CHAPTER 1

THE PROBLEM AND ITS SETTINGS

1.0 Introduction

Chemistry is often regarded as a difficult subject (Chang, 2010, Chittleborough, 2004; Gabel, 1999; Treagust, Duit & Nieswandt, 2000). Many research studies have revealed major learning difficulties and identified key causes of these difficulties (Chittleborough & Treagust, 2007; Gabel, 1998, 2000; Johnstone, 1991; Nakhleh, 1992; Reid, 2008; Sirhan, 2007). One of the main reasons for this difficulty is the nature of chemistry itself. Johnstone (1982, 1991, 1997, 2000a, 2000b, 2006) pointed out that in chemistry, students learn in three different representations simultaneously and how to inter-relate each new concept or fact in all three domains: macroscopic, submicroscopic, and symbolic. It is this aspect of chemistry learning that represents a challenge to many chemistry learners, in particular novices. This study seeks to investigate an area related to the three levels of thinking in chemistry. That is: Form four students' representational competence of basic chemical concepts. The study focuses on four aspects. These are: (i) understanding of basic chemical concepts, (ii) understanding of chemical representations, (iii) representational competence in chemistry, and (iv) factors influencing representational competence.

1.1 Education in Malaysia

The following sub-sections provide an outline of the Malaysian education system, chemical education in Malaysian schools, the Malaysian chemistry curriculum, as well as the Malaysian chemistry classroom.

1.1.1 The Malaysian education system

At present, the Malaysian Education System comprises six years of primary education (Standards one to six), five years of secondary education consisting of three years of lower secondary (Forms one to three) and two years of upper secondary (Form four to five), and another two years of pre-university education (Lower and Upper Form Sixth), to be followed by a three or four year college or university undergraduate program (*Appendix 1*).

1.1.2 Chemical education in Malaysian schools

The Integrated Secondary School Curriculum is divided into two parts, namely the lower secondary of three years, and the upper secondary of two years. At the lower secondary level, chemistry is taught as part of Integrated Science which deals mainly with the basic understanding of scientific principles in relation to life processes and the human environment. For the upper secondary level, chemistry is either taught as part of General Science for non-science students, or as a subject, Chemistry, for science students. For General Science, the curriculum only touches on the basic principles of chemistry. The basic philosophy is to equip the students with enough chemistry to understand the everyday events and phenomena. It is also aimed at making the students more aware of what is happening in the environment. On the other hand, the subject, Chemistry, is offered as an elective subject to science students who may be aiming for a career in science and technology. The chemistry covered is quite extensive. It not only provides the students with enough chemistry background to cope with everyday life, but also gives them enough chemical knowledge to prepare them for further studies in science and technology.

At the pre-university level, Chemistry is taught as a subject in the Higher School Certificate or *Sijil Tinggi Persekolahan Malaysia (STPM)*, the A-Level and other pre-university matriculation programs. The chemical principles covered are extensive. There is enough chemistry to prepare the students for a major in chemistry at the university level, or as a minor as pre-requisite in some other science programs and many other chemistry-related courses.

1.1.3 The Malaysian chemistry curriculum

Malaysia practices a centralized education system whereby the subject curriculum is designed by the Curriculum Development Centre (CDC), with the help of a panel consisting of CDC officers, exemplary teachers, experienced teachers of the subject area, university lecturers and teacher educators from the teachers' training colleges (*Kementerian Pelajaran Malaysia* [Malaysian Ministry of Education], 2001).

The Integrated Curriculum for Secondary Schools (ICSS) Chemistry Form 4 is articulated in two documents: the syllabus and the curriculum specifications.

The Chemistry Syllabus presents the objectives and the outline of the curriculum content for a period of two years. The Chemistry Curriculum Specifications provide the details of the curriculum which includes the aims and objectives of the curriculum, brief descriptions on thinking skills and thinking strategies, scientific skills, scientific attitudes and noble values, teaching and learning strategies, and curriculum content. The curriculum content provides the learning objectives, suggested learning activities, the intended outcomes and vocabulary. The content of the Chemistry Syllabus encompass five central themes. These are: (i) Introducing chemistry, (ii) Matter around us, (iii) Interaction between chemicals, and (iv) Production and management of manufactured chemicals. The content organization of *SPM* Chemistry is summarized in Table 1.1.

