-5}	5.00
	1.0×10^{-8}	8.00	1.0×10^{-6}	6.00
NEUTRAL	1.0×10^{-7}	7.00	1.0×10^{-7}	7.00
ACIDIC	1.0×10^{-6}	6.00	1.0×10^{-8}	8.00
	1.0×10^{-5}	5.00	1.0×10^{-9}	9.00
	1.0×10^{-4}	4.00	1.0×10^{-10}	10.00
	1.0×10^{-3}	3.00	1.0×10^{-11}	11.00
	1.0×10^{-2}	2.00	1.0×10^{-12}	12.00
	1.0×10^{-1}	1.00	1.0×10^{-13}	13.00
	1.0×10^{0}	0.00	1.0×10^{-14}	14.00
	1.0×10^{1}	−1.00	1.0×10^{-15}	15.00

Diagram for question 8

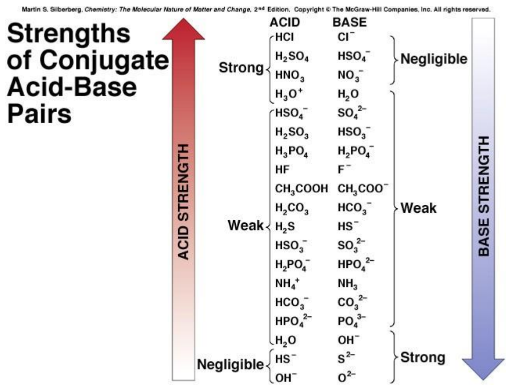


Diagram for Question 9

Diagram from Q8 – the relationship between hydronium concentration and pH.

13. How does the diagram in Q8 help you understand:-

a) The difference between $[H^+]$ and $[OH^-]$ and pH and pOH?

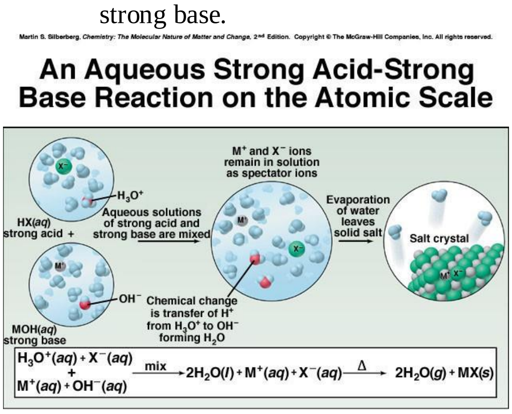
b) Changes that are occurring to the chemicals at the molecular level?

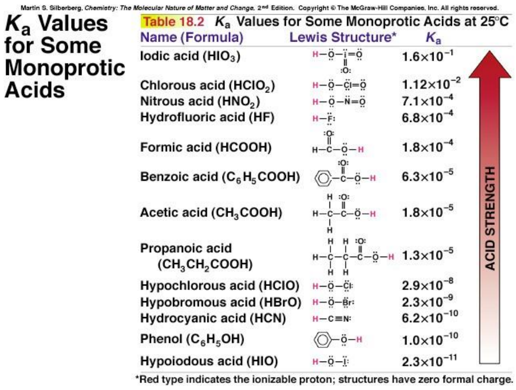
14. How does the diagram in Q9 help you understand:

a) The link between strong and weak acids and strong and weak bases?

b) Changes that are occurring to the chemicals at the molecular level.

In the pre-laboratory exercises for week 8, Q10 shows a reaction between a strong acid and a strong base.





Name (Formula)	K_a
Iodic acid (HIO_3)	1.6×10^{-1}
Chlorous acid ($HClO_2$)	1.12×10^{-2}
Nitrous acid (HNO_2)	7.1×10^{-4}
Hydrofluoric acid (HF)	6.8×10^{-4}
Formic acid (HCOOH)	1.8×10^{-4}
Benzoic acid (C_6H_5COOH)	6.3×10^{-5}
Acetic acid (CH_3COOH)	1.8×10^{-5}
Propanoic acid (CH_3CH_2COOH)	1.3×10^{-5}
Hypochlorous acid (HClO)	2.9×10^{-8}
Hypobromous acid (HBrO)	2.3×10^{-9}
Hydrocyanic acid (HCN)	6.2×10^{-10}
Phenol (C_6H_5OH)	1.0×10^{-10}
Hypoiodous acid (HIO)	2.3×10^{-11}

*Red type indicates the ionizable proton; structures have zero formal charge.

