# CHAPTER 3

# CONCEPTUALIZATION OF THE STUDY

## 3.0 Introduction

The general purpose of this study was to investigate representational competence of basic chemical concepts among Form four science students. Specifically, the study attempted to assess students' overall levels of understanding of basic chemical concepts, chemical representations, as well as their representational competence in chemistry. It also sought to compare students' with different levels of understanding of chemical concepts and chemical representations in their representational competence. In addition, an attempt was made to identify their alternative conceptions of chemical concepts, chemical representations, as well as their difficulties when interpreting and using chemical representations. Finally, semi-structured interviews were conducted to gain further insights and understanding into selected students' representations of basic chemical concepts. A further search was undertaken to explore possible relationships between students' prior knowledge, working memory capacity, developmental level, learning orientations and their representational competence in chemistry, and subsequently, to determine the best predictor variable for representational competence. The sample of this study comprised 411 Form four science students from 13 intact classes of seven urban secondary schools in the State of Perak. Data for the study was obtained from seven instruments namely: The test on Chemical Concepts (TCC), the Test on Chemical Representations (TCR), the Test on Representational Competence (TRC), the Classroom Test of Scientific Reasoning (CTSR), the Digit Span Backwards Test (DSBT), the Learning Approach Questionnaire (LAQ), and semi-structured interviews (SSI). The Statistical Package for the Social Sciences (SPSS) was used to process and analyze quantitative data collected from the study.

This chapter presents the theoretical framework as well as the conceptual framework of the study.

## 3.1 Theoretical Framework of the Study

"Human learning is a complex process, and there is much to go wrong even when proficient teachers work with model students." (Taber, 2003, p.104)

It is believed that learning involves internal mental processes and the acquisition of mental representations, in the form of cognitive structures called schemata. Research on learning and learning theories recognize the importance of learning through making connections between new concepts and existing schemata in the long-term memory (LTM). The goal of education is for individuals to build a complex network of interconnected concepts in the LTM that can be drawn upon when needed. However, classroom experience tells us that very often what is taught is not always what is learned (Johnstone, 2000a, 2000b). Hence, it can be said that teaching and learning are not equivalent. So, how is input information processed by the learner? What are the problems with information processing? Where do problems occur within the information processing model (IPM)? What are the possible factors affecting information processing?

### 3.1.1 Learning theories related to this study

Learning theories related to this study are: the information processing theory, schema theory, Ausubel's theory of meaningful learning, and Piaget's theory of cognitive development.

#### 3.1.1.1 The information-processing theory

Information processing theorists approach learning primarily through a study of memory – the storage and retrieval of information. The human mind is an information-processing system. Processing involves gathering and representing information, or encoding; holding information, or storage; and getting at the information when needed, or retrieval.

Although there are varying views of information processing within cognitive psychology, most cognitive psychologists agree with these basic principles: (i) the assumption of a limited capacity of the mental system, (ii) a control mechanism oversees the processing, transformation, encoding, storage, retrieval, and utilization of information, (iii) a dynamic, two-way flow of information as we try to make sense of the world around us.

The most widely accepted information processing theory, the “Stage Theory”, is based on the work of Aktkinson and Shiffrin (1968). The theory proposes that all information that is stored in the mind is first sensed by the individual. Some of this information goes into the short-term memory (STM) or working memory (WM) of limited capacity, and under the right conditions, is stored in the LTM. Information is processed and stored in three stages: input processing, storage and output.

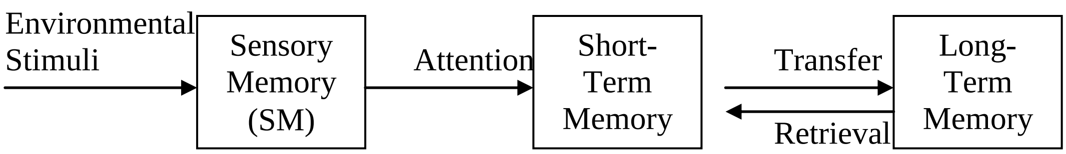



**Figure 3.1**: The Atkinson-Shiffrin Model (1968)

The multi-store model was the first to show a systematic account of the structures and processes that form the memory systems. The focus of this model is on how information is stored in memory. It shows how information is transferred from one storage area to another. The three memory stores are sensory memory (SM) or sensory register (SR), short-term memory (STM) or working memory (WM), and long-term memory (LTM). See Figure 3.1.

Beginning with the sensory memory, environmental stimuli, in the form of visual and verbal stimuli are registered by sensory receptors. Information that have been attended to is thought to pass into a working space or working memory (WM) where it is held and processed before being rejected or passed on for storage into the long term memory (LTM) through encoding. The information stored in the LTM can be retrieved and transferred to new situations.

However, information processing within the information processing model may not proceed in a smooth and sequential manner. A major problem with the information processing approach to explaining human cognition is the relative inefficiency of humans at processing information. This is partly due to the limited capacity of the working memory.

#### 3.1.1.2 The schema theory

> Schemata are the fundamental elements upon which all information processing depends. Schemata are employed in the process of interpreting sensory data,…in retrieving information from memory, in organizing actions, …, and generally in guiding the flow of processing in the system. A schema is a data structure for representing the generic concepts stored in memory… (Rumelhart, 1980).