Table 1.1
Content organization of *SPM* Chemistry

Themes	Learning areas or topics
i. Introducing chemistry	1. Introduction to chemistry
ii. Matter around us	2. The structure of the atom 3. Chemical formulae and chemical equations 4. Periodic Table of the elements 5. Chemical bonds 10. Rate of reaction 11. Carbon compounds 12. Oxidation and reduction 13. Thermochemistry
iii. Interaction between chemicals	6. Electrochemistry 7. Acids and bases 8. Salts
iv. Production and management of manufactured chemicals	9. Manufactured substances in industry 14. Chemicals for consumers

Note: Topics 10 to 14 are taught in Form five

An analysis of the Chemistry Curriculum Specifications revealed that representations have been the integral component in all topics of study except Topic 1 (see Table 1.1). Further analysis of each of these themes indicated that: (i) basic chemical concepts are all covered in Topics 2, 3, 4 and 5 in Form four (see Table 1.1 and *Appendix 3a*), (ii) students need to be able to represent chemical concepts for the various areas in each topic beginning with Topic 2 in Form four. Representation of chemical concepts requires not only sound understanding of the concepts and the chemical representations involved, but also representational competence. Any difficulty at this early stage of their chemistry course will impede further learning of chemistry. Hence, the urgent need to investigate Form four students' representational competence of basic chemical concepts.

1.1.4 The Malaysian chemistry classroom

Big class size is a normal phenomenon in Malaysia. For National Type Secondary School or *Sekolah Menengah Jenis Kebangsaan (SMJK)*, it can be as many as 46 students in a class. Teachers often have heavy workload - an average of 27 periods per week or five to six periods a day, apart from involvement in other areas of responsibility such as class management, co-curriculum activities and various paper works from time to time. Some chemistry teachers are not chemistry major while some may be teaching chemistry along with other subjects such as science and mathematics. Since the implementation of open certificate for the *SPM* in 2000, Chemistry has been named as an elective subject and only four periods a week are allocated to the subject. It normally occupies two double sessions of 70 minutes each, with a total time of about 140 minutes per week. Apart from a chemistry curriculum which is overloaded with content (Malaysian Ministry Of Education, 2006a), the Malaysian education system is also targeted at passing examinations. Due to the education system which is very much examination-oriented, time constraint and large classes, ways of teaching is mainly direct instruction (teacher-centred, chalk-and-talk, or teaching courseware). Further more, with the introduction of the School-based Assessment for Practical Work or *Pentaksiran Kerja Amali Berasaskan Sekolah (PEKA)* and the abolition of practical examination for pure sciences beginning 1999, practical work is further reduced. A lot of emphasis is given to examinations which are mainly paper-and-pencil tests.

Too much has to be taught about at the same time. Is there any possibility of overloading the working memory of learners? Do they have to resort to memorization of facts in order to pass examinations?

1.2 Background of the Study

Compared with other sciences, chemistry is commonly believed to be more difficult, at least at the introductory level (Chang, 2010). Chemistry educators and teachers, as well as students taking up chemistry probably agree that chemistry is not an easy subject to teach and to learn. This is because chemistry is a complex and multi-dimensional discipline. Understanding chemistry involves a wide variety of dimensions of knowing, and the complexity of interaction between them (Bucat, 2002b). Several dimensions of knowing Chemistry related to this study are: (i) Understanding the language of chemistry, (ii) the ability to alternate between the macro world and related submicroscopic models, (iii) interlinking learning. Chemical representations are elements of the chemistry language (Hoffmann & Laszlo, 1991). This is because chemical representations become the means by which chemists conceptualize unobservable chemical concepts and communicate abstract explanations of the phenomena we experience (Heitzman & Krajcik, 2005). However, the language of chemistry has a very specialized vocabulary. For example, as a symbolic language, atoms of elements are represented by chemical symbols such as C, H, O, and N. These symbols are the alphabets of chemistry. To represent molecules, chemical symbols are combined into chemical formulae, such as H_2, O_2, CO_2, H_2O and NH_3. Formulae are the words of chemistry. When we extend the symbolic language to include sentences, chemical equations are formed (Hill & Petrucci, 2002). Chemical symbols, chemical formulae and chemical equations are examples of representations in chemistry.