Diagram for Q10

Diagram for Q11

15. Does this reaction pictured in Q10 reach equilibrium? Why? or Why not?

In the pre-laboratory exercises for week 8, the diagram in Q11 shows the Ka value for some acids

16. Are these acids strong or weak? How do you know?

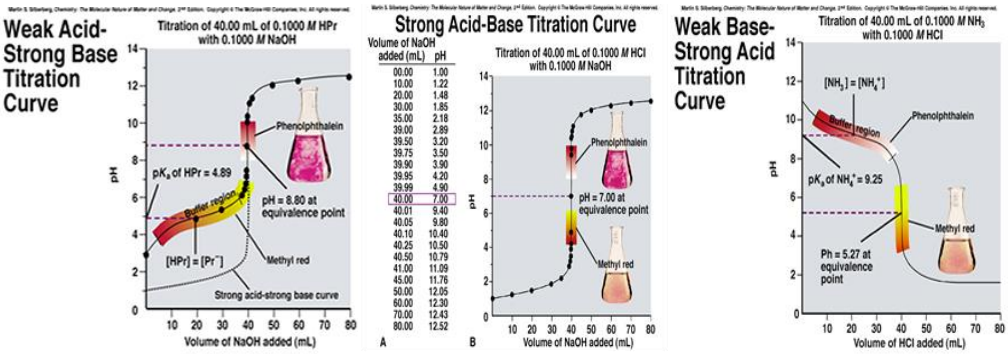
Considering that the equilibrium constant is K = $\dfrac{[H+][Ac-]}{[HAc]}$

17. Is it reasonable to expect the K value to increase, as the acid gets stronger explain?

Look at the extra questions –

In the lab you drew three titration curves.

18. Comment on the titration diagrams 1,2 & 3



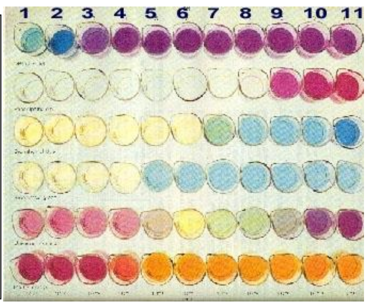
a) What does the equivalence point mean to you?

b) Why are particular indicators appropriate for particular situations?

c) Can you relate the graphs, equilibrium constant and the equations to the titrations you performed in the lab? Explain.

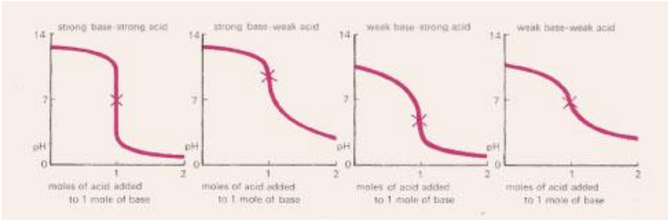
Week 9 – Indicators, Salts & Buffers

methyl violet
phenolthphthalein
bromothymol blue
bromcresol green
universal
methyl orange.



Indicator chart - shown in Q1

20. How does the diagram in Q1 help you understand the difference between indicators?



Titration curves presented in Q6

Look at the diagrams presented in Q6 of the pre-laboratory exercises for week 9.

20. How does the diagram help you understand:

a) The experimental method?

b) The difference between strong and weak acids?

c) Changes that are occurring to the chemicals at the molecular level?

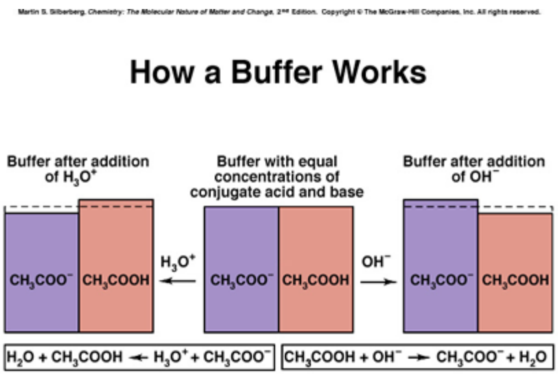


Diagram from Q8 concerning buffers

Look at Q8 &9 of the pre-laboratory exercises for week 9
How does the diagram help you understand:

a) The concept of a buffer?

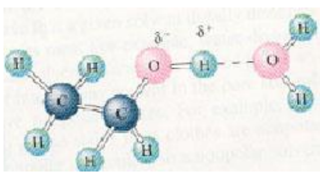
b) Changes that are occurring to the chemicals at the molecular level?

c) What do you understand by the term buffer?

Week 10 – Chem 118 Alcohols and Phenols

Refer to Q3:

In this experiment you looked at the solubility of various alcohols.*:*



copied from Zumdahl 2000 p447

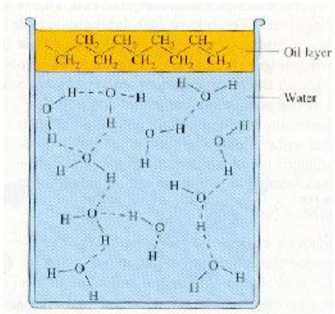
A chemical representation of the structure of an alcohol from Q3

22. How does the diagram help you understand

a) The experimental method?

b) Changes that are occurring to the alcohols at the molecular level when they dissolve?