Memory is one of the most important concepts in learning. If things are not remembered, no learning can take place. A considerable amount of research has been carried out on the nature and structure of memory, its functions and processes. One of the more recent developments in the organization of memory is the schema theory - a cognitive theory of mental representation.

The concept of “schema” is central to early cognitive theories of representations. The term “schema” was first used by Jean Piaget in 1926. He suggested that children learn using existing schema that are accommodated or assimilated. Barlett (1932) is credited with first proposing the concept of schema. From studies of memory he conducted, Barlett suggested that memory takes the form of schema which provides a mental framework for understanding and remembering information. Anderson (1977) and Rumelhart (1980) further developed the schema concept. Rumelhart (1980) defined a schema as “a data structure for representing the generic concepts stored in memory”. Several versions of schema theory incorporate many of Barlett’s ideas.

According to schema theory, the knowledge we have stored in memory is organized as a set of schemata or mental representations, each of which incorporate all the knowledge of a given type that we have acquired from past experience. Schema theory provides an account to the knowledge structure and emphasized the fact that what we remember is influenced by what we already know. Schemata are used to organize our knowledge, to assist recall, and to help us make sense of new experiences. Schemata facilitates both encoding and retrieval. Moreover, the mental structures are active. Memory can be restructured through the integration of current experience with prior knowledge. Schemata can change over time as a result of new experience and learning.

Research on functions of the schema focused on the impact of prior knowledge on comprehension and memory (Driscoll, 2000). There are two information resources: (i) the incoming information from the outside world, (ii) information already stored in memory.

The analysis of the sensory information coming in from the outside is known as bottom-up processing or data-driven processing. The information already stored in the memory in the form of prior knowledge influences our expectations and helps us to interpret the current input. This influence of prior knowledge is known as top-down or conceptual-driven processing. Schemata operate in a top-down direction to help us interpret the bottom-up flow of information from the world, which may lead to the activation, modification or generation of a schema.

There are many descriptions of what "schemata" are (Anderson, 1977; Rumelhart & Norman, 1981; and Winn & Snyder, 1996). However, all descriptions concur that a schema has these characteristics: (i) It is an organized memory structure, containing the sum of our knowledge of the world, (ii) a schema is a more abstract representation than a direct perceptual experience, (iii) it is a network, consisting of concepts that are linked together, (iv) it is dynamic, amenable to change by general experience or through instruction, (v) it provides a context for interpreting new knowledge as well as a structure to hold it (Winn, 2002).

Abstraction or generality is the characteristic that makes schema useful. Encoding every feature of every experience places a high demand on memory capacity and cognitive processing resources (Pinker, 1985, cited in Winn, 2002). Learning requires the modification of schemata so that they can accurately accommodate unusual instances, while still maintaining a level of specificity that makes them useful (Winn, 2002).

As schemata are dynamic structures, our memory and understanding of the world will change. Schema theory proposes that our knowledge of the world is constantly interpreting new experiences and adapting to it. Piaget (1969) called these processes "assimilation" and "accommodation". These two processes interact dynamically in an attempt to achieve cognitive equilibrium. Learning takes place as schemata change when they accommodate to new information in the environment and as new information is assimilated by them. Three different processes have been proposed to account for changes in existing schemata and the acquisition of new schemata due to learning (Rumelhart and Norman, 1981). These are: (i) accretion, (ii) schema tuning, and (iii) schema creation. In accretion, the new information is simply added to an existing schema with almost no accommodation of the schema at all. Schema tuning results in more radical changes in a schema. Schema creation involves the creation of entirely new schemata which replace or incorporate old ones.

Research on memory suggested that what was passed from the WM to the LTM was not a direct representation of the information in the WM but a more abstract representation of its meaning. These abstract representations are schemata.

#### 3.1.1.3 Ausubel's theory of meaningful learning

The primary idea of Ausubel's theory is that learning of new knowledge is dependent on what the learners already know. We learn by constructing a network of concepts and adding to them. Ausubel, Novak, and Hanesian (1978) emphasized the importance of learning through making connections between new concepts and existing cognitive structures or schemata. Ausubel (1968) also distinguished meaningful learning from rote learning. Meaningful learning is characterized by these characteristics: (i) Non-arbitrary, non-verbatim, substantive incorporation of new knowledge into existing cognitive structure, (ii) deliberate effort to link new knowledge with higher order concepts in cognitive structure, (iii) learning related to experiences with events or objects, and (iv) affective commitment to relate new knowledge to prior learning.

According to Ausubel, meaningful learning involves recognition of the links between concepts and the integration of new information into the learner's existing knowledge structure, which Ausubel defines as “sub-summers”. These sub-summers exist in the individual’s cognitive structure as a framework of hierarchically organized concepts. Rote learning occurs when relevant concepts, or sub-summers do not exist in the individual’s cognitive structure. In such a case, new information must be arbitrarily stored in the cognitive structure. Rote learning would not result in the acquisition of meanings. The learners view the new concepts as fragmented pieces of new information and are unable to transfer this knowledge to a new situation. Rote learning is necessary when learners acquire new information in a knowledge area completely unrelated to what they already know. Ausubel also believed that learning proceeds in a top-down, or deductive manner.

Ausubel’s work was the basis for understanding how meaningful learning can occur in terms of the importance of being able to link new knowledge on to the network of concepts, which already exists in the learner’s LTM.

