CHAPTER TWO

Making sense of prior knowledge and learning

As constructivists we see learners as mentally active agents struggling to make sense of the world. (Pines & West, 1986, p.584)

2.1 Introduction

In this chapter, the researcher aims to make sense of the research topic and the research questions accompanying it. By reviewing the relevant literature, the problems – both current and past – and the solutions surrounding the topic may be understood. According to Hart (1998), a topical literature review has a personal and a public dimension. The personal dimension is designed to develop the skills and abilities of the researcher, while the public dimension embodies the design features of the research and the educational purposes for carrying out independent research. This chapter emphasizes the public dimension of the literature, without necessarily excluding the personal dimension.

As indicated in Chapter 1, the purpose in this study was to explore and understand how students used their prior knowledge to construct understanding and generate meaning of scientific concepts, specifically in their learning of acids and bases. The review therefore focused on aspects related to students' prior understanding of acids and bases concepts and the construction of understanding and generation of meaning of related concepts. In addition, the literature study's focus was on the role of knowledge in learning, with particular reference to certain types of prior knowledge. The role of knowledge referred to here is its potential to enhance and/or inhibit knowledge construction and the generation of new meanings during learning.

The literature further illuminates on the nature of chemistry as a learning subject matter. Practical and theoretical aspects of chemistry and how these contribute to the outcomes of learning of acids and bases concepts are discussed. The literature review process was also important in the generation of a conceptual framework through which different views of learning could be used to evaluate the effect students' prior knowledge has on their (students') ability to learn (i.e. to construct understanding and generate meaning).

2.2 Understanding learning

For over a century (Biggs, 2003), the focus of research has been on developing the "one grand theory of learning" instead of exploring the ways students go about learning (p.11). However, Biggs concedes that this trend has been changing towards research in student learning. This study bears testimony to that change. Here, the objective was to understand learning – with specific focus on how students use their prior understanding of concepts during the learning of selected acid-base concepts.

Because of its importance for this study, learning has to be explained for contextual purposes. There are many definitions of learning, depending on one's view and context. Ormrod (2000) describes learning as a complex and multifaceted process with multiple definitions based on behavioural change and change in mental associations. Woolfolk (1998) describes learning as a process by which experience causes a permanent change in knowledge and one's behaviour. In fact Santrock's (2001) definition complements one aspect of Woolfolk's definition. That is, the contention that behavioural change is the outcome of learning. Santrock (2001) defines learning as a "relatively permanent change in behaviour that occurs through experience (p.238).

Wilson (1993) on the other hand describes learning in terms of "knowing". According to this definition, learning and knowledge are integral and inherent to everyday human activities. Here another dimension to that of change in behaviour and mental associations, namely that the learning object has to engage in some kind of activity for learning to occur is introduced. In addition, Kolb (1984) defines learning as "the process whereby knowledge is created through transformation of experience"(p.21).

The definitions of learning above clearly indicate the complexity of learning. However, the central point made about learning in the definitions indicates that learning involves some or other kind of change. What is not clear from these definitions though is how these changes are brought about when an individual engages in learning. Woolfolk (1998) clarifies this by setting a criterion for any change to be classified as learning. That is, "to qualify as learning, this change must be brought about by experience – by the interaction of a person with his or her environment" (Woolfolk, 1998, p.204–205). The "experience" referred to here is what the individual already knows (i.e. his or her prior knowledge).

From the definitions of learning earlier it can therefore be concluded that learning is a complex process that brings about temporary and permanent behavioural and cognitive changes through human activity. Some significant terms explaining what learning is and how it is brought about can be identified from the above definitions. These include "behavioural change", "mental (cognitive) associations", "human activity", "experience", "environment" and "interaction of the learner". At least three views on learning can then be derived from these terms, namely behavioural, cognitive and constructivist views.

2.2.1 Behavioural view on learning.

A major assumption of the behavioural perspective is the relationship between behaviour and the environment of the learning individual (Woolfolk, 1998). Behaviourism associates learning with stimuli and responses through the use of rewards, based on Thorndike's stimulus-response principle (von Glasersfeld, 1995). The environment is seen as a source of stimuli that influences an individual's responses.