Look at the diagram used in Q5 of the pre-laboratory exercise for Week 10. It shows differences between non-polar and polar solutions.



Oil and water (copied from Zumdahl 2000 p448)

23. What are the differences?

24. Does the diagram explain the reason for the differences?

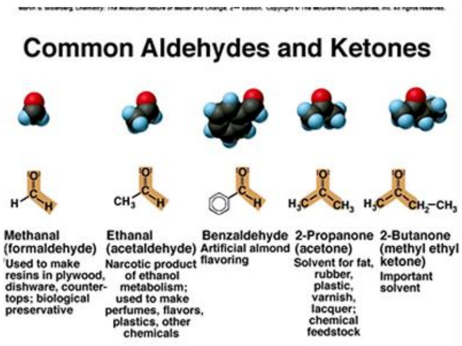
Q7 of the pre-laboratory exercise for Week 10 shows phenol and methanol as examples of aliphatic and aromatic alcohols respectively.

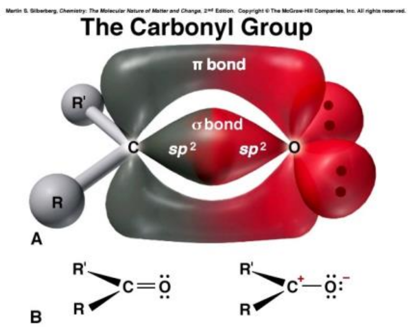
25 Can you explain the difference between an aromatic and an aliphatic alcohol?

Week 12 – Chemistry 118 Aldehydes and Ketones

Look at Q2 with the diagram of the common aldehydes and ketones.

26. How do the multiple representations help you understand the structure?





Q2 - Common Aldehydes and Ketones   Q3 Week 12 - the carbonyl group

27. Is it valuable to be given the common uses? Why?

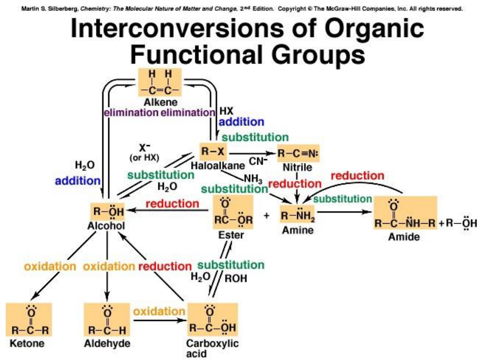
Q3 of Week 12 pre-laboratory exercises show the carbonyl group.

28. *What does this diagram show?*

29. *Is it useful in explaining the chemistry of the carbonyl group? Why?*

Week 13 – Chemistry 118, Carboxylic Acids and Derivatives.

In the pre-laboratory exercises for week 13, Q5 shows a type of concept map for organic reactions.



30. What does this diagram tell you? Do you find it of value?

31. *Are there any aspects of the structure of the carboxylic acid that you can relate to the laboratory work on carboxylic acids?*

Week 10 – Chemistry 128

In the pre-laboratory exercises for week 10, Q2 presents a reaction mechanism.

(1) $Cl^{\cdot} + CH_4$ --------> $HCl + CH_3^{\cdot}$

(2) Cl_2 ---- heat/uv----> $2Cl^{\cdot}$

(3) $CH_3^{\cdot} + Cl_2$--------> $CH_3Cl + Cl^{\cdot}$

This emphasises the fact that a reaction – symbolised by one equation is in fact made up of a number of steps that chemists ‘think’ happen to make up the reaction.

32. *Does the reaction mechanism help you understand how the reaction takes place? Explain.*

Appendix P

Practical Test and Results for Study 1

MOLECULAR MODELS

Alkanes

Methane (CH_4)

Use the molecular models provided to construct a model for the molecule of methane. Carefully observe the molecule. Does it look the same from all sides? (1)

Draw a structural formula for methane. (1)

Ethane(C_2H_6)

Remove one hydrogen atom from your model of the methane molecule and replace it with another CH3 group. This group should be identical to the one you hold. Try to rotate the ends of the molecule about the C-C bond. Record your observations. (1)

Draw a structural formula for ethane. (1)

Dichloroethane ($C_2H_4Cl_2$)

Remove two hydrogen atoms from your model of the ethane molecule and replace them with two chlorine atoms.