#### 3.1.1.4 Piaget’s theory of cognitive development

The focus of Piaget’s theory is on intellectual development. It questioned whether it was possible for students to learn certain ideas or concepts until they have reached an appropriate level of cognitive development. Two main aspects of Piaget’s theory are: (i) process of cognitive development, and (ii) stages of cognitive development.

Piaget (1929) believed that the developing child builds cognitive structures (or schemata) which are basic building blocks, organized systems of actions or thoughts that enable an individual to mentally represent the objects and events of the world. According to Piaget, a child’s schema increases in sophistication with cognitive development. Piaget described the two processes used by an individual in its attempt to adapt to the environment as “assimilation” and “accommodation”.

Assimilation is the process of taking in new information into the preexisting schema. Accommodation is the process of changing or altering our existing schemata in light of new information. New schemata may also be developed during this process. Piaget believed that another process – equilibration, helps explain how children are able to move from one stage of thought into the next. He argued that as children progress through the stages of cognitive development, it is important to maintain a balance between applying previous knowledge (assimilation) and changing behavior to account for new knowledge (accommodation).

Piaget proposes that a child's cognitive abilities progresses through four distinct stages. Each stage is characterized by the emergence of new abilities and ways of processing information. These stages are: (i) Sensory-motor stage (birth - 2 years): Stage during which infants learn about their surrounding by using their senses and motor skills; (ii) Pre-operational stage (ages 2 - 7): Stage at which children learn to represent things in the mind; (iii) Concrete operational stage (ages 7 - 11): Stage at which children develop the capacity for logical reasoning and understanding of conservation. They can use these skills only in dealing with familiar situations; (iv) Formal operational stage (beginning at 11 - 15): Stage in which one can deal abstractly with hypothetical situations and can reason logically.

### 3.1.2 Common elements of the above learning theories

The Schema Theory, Ausubel's Theory and Piaget's Theory overlap to some extent and are, in many ways inter-related. All the three theories recognize that:

(i) The processes that account for changes in existing schemata and the acquisition of new schemata due to learning are very similar. These are: sub-sumption (Ausubel's Theory); accommodation and assimilation

(Piaget's Theory); accretion, schema tuning and schema creation (Schema Theory).

(ii) Schema-like constructs form the basis of these theories of cognition. The most basic or smallest cognitive structure in the LTM refers to the same thing although given different labels. Piaget called it cognitive structure, Schema Theory refers to this as "schema", Ausubel called it "subsumer".

(iii) Prior knowledge is a key factor influencing learning. What we remember is influenced by what we already know and that the use of prior learning to deal with new information is a fundamental of how the mind works,

(iv) Learning involves making connections between new information and existing cognitive structures or schemata.

The importance of prior knowledge and making connections between new and prior knowledge can be seen clearly in the IPT. Therefore, in this study, the IPT will be the main theory for the theoretical framework, with the other theories supporting it.

### 3.1.3 Proposed theoretical framework for this study

The proposed theoretical framework interprets learning as a cognitive process and argues for a predominantly top-down information processing approach. Memory is recognized as an important concept in learning. The organization of memory as schemata in the LTM, as well as interaction between new information with prior learning is also emphasized.

Understanding, interpreting, and using chemical representations involve complex cognitive processes. Although the information processing model appears to be the main theoretical model supporting the study, it is believed that several other cognitive theories of learning also interact in one way or another to influence learning. These learning theories are: (i) Schema theory, (ii) Ausubel theory of meaningful learning, and, (iii) Piaget's theory of cognitive development.

Representational competence shall be interpreted from these theories wherever relevant, and integrated with the IPT whenever appropriate as it is believed that in isolation, none of these theories can explain the desired learning outcome. That is: representational competence. In the discussion, understanding of chemical concepts and chemical representations shall be discussed alongside representational competence, although representational competence appears to be the main construct in the conceptual framework of the study (see Figure 3.3). This is because representational competence cannot be studied out of context, and is believed to be linked to understanding of both chemical concepts and chemical representations.

There are many variants of the information processing model (IPM) in the literature. All these models are essentially the same although different labels are used. This is because learners all learn in essentially the same way. For the purpose of this study, a modified version of the IPM shall be used. This model, originally proposed by Atkinson and Shiffrin (1968), was later modified by Johnstone and El-Banna (1986) and Johnstone (1997, 2000b, 2006). Basically, there are three memory stores: (i) sensory memory (SM), (ii) working memory (WM), and (iii) long term memory (LTM). Figure 3.2 shows the proposed theoretical model for the study.