2.2.2 Cognitive view on learning.

According to Woolfolk (1998), this view is "a general approach that views learning as an active mental process of acquiring, remembering and using knowledge" (p.246). Learning is seen as the product of attempts by individuals to make sense of the world by making use of all the mental tools at their disposal. The outcome of learning, according to this view, is knowledge. Knowledge is regarded as more than the end product of previous learning; it guides new learning (Woolfolk, 1998). In fact (Greeno, Collins & Resnick,

1996) the knowledge that students bring into the learning situation determines to a great extent their future learning.

2.2.3 Constructivist view on learning.

There is a host of constructivist views on learning (Woolfolk, 1998). Therefore, any discussion on constructivism must at least specify which constructivist type of learning is being referred to because of the different intellectual roots constructivism has. Some of the people leading the discussions on constructivism include Piaget, Bartlett, Bruner, Dewey and Vygotsky. Another reason for its (constructivism) diversity is the varied backgrounds of the people interested in it. For example, constructivist approaches are followed by people with a scientific or mathematical interest, and those in the fields of educational psychology, anthropology and computer education (Woolfolk, 1998).

These different backgrounds and interests have exposed different views on constructivism. Some of these emphasise the shared, social construction of knowledge. This also has led to different types of constructivism. Constructivism is divided into Moshman's three categories (Woolfolk, 1998), whose assumptions on teaching and learning are summarised in Table 4 below:

Table 4: Types of constructivism and their assumptions about teaching and learning

Type	Assumption about learning and knowledge	Example theories
Exogenous	Knowledge is acquired by constructing a representation of the outside world. Direct teaching, feedback and explanation affect learning. Knowledge is accurate to the extent that it reflects the "way things really are" in the outside world.	Atkinson and Shiffrin
Endogenous	Transforming, organising and reorganising previous knowledge, construct knowledge. Knowledge is not a mirror of the external world, even though experience influences thinking and thinking influences knowledge. Exploration and discovery are more important than teaching.	Piaget
Dialectical	Knowledge is constructed based on social interactions and experience. Knowledge reflects the outside world as filtered through and influenced by culture, language, beliefs, and interactions with others, direct teaching and modelling. Guided discovery, teaching, models and coaching, as well as the individual's prior knowledge, beliefs and thinking affect learning.	Vygotsky

Exogenous constructivism differs fundamentally from the other two because of its assumption that the world is "knowable" (Woolfolk, 1998), and that there is an objective world that an individual could understand. The other two views suggest that knowledge is constructed and is based not only on prior knowledge but also on cultural and social contexts. Constructivism can therefore be defined (Fosnot, 1996; Resnick, 1986) as a process of knowledge construction that combines cognition with, among others, motivation and self-directed learning, with a focus on the social context of learning. In this study, scientific learning or knowledge acquisition was viewed through the constructivist lens.

2.3 Understanding knowledge

So far in this discussion, the term "knowledge" has been used without explaining exactly what it is or what its role is. Understanding knowledge in the context of this study is of the utmost importance. Woolfolk (1998) describes knowledge as the outcome of learning – it is more than the end product of previous learning, it also guides new learning. On this basis, knowledge is an important component and source of learning. It is therefore essential to establish the role knowledge plays in learning. But it would be premature to attempt to understand how knowledge brings about learning before understanding what it is.

Knowledge has been defined and described differently by different people. The diverse descriptions of knowledge may be one of the reasons for the difference in understanding that people have about knowledge and subsequent views on how it is acquired: The *Concise Oxford English Dictionary* (2006) defines knowledge as "awareness of familiarity gained by experience"(p.789). In the *Cambridge International Dictionary of English* (2002) it is defined as an "understanding of or information about a subject which has been obtained by experience or study and which is either in a person's mind or possessed by people generally" (p. 787). Gage and Berliner (1992) define knowledge as "the ability to remember – recall or recognise – ideas, facts, and the like in a situation in which certain cues, signals, and clues are given to bring out effectively whatever knowledge has been stored" (p.43). Furthermore, according to Socrates in Plato's dialogue, *The Theaetetus,* knowledge is referred to as "justified true belief" (Wikipedia, The free encyclopaedia, 2006).