Construct another model of a dichlorethane molecule different from the one you have already made. These two models are structural isomers. They have the same molecular formula but different structural formulas, that is, the order of the attachment of the atoms is different.

Draw structural formulas for the two isomers of dichloroethane and name them. (2)

Hexane (C_6H_{14}) and Cyclohexane (C_6H_{12})

Construct a model of straight chain hexane. Write the structural formula for straight chain hexane (1)

Write the structural formulas of the four additional isomers with formula C_6H_{14}. Two of these isomers have five-carbon chains and two have four carbon chains. (4)

Rearrange the model of the straight chain hexane so that it becomes the model of cyclohexane. Draw the structural formula for cyclohexane. (1)

Alkenes

Ethene (C_2H_4)

Construct a model for ethene. Draw a structural formula for ethene. (1)

Try to rotate the two ends of the molecule. What prevents rotation about the carbon-carbon- double bond? (1)

Dichlorethene ($C_2H_2Cl_2$)

Remove two hydrogen atoms from your model of the ethene molecule and replace them with chlorine atoms. Make two more models of isomers of $C_2H_2Cl_2$. Draw structural formulas of all three isomers and name them appropriately. (3)

Hexene (C_6H_{12}) and Cyclohexene (C_6H_{10})

Draw diagrams of the three straight chain isomers of hexene. What are there names? (3)

Construct a model of one of the isomers of hexene. Convert this to a model of cyclohexane in the same way in which you constructed a model of cyclohexane. Draw a structural formula for cyclohexane. (1)

Alkynes

Ethyne

Construct a model of an ethyne molecule. Draw the structural formula for ethyne. (1)

Study One

Test Results Practical Test and Theory Test for Organic Topic N=37

Name/ID	Practical Test			Theory Test		
Class A	Raw	Score %	Letter	Raw	Score %	Letter
1	20	90.91	A	31	88.57	A
2	21	95.45	A	23	65.71	B
3	19.5	88.64	A	12	34.29	E
4	20	90.91	A	29	82.86	A
5	21	95.45	A	26.5	75.71	A
6	14.5	65.91	B	10	28.57	E
7	21	95.45	A	23.5	67.14	B
8	20.5	93.18	A	28	80.00	A
9	21	95.45	A	20	57.14	C
10	21	95.45	A	21	60	C
11	19.5	88.64	A	?	?	C
12	20	90.91	A	21	60	C
13	16.5	75	A	25	71.43	B
14	16	72.73	B	19.5	55.71	C
15	18.5	84.09	A	19	54.29	C
16	17	77.27	A	24.5	70	B
17	20	90.91	A	26.5	75.71	A
Class B						
18	17.5	79.55	A	27	77.14	A
19	16	72.73	B	18	51.43	C
20	21	95.45	A	28.5	81.43	A
21	21	95.45	A	33	94.29	A
22	21	95.45	A	27	77.14	A
23	22	100	A	29	82.86	A
24	18	81.82	A	12	34.29	E
25	16.5	75	B	25	71.43	B
26	21	95.45	A	31	88.57	A
27	19	86.36	A	20.5	58.57	C
28	20.5	93.18	A	14	40	D
29	18	81.82	A	17	48.57	D
30	19	86.36	A	25	71.43	B
31	20	90.91	A	24.5	70	B
32	19	86.36	A	18.5	52.86	C
33	17.5	79.55	A	15	42.86	D
34	21	95.45	A	32	91.43	A
35	21	95.43	A	28	80	A
36	19	86.36	A	28.5	81.43	A
37	20	90.91	A	25.5	72.86	B

Appendix Q

Laboratory Notes for Equilibrium Experiment

DETERMINATION OF EQUILIBRIUM CONSTANT

EQUILIBRIUM CONSTANT FOR THE IODINE/TRI-IODIDE SYSTEM

INTRODUCTION

The reversible reaction,

$$I_2(aq) + I^-(aq) \rightleftharpoons I_3^-(aq)$$

occurs in aqueous solution and the equilibrium constant, K_c, is given by:

$$K_c = \frac{[I_3^-]}{[I^-][I_2]}$$

The equilibrium may be investigated by studying the distribution of iodine between an organic solvent and an aqueous iodide solution.

Since the distribution law only applies to the species common to both layers the concentration of free iodine in the aqueous iodide layer, $[I_2]aq$, can be determined from the relationship:

$$[I_2]aq = \frac{[I_2]org}{K_D}$$

where K_D is the distribution coefficient for iodine between the organic solvent and water and has a value of 38.

The iodine combined with I^- to form I_3^- may also be determined since the total iodine in the aqueous iodide layer may be obtained by titration.

The amount of iodide that has combined with iodine can then be found and if the original concentration of iodide is known the equilibrium concentration of iodide may be obtained by difference. Hence K_c may be calculated for the temperature at which the experiment was carried out.