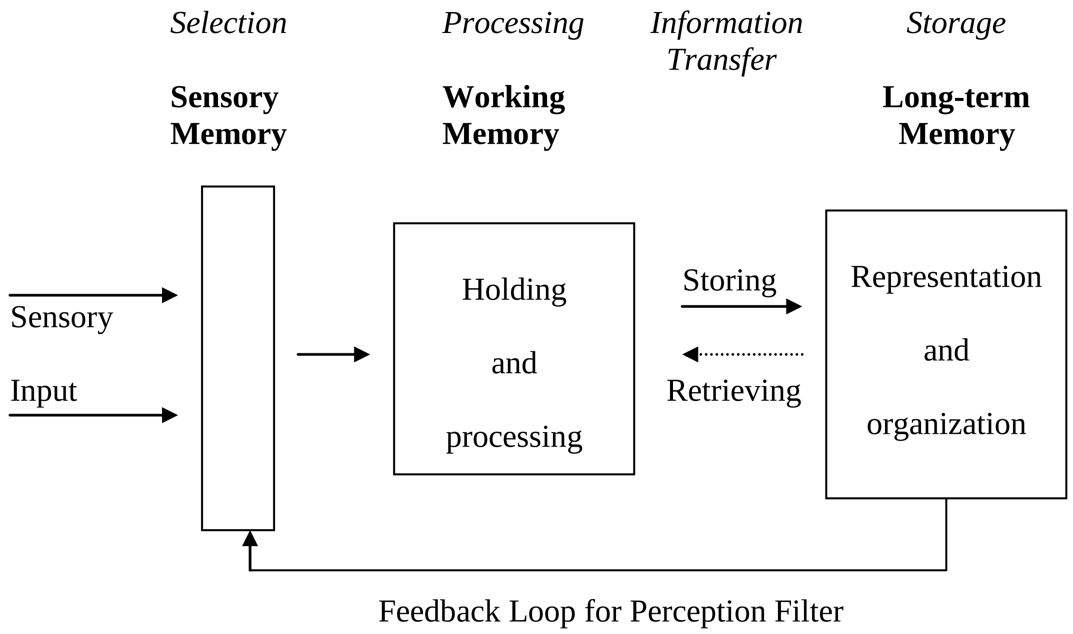



**Figure 3.2**: Proposed Information Processing Model for the study (after Johnstone, 1997)

#### 3.1.3.1 Sensory memory, long-term memory, and representational competence

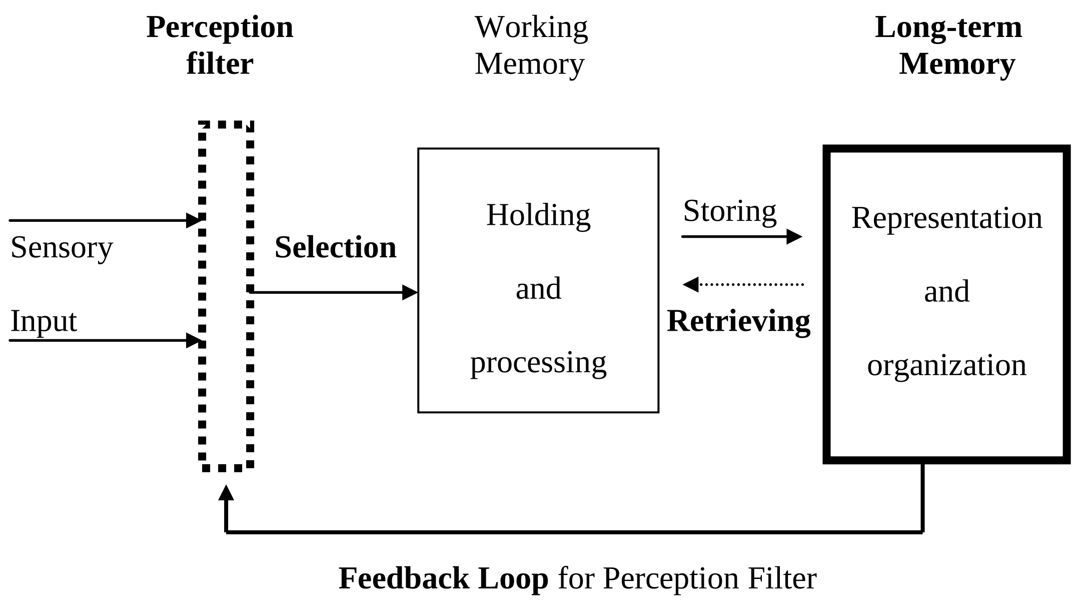



**Figure 3.2 (a)**: Sensory memory and long term memory

Sensory memory or sensory registry holds sensory information very briefly. Within the sensory memory, the perception filter selects raw information for further processing. In human information processing, sensory stimuli in the environment are selectively attended to. Selection is done by a perception filter. The schema theory argued that processing within the information processing system can be bottom-up as well as top-down. In top-down processing, experience and knowledge we acquired through prior learning can help to activate and control our perception filter (see the feedback loop in Figure 3.2 (a). Things which are familiar or which `make sense' to us are attended to while others are filtered out or rejected (Johnstone, 1997). Furthermore, according to Johnstone, "…human not only sense selectively but also add, from experience, to sensory information or fill out an otherwise incomplete sensory experience…" (Johnstone, 1997, p.263). Take a look at Figure 3.2 (a1). Then flip the page upside down and look again.

**Figure 3.2 (a1)**: What do you see in this figure?
(Johnstone, 1997, p.263, Figure 1)

**Figure 3.2 (a2):** Figure 3.2 (a1) flipped upside down
(Johnstone, 1997, p.264, Figure 1a)

During classroom instruction, learners are exposed to various environmental stimuli through lectures, demonstrations, experiments, and multimedia presentations. However, much of the sensory information will be filtered out or rejected, or a learner remembers only the peripherals but fails to grasp the essentials, if he/she does not possess the essential prior knowledge or concept due to missing or incomplete schema in their LTM. Some examples are: chemical representations such as chemical symbols and chemical formulae appear meaningless to a learner who does not know about basic chemical concepts like elements and compounds, atoms, molecules and ions; chemical equations are just chunks of letters and numbers to those who do not know what a chemical reaction is. Likewise, a learner who does not know the chemical concept or principle behind an experiment only remembers the bangs and pops of a demonstration. Hence, prior knowledge (Ausubel, 1968) within the LTM plays an important role in the selection process. In the context of this study, prior knowledge of the subjects includes basic chemical concepts (assessed by the TCC), and chemical representations (assessed by the TCR). 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 link the three levels of representations, as well as to translate between the three levels.