Chemistry educators and researchers identified three levels of representations in chemistry: macroscopic, submicroscopic, and symbolic levels (Gabel, 1998; Johnstone, 1982, 1991). At the macroscopic level, chemical phenomenon is observable, such as a burning candle. To explain this phenomenon, chemists develop concepts and models of atoms and molecules. At the particulate or submicroscopic level, a burning candle is thought of as a chemical reaction in which atoms of the wax react with oxygen molecules in the air to produce carbon dioxide molecules. Chemists can represent this process symbolically through the use of chemical symbols, chemical formulae and chemical equation such as: $C(s) + O_2(g) \rightarrow CO_2(g)$

Although chemists can represent sensory experiences by atoms and molecules, and translate them into symbols, formulae and equations (Wu, 2003), this threefold nature of representing matter makes chemistry appears very complex to the novice learners (Johnstone, 1982, 1991). This is because representation of chemical concepts requires the learners not only to understand the chemical concepts and chemical representations involved, but also the ability to translate between representations at the same level and across the three levels of representation. That is: representational competence.

An additional factor to add to the complexity of chemistry is the frequent use of mathematical symbols, formulae and equations to express relationships at the macroscopic and submicroscopic level. For example, the `mole' concept has both a macroscopic and a submicroscopic perspective. Hence, 1 mol (or 12g) of carbon contains 6.02×10^{23} atoms of carbon.

1.3 Statement of the Problem

Representation of chemical concepts has always been a problem area in chemistry. This is because in chemistry, phenomena at the macroscopic level such as chemical reactions can be conceptualized in terms of submicroscopic entities such as atoms and molecules, and translated into symbolic representations such as chemical symbols, formulae and equations (Wu, 2003). It is this multiple levels of representation, or multi-level learning that often makes chemistry a difficult subject, particularly for beginning chemistry students (Johnstone, 1991).

As representations are commonly used in explanations of macroscopic phenomena and as a way of communicating chemical ideas, representational competence becomes a necessary skill in understanding Chemistry (Treagust, Chittleborough & Mamiala, 2003). However, numerous studies have shown that learners at all levels of Chemistry have difficulties in interpreting and using representations of chemical concepts (Ben-Zvi, Eylon & Silberstein, 1986, 1987; Gabel, 1993, 1999, 2000; Harrison & Treagust, 2000; Heitzman & Krajcik, 2005; Kozma & Russell, 1997; Krajcik, 1991; Wu, Krajcik & Soloway, 2001). Some of these difficulties are: (i) using representations to generate explanations, (ii) translating one representation into another and (iii) making connections between representations and concepts or interlinking learning. According to Kozma (2000a), all these difficulties indicate a lack of links among chemical phenomena (macroscopic), representations (symbolic), and relevant concepts (submicroscopic).

Translating chemical representations involves thinking about phenomenon in three different levels of representation – macroscopic, symbolic and submicroscopic, that are directly related to each other (Gabel, 1999; Johnstone, 1982, 1991, 1993, 2000a, 2000b). The ability to move fluidly back and forth among chemical representations at both the macroscopic and submicroscopic levels and to link them in meaningful ways is another dimension which one's understanding of chemistry can be enriched (Bucat, 2002b). However, making translations between representations is an information processing task that requires knowledge and understanding of the underlying concepts (Keig & Rubba, 1993). While chemists can manipulate representations at all three levels effortlessly, novices may find it confusing when their chemistry teachers and textbooks seem to be continually shifting back and forth between the macroscopic and microscopic worlds. This is because many novice learners are unable to create a link between the three levels of thinking simultaneously. This may result in rote learning to acquire fragments of unrelated information. In the absence of linkages, knowledge is compartmentalized in the long term memory. However, introducing all three levels simultaneously overloads their working memory (Johnstone, 1997, 2000a, 2000b, 2006). Johnstone (1997) proposed that students cannot handle more than two levels in their working memory at one time, and the submicroscopic level appears to be neglected.

Several studies showed students' difficulty in navigating through chemical representations may intensify if (i) they are novices at using representations, and (ii) their understanding of chemical concepts are not yet coherent (Heitzmann, Krajcik, & Davis, 2004; Wu, 2002; Wu et al., 2001;). Unlike in some western countries like the U.S.A. where children are introduced to basic chemical concepts such as atoms and molecules as early as in Grade 3 (Halpine, 2004), students in Malaysia only begin to take up chemistry as a subject at Form four (Year 9). Therefore, Form four students in Malaysia are probably facing these two problems. Not only are they novices in using representations in chemistry, they are also just beginning to experience and learn fundamental chemical concepts in a formal instructional setting.