PROCEDURE (Students to work in pairs)

Fill a screw-top bottle to the 200 mL mark with 0.100 M potassium iodide solution. Add 30 mL of a solution of iodine in light petroleum and shake for about 15 minutes.

Fill a second screw-top bottle to the 200 mL mark with 0.100 M potassium iodide solution. Add 20 mL of a solution of iodine in light petroleum, 10 mL of light petroleum, and shake for about 15 minutes.

Record the temperature of the solutions after shaking.

Name: ______________________________

Name of Partner: ______________________________

For each bottle:

1. Pipette 50 mL of the aqueous layer into a conical flask and titrate with 0.02 M sodium thiosulfate solution (see page 71).

2. Pipette 5 mL of the organic layer into a conical flask containing about 20 mL of water, 0.5 g solid KI and 2 drops of 3 M sulfuric acid. Titrate with 0.002 M sodium thiosulfate solution.

Reshake the bottles and when equilibrium has been re-established analyse the two layers again as above.

RESULTS

Record the temperature of the solutions

AQUEOUS LAYER

50 mL aliquots titrated with 0.02 M $Na_2S_2O_3$.

Burette Readings (mL)	30 mL Sample Bottle		20 mL Sample Bottle	
Final				
Initial				
Titre				

ORGANIC LAYER

5 mL aliquots titrated with 0.002 M $Na_2S_2O_3$.

Burette Readings (mL)	30 mL Sample Bottle		20 mL Sample Bottle	
Final				
Initial				
Titre				

CALCULATIONS

1. Determine the $[I_2]$org from the titre figure for the light petroleum layer. Express the value in moles per litre.

2. Use the value of K_D to evaluate $[I_2]$aq.

3. Determine the $[I_2]$aq + $[I_3^-]$aq from the titre figures for the aqueous layer. Express the value in moles per litre.

4. Subtract the $[I_2]$aq from the above value to determine $[I_3^-]$.

5. Determine the equilibrium concentration of I^- by subtracting that which has reacted to become I_3^- (= $[I_3^-]$) from the initial concentration of I^-.

6. Substitute the values thus obtained in the equilibrium constant expression and evaluate K_c.

	1	2	3	4	5	6
I_2 Sample	$[I_2]$org	$[I_2]$aq	$([I_2]aq + [I_3^-])$	$[I_3^-]$	$[I^-]eq = ([I^-]init - [I_3^-])$	$K_c = \frac{[I_3^-]}{[I^-]eq[I_2]}$
30 mL						
20 mL						

Average K_c = ________________ at ________ °C

MARK	

Appendix R

Typical Test for Topic 38 - Alcohols

Curtin University of Technology

SCHOOL OF APPLIED CHEMISTRY

P.S.I. CHEMISTRY

NIT 38 THIS IS A TYPICAL TEST ON THIS UNIT

1. Which one of these compounds is a tertiary alcohol?

(a) cyclohexanol
(b) 2-methylcyclohexanol
(c) 3-methylbutan-1-ol
(d) 3-methylbutan-2-ol
(e) 1-methylcyclohexanol

2. Which one of the following compounds does not exhibit hydrogen bonding?

(a) $CH_3CH_2CH_2OH$
(b) CH_3CH_2COOH
(c) $CH_3CH_2OCH_2CH_3$
(d) PhOH
(e) $CH_3OCH_2CH_2OH$

3. Which reagent can be used to convert methanol to bromomethane?

(a) bromine
(b) conc. hydrobromic acid
(c) phosphorus oxy bromide, $POBr_3$
(d) potassium bromate
(e) sodium bromide

4. The most suitable laboratory reagent to convert 2-butanol to 2-butene is

(a) hydrogen chloride
(b) bromine
(c) potassium dichromate
(d) hot conc. sulfuric acid
(e) sodium metal

5. A compound with the formula $C_4H_{10}O$ evolves hydrogen gas with sodium, but does not react with acidified potassium dichromate. The compound could be

(a) $CH_3CH_2CH(OH)CH_3$
(b) $CH_3OCH_2CH_2CH_3$
(c) $CH_3CH_2CH_2CH_2OH$
(d) $(CH_3)_3COH$
(e) $(CH_3)_2CHCH_2OH$

6. Which of these compounds will give hydrogen chloride gas on treatment with acetyl chloride?

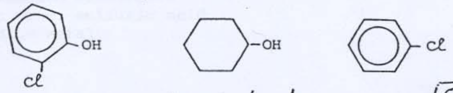
(i) $CH_3CH_2CH_2OH$
(ii) $(CH_3)_2CHOH$
(iii) CH_3CH_2CHO
(iv) $CH_3C(=O)CH_3$