Many concepts in chemistry are very abstract (Cantu & Herron, 1978). Although chemical representations are apparently visual representations, they are also conceptual constructs and are therefore more abstract compared to pictorial diagrams. Chemical phenomena are interpreted at the particle level, requiring students to think increasingly in abstraction. For students who are unable to visualize and interpret molecular and symbolic representations, they only recognize the surface features of chemical representations and hence see chemistry as a science of symbols, formulae and equations. For example, novices in chemistry who do not know that the letters and lines in structural formula actually represent atoms and chemical bonds, respectively, may see merely lines and letters. Likewise, molecular models such as ball-and-stick models may just appear as balls with different colours and sizes, and sticks to them. As a result, their understanding of chemistry tends to stay at the macroscopic or sensory level. According to Piaget's four stages of cognitive development, the subjects in this study (average age=16 years) should be formal operational thinkers, capable of thinking abstractly and can logically use representations related to abstract concepts. However, it is believed that some individuals are chronologically adults but still remain in concrete operational stage and may be limited in their understanding of abstract concepts.

### 3.1.3.2 Working memory and representational competence

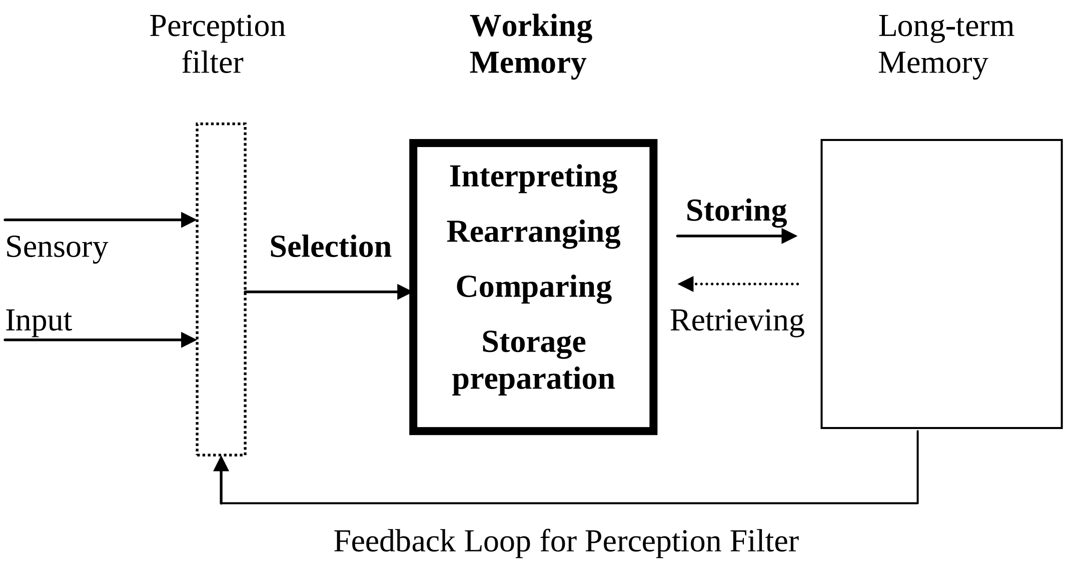



**Figure 3.2 (b)**: The working memory

Information that pass through the perception filter are temporarily held in the WM where interaction occur, either with itself or with information drawn from LTM store in order to "make sense" of the new information. However, this working memory space is of limited capacity (Baddeley, 1999). This shared space is a link between what has to be held in conscious memory, and the processing activities (interpreting, rearranging, comparing, transforming or encoding) required to get the information ready for storage in the LTM. Therefore, if a lot of processing is required, not much information can be stored; if there is too much information to hold, there is insufficient space for processing (Johnstone, 1997).

In any teaching-and-learning session, not only do learners filter the in-coming stimuli, there is also a limit on the quantity of information they can process within a certain time limit. Hence, several problems related to the limited capacity of the working memory can arise during a chemistry class for beginning students. For example, an unfamiliar substance will take up a much larger space in the WM compared to something familiar because more time is needed to "make sense" of the new information. If students are so unfamiliar with a substance and cannot describe the physical properties of the material, they will not see the relationship between the macroscopic or sensory level and the other two levels – submicroscopic and symbolic. This adds memory overload to the learning situation (Gabel, 2000). According to Johnstone (1997) and Reid (2008), if working memory is overloaded, learning will more or less ceased.

Being conceptual, much of chemistry requires the learners to hold many ideas at the same time to gain understanding (Reid, 2008). Besides, the need for a chemistry student to move seamlessly between Johnstone's three "thinking levels" represents a significant challenge to novices in chemistry (Tasker & Dalton, 2006). Making translation between representations either at the same levels (such as translating a structural formula into a molecular formula), or across levels (such as drawing a molecular representation for a chemical reaction) is a new and demanding task for novices. According to Keig and Rubba (1993), making translation between representations is an information processing task that requires conceptual understanding about the representations. Unlike experienced chemists who can manipulate all 3 levels of chemical representation fluently and effortlessly, introducing the 3 levels simultaneously to beginning chemistry students can lead to cognitive overload of the working memory (Gabel, 1999; Johnstone, 1982).