Chemistry is recognized by chemists as the molecular science (Habraken, 1996) or microscopic science (Wu & Shah, 2004). Although the macroscopic observable phenomena form the basis of chemistry, explanations of these macroscopic phenomena rely on the symbolic and submicroscopic levels of representations (Treagust et al., 2003). There is abundant evidence from research literature that students have most difficulties with the submicroscopic or molecular level of representations which deals with invisible particles such as electrons, atoms, molecules and ions (Ben-Zvi et al., 1986; Kozma & Russell, 1997; Krajcik, 1991; Nakhleh, 1992; Nurrenberg & Pickering, 1987; Sawrey, 1990; Sim, 2006). Unlike chemists who are regarded as highly visual people (Zare, 2002), novice learners who cannot think abstractly are unable to visualize these physical entities in the imaginary submicroscopic world. According to Cantu and Herron (1978), many of the micro-level concepts fall into the formal operational categories, making chemistry abstract and difficult to learn. However, research findings showed that less than one-third of Malaysian upper secondary level students were still in the late concrete operational level (Chan, 1988) although according to Piaget's theory of cognitive development (Piaget & Inhelder, 1969) they should have attained formal operational level based on their age. More recent studies on the developmental levels of Malaysian upper secondary school students revealed more disappointing findings. In a study involving 294 Form six science students in Sarawak, Eng (2002) found that only 18.4% of the subjects attained formal operational level, with 23.8% still at the concrete operational level while the remaining 57.8% were at the transitional level. In Nagalingam's study (2004), only 6.8% of the 381 Form four science students were formal operational thinkers.

With the problem identified and the problem statement clearly presented, this study inquires into Form four students' representational competence of basic chemical concepts.

1.4 Rationale of the Study

Chemical representations have been extensively used in the teaching and learning of chemistry, and acknowledged as an essential part in chemical education. Although chemistry educators and teachers acknowledge the important roles played by chemical representations, there is generally a lack of knowledge on students' conceptions of chemical representations. Apart from what can be gathered from students' outputs such as written exercises, laboratory reports, answers from tests and examinations, relatively little is done to explore students' conceptions of chemical representations in Malaysian classrooms. Globally, there have been numerous studies on or related to chemical representations (Chittleborough, 2004; Kozma & Russell, 1997; Treagust et al., 2003; Wu, Krajcik & Soloway, 2001; Wu & Shah, 2004). Most of these studies have been conducted in other countries with very different educational contexts. Findings of these studies cannot be generalized to the local context. Unfortunately, in the local chemical education research literature, there is no documented study in this area. In Malaysian classrooms, chemical representations have also been extensively used in the teaching and learning of chemistry. Surprisingly, the term "chemical representations" is not explicitly mentioned in the Chemistry Syllabus, Curriculum Specifications for Chemistry or Chemistry text books recommended by the Ministry of Education (MOE). As a result, the term "chemical representations" remains relatively new for many people, even those in chemical education. Informal interviews with chemistry teachers conducted by the researcher in July and August 2007 followed by preliminary survey through questionnaire with chemistry teachers (n=40) during a Chemistry Seminar in Perak in October 2007 revealed majority of them were not familiar with the term "chemical representations", neither were they aware of the existence of the three levels of thinking in chemistry (see *Appendix 2*). It is likely that much less is expected from the students taught by these teachers, in particular beginning chemistry students. Nevertheless, in the absence of empirical data, no conclusion can be made. There is therefore a dire need to inquire into Form four students' overall level of understanding of chemical representations, as well as their conceptions of representations in chemistry.