The definitions of knowledge here illustrate that knowledge is not a commodity that can be transferred from one mind to the other without transformation (Bettencourt, 1993). "Transformation" here means the generation of meaning using existing knowledge or experience. In the Oxford definition, “experience” stands out as reflecting the importance of prior knowledge in learning. It is a "tool" through which the individual becomes familiar with new information. In this case, knowledge plays a role in the individual being aware (familiar) of the new information. The definition given in the Cambridge dictionary introduces the term "understanding". According to this definition (The Cambridge's), it is difficult, if not impossible, for one to understand or know *how* or *why* something is done in the absence of experience or knowledge. Individuals need knowledge to construct new knowledge. In fact, Bettencourt (1993) asserts that "to know is, in some sense, to transform the object of knowledge"(p. 39).

In the latter two definitions of knowledge, previous interaction with the learning material or environment plays a crucial role. A person will recognise something if he or she can associate it with something similar that happened before. "Cues, signals and clues" indicate that the learning individual must have seen them before. They are a language the student can associate with and make sense of. For knowledge to be a "justified true belief" it is important that the individual is seen as "unique" in a learning environment. The term "unique" here is used to acknowledge that every individual enter a learning situation with a background (social, cultural, historical, language and beliefs) that influences the way they respond to learning. The individual would therefore have his or her own *truth* and *beliefs* that *justify* his or her actions in a learning situation. This concurs with Bettencourt's (1993) assertion that, "all we come to know is our own construction" (p.39).

The importance of the student in learning is also reflected in some constructivist views on learning. According to Driver and Bell (1986, p.444), constructivism views learning as an active process that engages the student to construct meaning. This construction could be from text, dialogue or physical experiences. The active construction of meaning is outlined as follows:

- Learning outcomes depend not only on the learning environment, but on what the student already knows: Students' conceptions, purposes and motivations influence the way they interact with learning material in various ways.

- Learning involves constructing meanings: People construct meaning to what they hear or see by generating links between their existing knowledge and new phenomena.
- The construction of meaning is a continuous and active process: When we learn we are actively hypothesizing, checking and possibly changing ideas as we interact with phenomena and other people.
- Belief and evaluation of meanings: Although students may successfully construct an intended meaning, they may be reluctant to accept or believe it.
- Students have the final *responsibility* for their learning. They decide what attention they give to a learning task, construct their own interpretation of meaning for the task and evaluate those meanings.

Since this study deals with exploring and understanding how students construct understanding and generate meaning during learning the constructivist framework of learning is a useful point of reference. According to this framework (Biggs, 2003) the construction of understanding by individuals depends on their motives and intentions; *on what they already know*; and *on how they use their prior knowledge*. The constructed meaning then becomes personal, since it depends on the individual's background, which includes his or her prior knowledge. On the whole, understanding how students learn or acquire science knowledge (through construction of understanding and generation of meaning) would be mostly focused on the individual's prior knowledge.

2.4 Knowledge acquisition

Acquiring knowledge and using it to solve problems should be the most important purpose of teaching. In any teaching situation, the objective is mainly to enhance the student's present level of knowledge. However, this would not be a simple task if one is not aware of the different types of knowledge and their effect on learning, especially learning with understanding. According to Shuell (1985), being aware of the different types of knowledge is important both for the theoretical and practical understanding of how knowledge is represented and for teaching and learning purposes.

As this study is about the quality and effect of prior knowledge (i.e. declarative, procedural and conditional) on students' understanding and use of prior knowledge, the three types of knowledge should be seen (Alexander *et al*., 1991) as distinct – the acquisition of one form of knowledge does not *automatically* and *immediately* guarantee another. In fact, Shuell (1985) contends that the acquisition of one type of knowledge does not automatically enable a person to perform a related task involving a different type of knowledge. For example, declarative knowledge does not necessarily translate into procedural knowledge or procedural knowledge into conditional knowledge. Therefore, one needs to ask how knowledge is acquired considering the different types of prior knowledge and knowledge in general.

Alexander *et al.* (1991) add that all forms of knowledge are interactive in that the presence or activation of one form of knowledge can directly or indirectly influence any other. This is the case provided there is restructuring/reorganisation of one type of knowledge into another. Reorganisation is possible if relevant prior knowledge is available, accessible and of reasonable amount (Dochy, 1992). Without necessary or relevant knowledge a student cannot be motivated to engage in the task or set specific goals relative to the task (Marzano & Kendall, 2007). The type or quality of knowledge acquired or constructed is influenced by one's use of existing knowledge.