### 3.1.3.3 Working memory, long-term memory, and representational competence

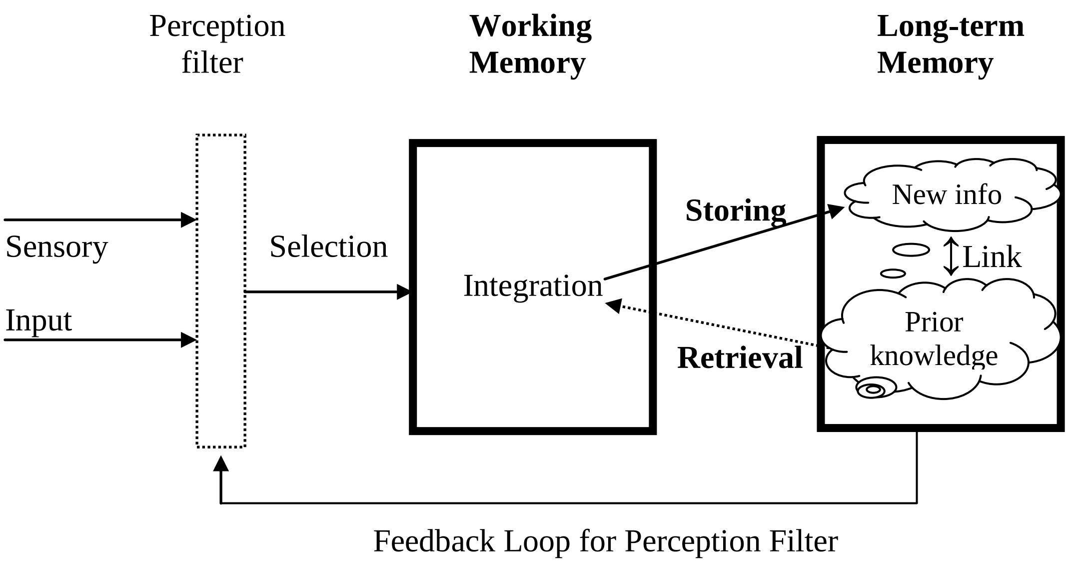



**Figure 3.2 (c)**: The working memory and long-term memory

It is believed that linkages exist between WM and LTM store (see the 2-way arrows in Figure 3.2c). While processed information in the WM is passed to the LTM for storage as new information, information or knowledge from prior learning is also being retrieved from the LTM to help with processing in the WM.

Working memory space cannot be expanded but it can be utilized more efficiently through the process of chunking. "Chunking" refers to the ability to use some strategy to bring together several items into one meaningful unit, thus reducing working space demands (Miller, 1956). Items in the WM are handled as `chunks' of information, varying from single characters to abstract concepts and complex images (Johnstone & Kellett, 1980). The more you know about the topic, the easier it is for chunking since chunking usually depends upon some recognizable conceptual framework or existing schema in the LTM. However, novice learners in chemistry lack such chunking devices (Johnstone & El-Banna, 1986). For example, when given a structural formula as shown in Figure 3.2 (c1), a novice learner may see the structure as 2 carbon atoms, 2 oxygen atoms, 4 hydrogen atoms, a double bond, and 6 single bonds; a total of 15 pieces of information; or the structure may even appear as meaningless letters and lines. However, an expert such as a chemist easily recognizes it as $CH_3COOH$ or ethanoic acid; just one piece of information.

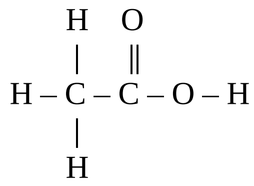


**Figure 3.2 (c1)**: Structural formula of ethanoic acid

Another commonly used chemical representation is equation. For example: given an equation:

$$10I^- + 2MnO_4^- + 16H^+ \rightarrow 5I_2 + 2Mn^{2+} + 8H_2O$$

An expert quickly identifies the statement as an ionic equation for a redox reaction. To a novice, it appears as chunks of letters and numbers.

Integrating a large number of information bits into smaller number is an example of pattern formation, which is one way of chunking (Sirhan, 2007). According to the schema theory, schemata are the cognitive structures that make up an individual's knowledge base. The contents of the LTM are not a group of rote-learned facts but schemata, which enable us to treat multiple elements as a single entity. Learning requires a change in the structures of schemata in the LTM. Since schemata are acquired over a lifetime of learning, novice has not acquired the schemata of an expert and is severely limited by the working space. Hence for a novice, making translations between representations is a demanding task.