While it is well accepted that skills in interpreting and using chemical representations is vital for success in chemistry, a review of literature on studies conducted locally in science education shows hardly any research has been conducted on or related to students' representational competence in chemistry. To date, there is no documented study on the assessment of representational competence of students in chemistry at any level in Malaysia. Although chemical education research is flooded with literature on representational competence or representational fluency (Chittleborough & Treagust, 2007; Kozma, 2000a, 2000b, Kozma & Russell, 1997, 2005; Russell & Kozma, 2005; Stieff & McCombs, 2006; Wu & Shah, 2004), many of these studies were conducted in the West, particularly in the U.S.A., U.K. and Australia. The educational settings of these countries are different from Malaysian classrooms in many ways such as differences in the Chemistry Curriculum, pedagogy, assessment instruments, and classroom contextual factors. Besides, the subjects in most of these studies were college students, undergraduates, and even postgraduates and expert chemists. Findings of these studies cannot be generalized to the local context. Not only is representational competence domain-specific, representational competence may also vary across age or educational levels, as well as between experts and novices (Chi, Feltovich & Glaser, 1981; Kozma & Russell, 1997). Although the study by Heitzmann and Krajcik (2005) related to representational competence used secondary school students as the sample, the study specifically examined urban 7th grade students' difficulty with translation of chemical equation only. Chemical equation is only one particular type of chemical representation. The present study intends to explore a broader range of representations commonly used by novice chemistry learners (*Appendices 9 & 9a*).

The use of representations is an integral part in the study of chemistry (Coleman, undated). The interaction and distinctions between the three levels of representation of matter are important characteristic of chemistry learning and necessary for achievement in comprehending chemical concepts. Hence, it is important for chemistry students to be competent in interpreting and using chemical representations to learn chemistry. If students encounter difficulties at one of the levels of representation, or have confusion between the three levels, it may interfere with further learning in chemistry. The right time to begin acquiring some skills in using representations is at an early stage in their chemistry course. Therefore, an attempt to assess Form four students' representational competence in chemistry, and to identify their difficulties when interpreting and using chemical representations in learning chemistry, is both timely and appropriate.

However, chemical representations and representational competence cannot be studied out of context. Since the problem or research topic is Form four students' representational competence of basic chemical concepts, therefore students' overall levels of understanding, as well as their conceptions of basic chemical concepts, also need to be assessed.

Besides, in terms of methodologies, many of the studies on chemical representations, and representational competence were case studies (Chittleborough & Treagust, 2007; Hinton, & Nakhleh, 1999; Kozma, Chin, Russell, & Marx, 2000). With small sample sizes, the findings were not generalizeable. The present study used a mix of quantitative and qualitative techniques to collect data. A large, representative sample (n=411) increased generalizability of the findings while a smaller purposive sample (n=9) was selected for in-depth interviews to add depth and richness of data to the findings.

In addition, findings from research literature also suggest that a variety of cognitive factors are responsible for chemistry achievement. Although the information processing model (IPM) forms the theoretical framework in many studies investigating the influence of selected cognitive variables on performance in chemistry, many of these studies were either on the role of selected cognitive factors in chemistry achievement in general (Chandran, Treagust & Tobin, 1987) or predominantly on problem solving in stoichiometry (Johnstone, 1984; Nagalingam, 2004; Niaz, 1988, 1989; Niaz & Lawson, 1985; Schmidt, 1990; Staver & Jacks, 1988; Sweller, 1988; Tsaparlis, 1998, 2005). The influence of cognitive variables such as prior knowledge, developmental level, working memory capacity, and learning orientations on beginning chemistry students' representational competence in chemistry, however, does not seem to attract much research interest.

Furthermore, apart from studies done by Johnstone and some of his colleagues (Johnstone, 1997, 2000a, 2000b, 2001, 2006; Reid, 2008), most of the studies using the IPM as theoretical framework only focused on the working memory (WM) (Nagalingam, 2004; Niaz, 1988, 1989; Sweller, 1988; Yuan, Steedle, Shavelson, Alonzo, & Oppezzo, 2006), neglecting the other components of the IPM such as the perception filter and the long-term memory (LTM). It is believed that chemistry learning involves the presentation of chemistry knowledge as incoming stimuli, the perception and selection of the knowledge presented, and the processing of the knowledge within the WM, as well as the organization and the representation of the knowledge in the LTM. While it is believed that each learning theory has a contributing role in the understanding of chemistry learning, taken in isolation, none of these theories can predict performance nor describe an overall positive effect on the learning process (Johnstone, 2006; Mbajiorgu & Reid, 2006). The information processing system should not be treated as separate memory stores but as an integrated information processing system, emphasizing the relationship and interaction of the different learning theories (see Chapter 3- Section 3.1: Theoretical framework of the study). Hence, this study attempts to make a further search to examine the influence of the above mentioned cognitive variables namely: prior knowledge, developmental level, working memory capacity, and learning orientations, on representational competence in chemistry to add knowledge to this neglected area of research in chemical education.