(a) (i) and (ii) only
(b) (i), (ii) and (iii) only
(c) (iii) and (iv) only
(d) (i), (ii) and (iv) only
(e) all four

7. An ester would NOT be formed by reaction between

(a) an alcohol and a carboxylic acid (with H^+ catalyst)
(b) an alcohol and an aldehyde
(c) phenoxide ion and an acid chloride
(d) an alcohol and an acid chloride
(e) an alcohol and an anhydride

8. Describe TWO simple chemical tests to distinguish between the following compounds. Give both reaction equations.



1) dil. NaOH — phenol dissolves → (Cl-phenoxide, O^-Na^+)
(or $FeCl_3$ test)

(3 marks)

2) Na metal, alcohol reacts → phenyl-O^-Na^+ + $\frac{1}{2}H_2(g)$ ../3

Appendix S

Presentations and Publications

Publications

Treagust, D. F., Chittleborough, G. D., & Mamiala, L. T. (in press). Students' understanding of the descriptive and predictive nature of teaching models in organic chemistry. *Research in Science Education*.

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2003). The role of sub-microscopic and symbolic representations in chemical explanations. *International Journal of Science Education*, *25*(11), 1353-1369.

Chittleborough, G. D., Treagust, D. F., & Mocerino, M. (2002). Constraints to the development of first year university chemistry students' mental models of chemical phenomena. In A. Bunker & G. Swan (Eds.), *Focusing on the student* (pp. 43-50). Perth, WA: Professional Development@Learning Development Services.

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2002). Students' understanding of the role of scientific models in learning science. *International Journal of Science Education*, *24*, 357-368.

Treagust, D. F., & Chittleborough, G. (2001). Chemistry: A matter of understanding representations. In J. Brophy (Ed.), *Subject-specific instructional methods and activities* (Vol. 8, pp. 239-267). Oxford: Elsevier Science Ltd.

Presentations

Chittleborough, G., Treagust, D. F., & Mocerino, M. (February, 2004). *Capitilising on university students' metacognitive qualities.* Paper presented at the Teaching and Learning Forum, Murdoch University, Perth, Western Australia.

Chittleborough, G., Treagust, D. F., & Mocerino, M. (December, 2003). *Understanding the Sub-Microscopic Level in Chemistry.* Paper presented at the Western Australian Science Education Association, Curtin University, Perth, Western Australia.

Chittleborough, G. (August, 2003). *The use of physical and mental representations in learning chemistry*. Paper presented at the annual forum for the Western

Australian Institute for Educational Research, Edith Cowan University, Perth, Western Australia.

Chittleborough, G., Treagust, D. F., & Mocerino, M. (February, 2003). *Providing immediate feedback: A responsible approach to learning.* Paper presented at the Teaching and Learning Forum, Edith Cowan University, Perth, Western Australia.

Chittleborough, G., Treagust, D. F., & Mocerino, M. (December, 2002). *Factors influencing the development of first year university chemistry students' mental models of chemical phenomena.* Paper presented at the Western Australian Science Education Association Conference, Perth, Western Australia.

Chittleborough, G., Mocerino, M., & Treagust, D. F. (August, 2002). *An evaluation of the introduction of online resources in a first-year chemistry course.* Paper presented at the annual forum for the Western Australian Institute for Educational Research, Edith Cowan University, Perth, Western Australia.

Chittleborough, G. D., Treagust, D. F., & Mocerino, M. (April 7- 10, 2002). *Constraints to the development of first year university chemistry students' mental models of chemical phenomena.* Paper presented at the National Association for Research in Science Teaching, New Orleans, LA.

Treagust, D. F., Chittleborough, G. D., & Mamiala, L. T. (7-10 April, 2002). *The role of macroscopic, symbolic and sub-microscopic representations in chemical explanations.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (1-5 April, 2002). *The function of macroscopic, symbolic and sub-microscopic representations in explaining concepts in high school chemistry.* Paper presented at the American Educational Research Association, New Orleans, LA.

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (August, 2001). *Students' concept of models: An epistemological and ontological perspective.* Paper presented at the Western Australian Institute for Educational Research 16th Annual Research Forum, Edith Cowan University, Perth, Western Australia.

Treagust, D. F., Chittleborough, G. D., & Mamaila, T. L. (April, 2001). Learning introductory organic chemistry: Secondary students' understanding of the role of models and the development of scientific ideas. Paper presented at the American Education Research Conference (AERA), Seattle, Washington.

Treagust, D., Chittleborough, G. D., & Mamiala, L. T. (2001, March 2001). *The role of models and the development of scientific ideas in learning organic chemistry.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, St Louis, Illinois, USA.