### 3.1.3.4 Long term memory and representational competence

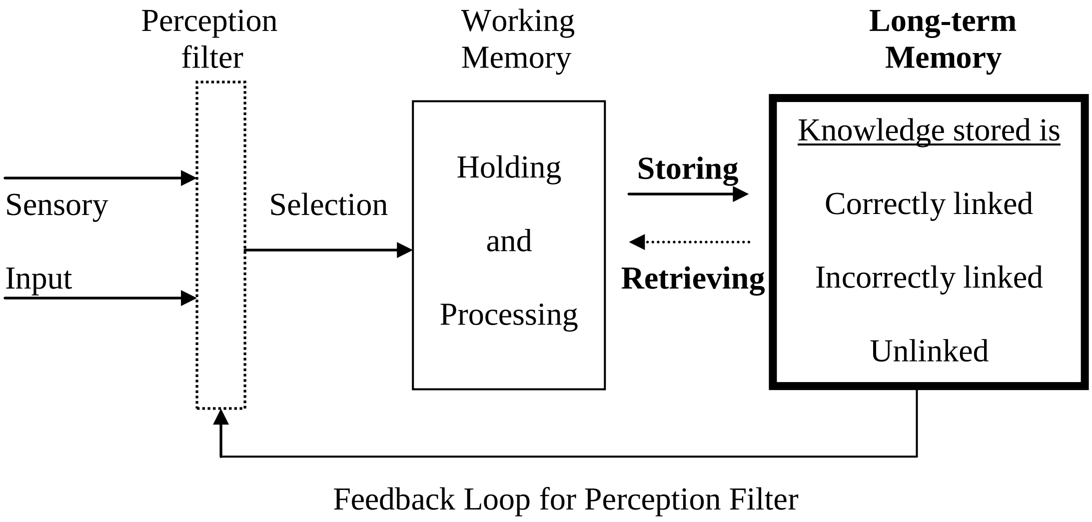



**Figure 3.2 (d)**: The long term memory

Processed information in the working memory is passed into the long term memory for storage. On storage and retrieval of information, it is believed that real understanding requires not only the grasp of key concepts but also the establishment of meaningful links to bring the concepts into a coherent network. Retrieval of information is highly dependent on the way it is stored in the long term memory (Reid & Yang, 2002a, 2002b; cited in Reid, 2008). The more knowledge is understood and stored meaningfully, the more links are created between ideas and concepts (Al-Qasmi, 2006, cited in Reid, 2008; Johnstone, 1997).

Hence, three possible situations may arise. (i) If the new information is successfully linked to, or well-integrated with, some existing concepts or schemata in the LTM, the smaller schema will grow to produce larger network of concepts. With multiple linkages, the existing knowledge and understanding is enriched and retrieval is easier with more retrieval cues. This is meaningful learning; (ii) if a learner cannot link the new information with any existing knowledge, or if there is no existing schema in the LTM to which the new information can be attached, the new information will either not be stored (no learning), or it will be stored unattached, resulting in fragments of unrelated knowledge. This is rote learning; (iii) learners incorrectly making such links, leading to misconceptions or alternative frameworks.

To enable easy retrieval of information from the LTM, learners need to actively construct, organize, and structure internal connections that hold the information together. The systematic organization of knowledge or the ordering of the component knowledge items in a logical, coherent, concise, and principle-based manner, is important for the effective learning, recall, manipulation, and use of knowledge (Salvaratnam, 1993; Sirhan, 2007).

Many chemical concepts observable at the macroscopic level can only be explained at the particulate level and represented at the symbolic level. Teaching chemistry using the three levels separately may result in students forming powerful individual networks on each level, but do not see the connections between the levels. Learners who are unable to link the three levels of chemical representation may store them as fragments of unrelated information in the LTM. Johnstone (1997) called this boxed learning. Learning is compartmentalized and retrieval is difficult or sometimes impossible. Such learners are also unable to manipulate the three levels of representations simultaneously, or translating between the levels. Their representational competence is limited.

With the information processing model as the main theoretical framework to provide the direction and stimulus for the study, and several cognitive learning theories as underpinning psychological theories, this study attempts to propose a model of learning which can be useful in promoting meaningful learning of chemical concepts, chemical representations, as well as representational competence, among beginning chemistry students.

## 3.2 Conceptual Framework of the Study

First proposed by Johnstone (1982), the three conceptual levels or the three levels of thinking in chemistry has been extensively researched and well documented. This study seeks to investigate an area related to the three levels of thinking in chemistry. That is: students' representational competence of basic chemical concepts. The study focuses on three aspects. These are: (i) understanding of basic chemical concepts, (ii) understanding of chemical representations, and (iii) representational competence in chemistry.