1.5 Objectives of the Study

The general purpose of this study is to investigate Form four students' representational competence of basic chemical concepts. The main aims of this study are: (i) to investigate Form four students' understanding of basic chemical concepts, (ii) to evaluate their understanding of chemical representations, (iii) to assess their representational competence in chemistry, and (iv) to examine the influence of selected cognitive variables on their representational competence.

Specifically, the objectives of this study are:

i. To assess Form four students' overall levels of: (a) understanding of basic chemical concepts, (b) understanding of chemical representations, and (c) representational competence in chemistry.
ii. To compare Form four students' of high, medium, and low overall levels of understanding of: (a) basic chemical concepts, and (b) chemical representations, in their overall levels of representational competence in chemistry.
iii. To identify Form four students' alternative conceptions of: (a) basic chemical concepts, and (b) chemical representations.
iv. To identify Form four students' learning difficulties when interpreting and using representations in chemistry.
v. To gain further insights and understanding into Form four students' conceptions of chemical representations and their representational competence in chemistry.
vi. To explore possible relationships between selected cognitive variables of: (a) prior knowledge of chemistry, (b) developmental level, (c) working memory capacity, (d) learning orientations, and the representational competence of Form four students.
vii. To formulate a regression model that incorporates representational competence as the criterion variable, with prior knowledge, developmental level, working memory capacity, and learning orientations as the predictor variables.

1.6 The Research Questions

Guided by the theoretical and conceptual frameworks of the study, and corresponding to the objectives listed in Section 1.5, the following research questions have been formulated:

i. What are Form four students' overall levels of: (a) understanding of basic chemical concepts, (b) understanding of chemical representations, and (c) representational competence in chemistry?

ii. Is there any significant difference between Form four students' of high, medium, and low overall levels of understanding of: (a) basic chemical concepts, and (b) chemical representations, in their overall levels of representational competence in chemistry?

iii. What are Form four students' alternative conceptions of: (a) basic chemical concepts, and (b) chemical representations?

iv. What are the difficulties demonstrated by Form four students when interpreting and using chemical representations?

v. What are the similarities and differences among Form four students of high, average, and low overall levels of representational competence, in their representations of basic chemical concepts?

vi. Is there any significant relationship between: (a) prior knowledge of chemistry, (b) developmental level, (c) working memory capacity, and (d) learning orientations, and Form four students' representational competence?

vii. Which is the best predictor variable of representational competence?

1.7 Definition of Terms

For the purpose of this study, several terms were defined as follows:

Multi-level learning in chemistry (Johnstone, 2006, p.59)

The three levels of representations of matter may also be referred to as the three levels of thinking in chemistry, or the three conceptual levels in chemistry. These are: the macroscopic, the submicroscopic, and the symbolic levels (Johnstone, 1982, 1991, 1997, 2006). In this study, the terms "the three levels of representation of matter", "the three thinking levels or conceptual levels in chemistry" are used interchangeably to refer to the same idea.

Submicroscopic

The atomic or molecular or particulate level of chemical representation of matter. In this thesis, the terms submicroscopic, microscopic, molecular, and particulate are used interchangeably to refer to the same meaning.

Symbolic

A representation of the submicroscopic or macroscopic level.

Test on Chemical Concept, TCC

A two-part paper-and-pencil test (*Appendices 5 & 5a*) designed and used by the researcher to assess the prior knowledge of chemistry (basic chemical concepts) of the Form four students in this study.

Test on Chemical Representations (TCR)

A two-part paper-and-pencil test (*Appendices 11&11a*) designed and used by the researcher to assess the prior knowledge of chemistry (chemical representations) of the Form four students in this study.

Test on Representational Competence (TRC)

A two-part paper-and-pencil test (*Appendices 15 & 15a*) designed and used by the researcher to assess the representational competence of the Form four students in this study.

Conceptions

Refer to the abstract mental representations that exist in the mind of the learners, or mental representation of the structure of a word, or a process, or a phenomenon, that exists in a student's mind (Sa'adah, 2004); or conceptions are defined as students' understanding of a natural phenomenon or a science idea, through their common sense interpretation or through formal instruction. Such conceptions may or may not be congruent with the generally accepted scientific view (Man, 1999).