Chittleborough, G., Treagust, D. F., & Mamiala, T. L. (August, 2000). *Contradictions in secondary students' understanding of scientific models.* Paper presented at the annual forum for the Western Australian Institute for Educational Research, Edith Cowan University, Perth, Western Australia

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Appendix T

So you want to pass this unit

This appendix contains copies of the information in the section of the website called "So you want to pass this unit". There are eight separate web pages radiating out from the homepage for this section. Details from each page are provided - they include:

- Comments From Students 2002
- Time Management
- What You Have To Do
- Using WebCT
- How Do I Learn Best?
- Learning Strategies
- Interpreting Diagrams
- Chemical Representations

Comments From Students 2002

Keep up the good work for WebCT but make more room for extra feedback in the lab practical sections for more in depth understanding of the experiments and development of critical analysis. It is important for the university that it helps to make students understand the concepts of the lab rather just give practicals without enough information. This way, we can understand what exactly we are doing in the lab and know what our numbers mean, how we get them, and the logic thinking in getting them.

I think that the PSI testing should have a due date for each topic as motivation to keep ahead

I don’t really like chemistry and not being able to understand the topic fully has made it more difficult. Even though i read books and other material i still couldn't understand the topic. i don’t believe this course IS designed for those who have never done chem, bcoz i had trouble with it. The pace and deep should of been more thorough

The psi system is useful because you have to know what you are talking about to pass! the chemistry syllabus is good and has improved my chemistry learning but the psi test and pre-labs are stressful (psi tests especially) as so much extra time is needed to study for and complete them, and they are within time limits which puts pressure on students. maybe there could be less psi topics??

Because of the structure of Chem 118, I have understood and enjoyed chemistry more. Being able to set my own pace with only my own pressure has meant learning it more thoroughly and more effectively. I have felt more satisfied with myself. I feel this way of learning helps you to retain what you have learnt rather than just cram and forget - This is especially true as a pre-requisite subject. Although there will only be biochemistry in my course after this year, 117 and 118 has laid a good foundation.

Some postings from the discussion page from the Chemistry 117 website 2002

I was wondering if i fail Chemistry 117 would it result in failure of my course. If I fail chem 117 Do i have to repeat the unit if i am dropping chemistry next semester!

I am just a bit worried as i have 4 compulsory topics left to do in the next week and i am afraid i may not finish or pass them all! Thanks

I am concerned that I am not going to get my PSI tests completed in time. I am aware that this is my own fault, thru poor time management throughout the semester but i really want to do well,

Time Management

Many students find themselves at the end of the semester with too many psi tests to do!!! Check out the comments from past students.

The tutors cannot help you if there are hundreds of students trying to complete the tests in the last week! The Library has some hints on how to improve your time management. - Go To *Study Trek*. Now is the time to think about this!!

What You Have To Do

- Complete the Pre-laboratory exercises (using web-CT) before each lab session.
- Submit a lab report for each lab to your Demonstrator.
- Complete the PSI test for each topic (Building 303 Level 2) - best to get one done every week so you don't get behind.
- The first three PSI tests must be completed by Week 6.
- If you have completed the PSI tests for all the topics- compulsory and optional, you can take the optional review exam. It is taken in the PSI lab - like a normal psi test and can be taken at any time. When you log in for the exam you write Topic 118, (or Topic 128, Topic 012 or Topic 028) - this is the test for the whole unit with questions from all the topics.
- The pre-lab exercises provide flexibility - they can be done at uni or at home using the Curtin website.
- Each weekly pre-lab exercise is only available for two weeks- the week before the lab and the week of the lab- so you have to access the site in that period in order to complete the exercises.
- PSI tests are based on the lecture material and the yellow course notes. For each topic you must pass the PSI topic test. The pass mark for each PSI test is 80%.
- The PSI tests must be taken in the PSI testing room - Building 303 Level 2.
- It is recommended that you book in for the test in advance.
- If you have completed the PSI tests for all the topics- compulsory and optional you can take the optional review exam during exam week.
- Ask for help - use e-mail and discussion page to contact other students and staff.

Using WebCT

WebCT is a platform that allows you easy access to resources at any time – providing greater flexibility. Web-CT facilities include e-mail, discussion, test solutions, unit information and relevant internet sites. These facilities are useful :

- you can ask a question - via e-mail or the discussion page - you may find that others have the same problem!

- you can check your answers to the typical topic test so that you are well prepared to attempt the PSI test.
- check your grades - for the prelab exercises and the lab reports.

If you are finding the page difficult to manage there are some adjustments you can make to your computer screen:

use a full screen

hide the navigation bar- on LHS of web-CT page

use a smaller font - select view, then text size - (or use control + scroll button)

hide the title bar by pressing on F11 and Press F11 for it to reappear.