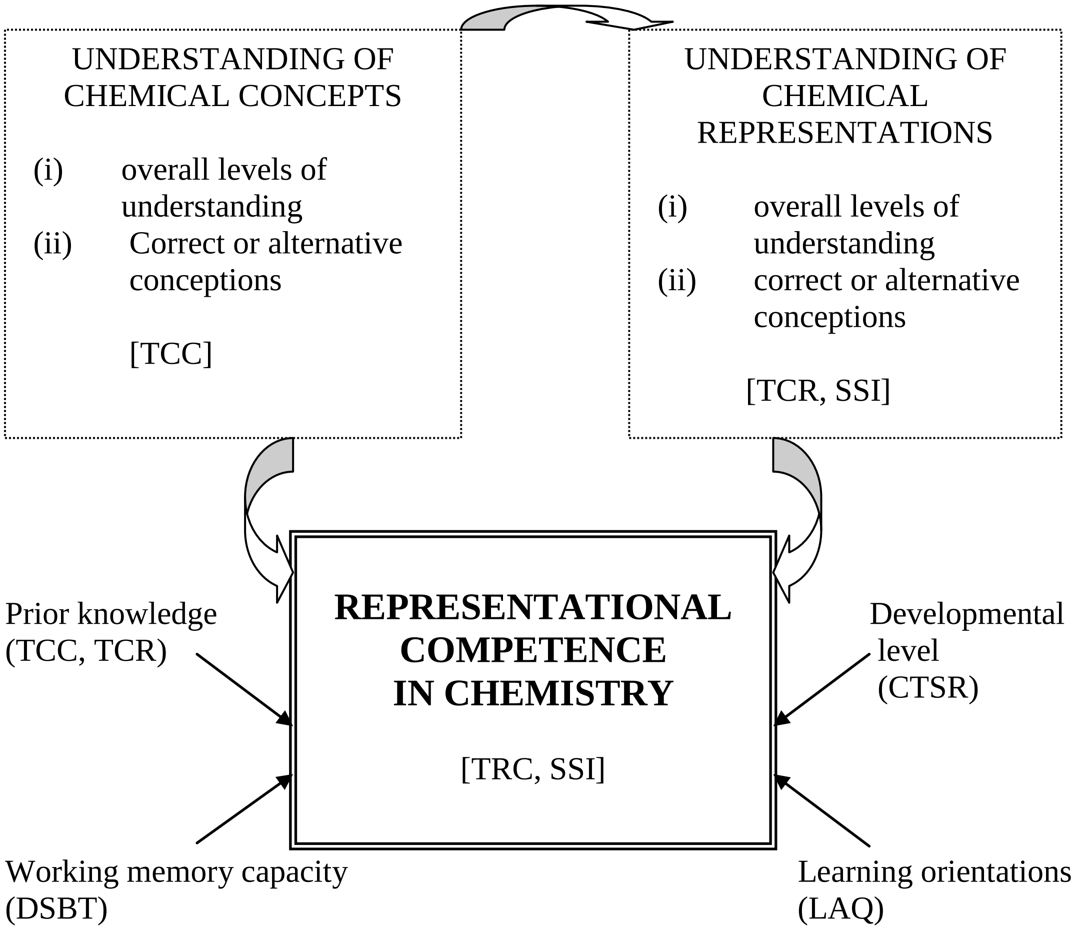
The three levels of understanding chemical concepts or linking the three levels of chemical concepts are the macroscopic, submicroscopic, and symbolic levels. Students should be able to relate a symbolic representation to both the macroscopic and sub-microscopic realities. For example: Given a chemical symbol "Cu", students should be able to relate this symbol to the element copper (macroscopic), or copper atom (submicroscopic). The mole concept also has both macroscopic and submicroscopic perspectives. For example: 1 mol Cu can refer to 64g of the element copper (macroscopic), or $6.02 \times 10^{23}$ copper atoms (submicroscopic).

Due to the abstract nature of many chemical concepts, communication of chemical concepts is often dependent on symbols and representations. However, chemical representations are visual representations as well as conceptual constructs. According to Chittleborough and Treagust (2007), a lack of understanding of the various chemical representations corresponds to a lack of understanding of the chemical concepts. It is also reasonable to believe that a sound understanding of chemical concepts (indicated by the TCCt score), as well as chemical representations (indicated by the TCRt score), is necessary for a student to be able to interpret and use representations in chemistry. That is: representational competence (indicated by the TRCt score).

A two-part paper-and-pencil test, the Test on Chemical Concepts (TCC) was used to assess their overall levels of understanding of basic chemical concepts, as well as to investigate students' conceptions of basic chemical concepts. The total number of correct responses in the TCC gave the test score for the TCC, which was used as a measure of a student's overall level of understanding of basic chemical concepts. Students' correct or alternative conceptions could be identified from their response for each item. Another paper-and-pencil test, the Test on Chemical Representations (TCR) was used to evaluate their overall levels of understanding of chemical representations, as well as to investigate students' conceptions of chemical representations. While the total number of correct responses in the TCR yielded the test score for the TCR, the response for each item indicated their correct or alternative conceptions tested. The TCR test score was used as a measure of a student's overall level of understanding of chemical representations. A further two-part paper-and-pencil test, the Test on Representational Competence (TRC) was used to assess students' overall levels of representational competence in chemistry, as well as to identify their difficulties when interpreting and using chemical representations. While the TCC is a test on conceptual understanding, and the TCR is mainly a test on content knowledge and understanding, the TRC is more an assessment of application and skill.

This study also attempts to ascertain to what extent students' understanding of chemical concepts influence their understanding of chemical representations, as well as their representational competence. It also attempts to compare students' with different levels of understanding of (i) chemical concepts, and (ii) chemical representations, in their representational competence in chemistry. Semi-structured interviews were subsequently conducted to gain further insights and understanding into selected students' conceptions of chemical representations and their representational competence. From learning theories and literature review, several cognitive variables are also found to have an influence on students' learning in chemistry. Hence, a further search was also conducted to examine the influence of selected cognitive variables namely: (i) prior knowledge, (ii) developmental level, (iii) working memory capacity, and (iv) learning orientations, on students' overall levels of representational competence in chemistry. Subsequently, the best predictor variable of representational competence was identified and a regression model with representational competence as the criterion variable was generated. Figure 3.3 shows the conceptual framework of the study.

In Chapter 4, methodology of the study will be discussed in detail.




Goal 1: to predict Y from a set of X variables
Goal 2: to understand how the various X variables impact Y
(X=independent/predictor variable; Y=dependent/criterion variable)

<u>Instruments used</u>

TCC = Test on Chemical Concepts
TCR = Test on Chemical Representations
TRC = Test on Representational Competence
CTSR = Classroom Test of Scientific Reasoning
LAQ = Learning Approach Questionnaire
DSBT = Digit Span Backwards Test
SSI = Semi-structured interview

**Figure 3.3**: Conceptual Framework of the Study