Alternative conceptions

Any conceptual idea that differs from the commonly accepted scientific consensus, as defined by Cho, Kahle and Nordland (1985); or knowledge spontaneously formed from making sense of the surrounding world that is incompatible with formal scientific knowledge (Galili & Hasan, 2000); or ideas held by students that differ from the accepted and intended scientific viewpoints (Sa'adah, 2004); or experienced-based explanations constructed by a learner to make a range of natural phenomena and subjects intelligible (Wandersee, Mintzes, & Novak, 1994).

In this study, the term `alternative conceptions' is used to describe student conceptions that differ from scientific concepts. Students' alternative conceptions of chemical concepts and chemical representations were identified from students' responses to the test items in the TCC and the TCR respectively.

Conceptions of chemical concepts

In the TCC (*Appendix 5 & 5a*), each item in Part A contains a statement which is either true or false. For example, the statement for item A2 "All molecules exist as compounds" is a false statement. Therefore, students whose response is "False" have correct conception of "molecules" while students whose response is "True" have alternative conception of "molecules".

Conceptions of chemical representations

In the TCR (*Appendix 11a*), each item in Part A contains a statement which is either true or false. For example, the statement for item A7 "Only compounds have chemical formulae" is a false statement. Therefore, students whose response is "True" have alternative conception of chemical formulae.

Overall levels of understanding of chemical concepts

A student's overall level of understanding of chemical concepts was indicated by his or her test score in the TCC, which may range from 0 to 30 points.

Overall levels of understanding of chemical representations

A student's overall level of understanding of chemical representations was indicated by his or her test score in the TCR, which may range from 0 to 36 points.

Overall levels of representational competence

In the assessment of representational competence, Form four students' overall levels of representational competence were based on the test score obtained in the TRC, which may range from 0 to 40 points.

Representational Competence

A term used to describe a set of skills and practices that allow a person to reflectively use a variety of representations, singly and together, to think about, communicate, and act on chemical phenomena in terms of underlying, aperceptual physical entities and processes such as atoms, molecules and their reactions (Kozma, 2000a, 2000b; Kozma & Russell, 1997; Kozma, Chin, Russell and Marx (2000).

In this study, "representational competence" is defined as "skills in interpreting and using representations". These skills include: (i) the ability to interpret meanings of chemical representations, (ii) the ability to translate between different representations at the same level (for example: given the structural formula of a compound and asked to write its molecular formula, i.e. from symbolic level to symbolic level), (iii) the ability to translate between representations across levels or from one level to another (for example: given a molecular representation of a chemical reaction and asked to write or choose the correct chemical equation representing the reaction, i.e. from molecular level to symbolic level), (iv) the ability to use representations to generate explanations, and (v) the ability to make connections between representations and concepts.

Classroom Test of Scientific Reasoning, CTSR (Lawson, 2000)

A 24-item (or 12 question, 2-tiers) multiple choice paper-and-pencil test used to assess the developmental level of the Form four students in this study.

Developmental level or cognitive level

In this study, the developmental level of the subjects was indicated by their CTSR scores. In the report, the terms "developmental level" and "cognitive level" were used interchangeably to refer to the same idea.

Prior knowledge of chemistry

In this study, prior knowledge of the subjects was measured by their TCC and TCR scores. For each of the TCC and TCR, the subjects were categorized into three groups or levels (Low, Medium and High), based on quartiles of their TCC and TCR scores respectively (see *Appendix 28).*

Digit Span Backwards Test, DSBT (Johnstone, 2001)

A test used to measure the working memory capacity of the subjects in this study.

Working memory capacity

Working memory capacity refers to the working memory space available to hold and process information. In this study, working memory capacity of the subjects was determined by the DSBT scores.

Learning Approach Questionnaire, LAQ (Boujaoude, Salloum & Adb-El-Khalick, 2004)

The 23-item questionnaire is a 4-point Likert-type instrument used to assess students' learning orientations or approaches to learning chemistry in this study.

Learning orientations

Relate to students' inclination or generalized tendency to learn. That is: their general approach to learning. Two dimensions of learning orientations distinguished in this study are meaningful learning orientation and rote learning orientation. In this study, learning orientations of the subjects were indicated by their LAQ scores.