The pre-lab exercises which can only be accessed through WebCT, are designed to:

- provide basic information for students with little or no chemical background.
- provide students with some immediate feedback on their understanding,
- use diagrammatic and illustrative resources to enhance explanations.
- better prepare students for labs.
- to improve links between theory and practical work
- give you the opportunity to repeat and improve
- provide you with a way of 'working it out for yourself''(q 23, ID 37).

How Do I Learn Best?

Do any of these learning objectives apply to you?

- To learn how to learn
- To learn how to think
- To conceptualise new ideas
- To become an independent learner
- To have a self-awareness of my learning
- To understand the way I learn

- To improve my self efficacy (self confidence)

What sort of learner are you?

- Are you a PASSIVE learner? or an ACTIVE learner ?
- Do you have a DEEP understanding ...or a SHALLOW understanding...
- Are you an INTENTIONAL learner? or an ACCIDENTAL learner?
- Do you ROTE learn? Do you have a CONCEPTUAL understanding of a topic?
- Do you have any MISCONCEPTIONS? or ALTERNATIVE CONCEPTIONS that are affecting the way you learn.....

Most people fit into all of these types at different times and for different topics or requirements.

If you are interested in finding out your learning preferences go to this site: Motivated Strategies for learning questionnaire

Learning Strategies

Many things can influence your learning of chemistry including:

- ·good explanations- easy to follow
- · using a variety of diagrams/models to represent the chemicals,
- · your background knowledge in chemistry
- · your background knowledge in mathematics
- · your motivation for learning chemistry? perserverance; discipline;
- · a desire to learn chemistry or a need to pass the exam in order to meet course requirements
- · the pace of the course; the content of the course; the assessment of the course
- · links between the practical work and the theoretical work
- · the assessment format can direct your learning - you do what you have to, to pass.

It helps to be aware what affects your learning - then you can choose learning strategies most suitable for you! Many students try to do it all alone - learning in isolation - but often it is better to work with other students. People learn from each other - so it is a good idea to make contacts with other students. Maybe set up a study group or communicate through e-mail (WebCT). You have ability to control some of these influences.

Effective Learning Strategies

Consider which of these learning strategies you find most effective:

- underlining;

- highlighting;
- copying out notes;
- memorising,
- reading
- working out problems
- practising problems;
- using solutions to understand the problems,
- working with friends; asking friends for help; asking tutors/demonstrators for help,
- looking up other texts; using the course notes; using the web-site,
- drawing concept maps; drawing diagrams.

Direct your energies to the most effective learning strategies for you.

Interpreting Diagrams

Research has shown that sometimes people **"read"** diagrams quickly - not always anticipating correctly what the diagram means.

Hints for making the most of diagrams

Take time to read carefully all the writing on the diagram.

Take time to inspect the diagram carefully - Assume there is more to the diagram.

If the diagram has symbols - make sure you understand what the symbols represent.

Inspect the direction of lines, the direction of arrows.

Look for the trends in tables and graphs. Suggest a reason why these trends are occurring.

If the diagram has a direction - identify the various stages and start at the beginning and follow each stage through.

Questions to ask yourself about diagrams

- What does the diagram represent?
- Is the diagram representing a fact? or an idea, or a theory?
- What level is the diagram representing?
- -Is it like the real apparatus - macroscopic?

- Is it representing the sub-microscopic level of atoms, molecules and ions?
- Is it a symbolic representation?
- How accurate is the diagram? - Is the diagram an exact replica or scale model? Is it imprecise or impressionistic? Is it precise?
- What is the purpose of the diagram?

Chemical Representations

Chemistry deals with abstract ideas and concepts. Chemists use a variety of representations to illustrate and picture what is happening in chemistry. There are three main levels of chemical representations:

- Macroscopic
- Sub-microscopic
- Symbolic

Macroscopic what you actually observe

e.g. a reaction, a smell, a sensation, a colour, a texture etc

For example, consider copper, we know it's colour, state, uses **-** all this information about its macroscopic properties, but this data does not tell us anything about its microscopic nature.

Sub-microscopic - using the particulate theory of matter to describe the position and movement of the atomic and sub-atomic particles in the chemical.

The evidence for this level of representation comes from interpretation of experimental results.

More frequently ball type structures are used to represent atoms at the sub-microscopic level.

How we visualise this level is our mental model of the chemical at the sub-microscopic level.

To visualise this level we use a variety of symbols, and this is the third level of chemical representations.

Symbolic – a large variety of pictorial representations, algebraic, physical and computational forms.

It is proposed that by distinguishing each level and using all 3 levels when considering chemical concepts provides a more holistic and integrated understanding of the concept.