1.8 Significance of the Study

Relatively little is known about students' representational competence of chemical concepts in Malaysian schools. Therefore, findings on Form four students' representational competence of basic chemical concepts can be important feedbacks for Malaysian chemistry teachers and educators, as these findings can contribute to our understanding of some of the difficulties that students experience in their chemistry classes. Such findings shall also provide valuable inputs for curriculum developers with regards to the drafting of curriculum specifications and the preparation of other curriculum materials in chemistry.

It is also beneficial to identify Form four students' alternative conceptions of chemical concepts and chemical representations so that timely and appropriate strategies may be formulated that will challenge their understandings at this early stage of their chemistry course, in order to help them develop scientifically correct conceptions.

In view of the important roles played by chemical representations and the importance of representational competence in chemistry learning, research on students' representational competence is crucial. As there is no documented study on the representational competence of Form four students in the local context, findings from this study on a specific domain (Chemistry) should contribute significantly to chemical education in terms of empirical data and knowledge, as well as expanding the local chemical education research literature which is poorly lacking in Malaysia.

Furthermore, findings on Form four students' representational competence offer useful pointers for writers and publishers of educational media such as text books and other references as to how representations in chemistry may be more effectively illustrated or presented and shared with novice chemistry students.

Since there is no similar study conducted locally, identification of Form four students' learning difficulties when interpreting and using chemical representations should provide useful insights for teachers who are unaware of students' difficulties with the three levels of thinking in chemistry. Indeed, how teachers represent the subject content knowledge to their students and their knowledge about students' learning difficulties are important elements of the pedagogical content knowledge (PCK) of teachers (Shulman, 1987; cited in Chien, 2006). Hence, findings of this study might help enhance the PCK of chemistry teachers, in particular newly practicing teachers who handle Form four students.

This study both adds to and compliments the literature of chemical representations by describing the difficulties that novices have as they begin to use representations and as they begin to experience and learn about chemical concepts in a formal instructional setting. Considering the fact that the sample in this study was from urban secondary schools, there is a possibility their counterparts in the rural areas may have similar or even more serious learning difficulties.

Although there were previous studies examining the relationship between variables such as developmental level, working memory capacity, and prior knowledge with achievement in chemistry, there are no documented records of studies that specifically investigate the relationship between these cognitive variables and representational competence in chemistry. Therefore, finding of any significant relationship between any of the selected variables and the representational competence of Form four students can inform chemistry teachers on possible cognitive factor(s) and the extent of their influences on the representational competence of novice learners in chemistry.

Apart from explaining the influence of selected cognitive variables on representational competence, the regression model generated from the findings of this study can also be used to predict representational competence in chemistry for a similar sample of Form four science students.

1.9 Scope and Limitations of the Study

Form four students' conceptions of chemical representations and their representational competence were examined with regards to the learning of selected basic chemical concepts only. These were: pure substances and mixtures; elements and compounds; atoms, molecules and ions; sub-atomic particles; proton number and nucleon number; electron arrangement and valence electron; chemical symbols, chemical formulae and chemical equations; physical change and chemical change; and chemical bonds. Students' representational competence related to investigative tasks was not examined.

The subjects of this study comprised only Form four science students from the State of Perak. Therefore the findings of this study may not allow generalization to be made on other forms or levels of science students.

The sample from seven urban secondary schools with 74.2% Chinese, 18.5% Malays and 7.3% Indians appears to be ethnic biased as the proportion does not represent the target population.

As representations and representational competence is domain-specific, findings of this study may not be generalizable to other subject areas, even the sciences such as physics and biology.

1.10 Chapter Summary

This chapter described the problem and its setting. Section 1.0 provided an introduction to the chapter. Section 1.1 gave an outline on education in Malaysia. Section 1.2 provided the background of the study and a brief literature review. In Section 1.3, statement of the problem gave a detailed description of the problem while Section 1.4 outlined previous researches related to this study to check what had been done. Gaps that need to be filled or areas that are unexplored or require further investigation were identified, thereby creating the rationale for the study to be conducted. In Section 1.5, the general purpose of the study was stated, main aims listed, and specific objectives identified. Subsequently, relevant research questions were formulated in Section 1.6. In Section 1.7, important terms used in the study were defined with reference to the context in the study. Section 1.8 highlighted the significance of the study. The chapter concludes by stating the scope of the study, as well as some of its limitations in Section 1.9.

In Chapter 2, literature review related to this study will be discussed.