2.4.1 Knowledge construction.

Learning or knowledge acquisition was described earlier as a complex process that brings about temporary and permanent behavioural and cognitive change through human activity (Ormrod, 2000; Woolfolk, 1998). However, how this happens was not explained. There are different views on how knowledge is acquired, which can be explained within "empiricism" and "nativism". Empiricism (Lawson, 1994) emphasises that all knowledge is derived from sensory experience of the external world. That is, the main source of knowledge is external to the acquirer thereof. Nativism, on the other hand, regards knowledge as derived from within the acquirer.

After a series of experiments on knowledge acquisition, Lawson (1994) concluded that knowledge acquisition involves complex interaction between sensory impressions, properties of the developing brain, and behaviour in a dynamic and changing environment. Understanding knowledge acquisition should therefore be carefully approached. That is, models, methods and procedures used for this purpose should describe elements (e.g. the quality of prior knowledge and the learning environment) that make knowledge acquisition complex for different individuals.

Since learning or knowledge acquisition is a complex process, its understanding should be through relevant methods or models (e.g. the constructivist view) of knowledge acquisition. The information-processing model and the equilibration theory (Kolb, 1984; Wilson, 1993; Woolfolk, 1998) could be used to explain knowledge construction. For example, Santrock (2001) gives four characteristics of the information-processing model, namely *encoding*, *strategy construction*, *transfer* and *meta-cognition*, which could be appropriately used to explain knowledge construction. Encoding, which is a key aspect of solving problems (Santrock, 2001), helps in the selection of *relevant* information and ignores irrelevant information. This selection is in agreement with Dochy's (1992) notion that one needs *relevant* prior knowledge to construct new and accurate knowledge. Strategic construction is used to coordinate the information with relevant prior knowledge to solve problems. One cannot reorganise or restructure knowledge if one does not possess relevant prior knowledge (Dochy, 1992). Transfer, for example, occurs when the student applies previous knowledge (prior knowledge) and experience during learning or problem solving (p.275). Meta-cognition within the information-processing model involves monitoring and reflecting on one's current knowledge (Santrock, 2001).

In terms of the nature of what is to be learned and how it could be taught, the information-processing model gives insight into how the nature of what is to be learned can be a barrier to learning. In the case of this study, chemistry will be the focus of what is to be taught and learned. In one of his studies, Johnstone (2000a) asks whether the teaching of chemistry is logical or psychological. Johnstone regards chemistry as both logical and psychological. The information-processing model explains the psychological aspect, while the logical aspects are based on its nature. Since the model emphasises the perception of incoming information, it would be ideal to explain the mental models of learners and the information that is finally processed in its three stages (sensory, short-term memory and long-term memory). The information-processing model explains the difficulty of learning chemistry in terms of students' capacity to handle such complexities in the form of perceived and constructed and reconstructed external information.

The equilibration theory, on the other hand, recognises the fact that organisms respond differently to environmental pressures. This is relevant to this study as it explains the different responses of individuals owing to their different academic backgrounds or to be more specific their different prior knowledge. As this study deals with knowledge construction and meaning generation, it is appropriate to explain it with a theory that considers the influence or the effects of previous learning environment (e.g. previous teaching and learning experiences) on a learner's ability to respond to new learning. The equilibration theory stresses the influence of environmental pressures in terms of the way students use their prior knowledge and intellectual skills to reason.

The complex interactions through which knowledge is acquired, is explained and a comparison is made between the information-processing model and equilibration theory. Knowledge acquisition of the three information-processing aspects is compared to the three aspects of the equilibration theory (Table 5).

Table 5: Knowledge acquisition: Comparison of the equilibration theory and the information-processing model.

Information-processing model	Equilibration theory
Sensory memory As information is made available from the external environment, it is stored in this memory for a short space of time. Information can be accepted in this memory through a *known pattern*.	**Assimilation** Assimilation can only take place if there is "the establishment of a *web of coordination* among schemata and among objects" (Karlsson & Mansory, 2003, p.14).
Short-term memory In this memory, information needs to go through two important stages if it is to be retained, namely *organisation* and repetition.	**Accommodation** At this stage of information processing "assimilation schemata must exist in advance". Accommodation occurs when existing *schemes* or operations are "modified to account for new experience" (Karlsson & Mansory, 2003, p.14)
Long-term memory Processed information from the short-term memory is unlimited and is *permanently stored* for later use. It stays as knowledge that can be used later.	**Equilibration** This is the final stage of information processing. At this stage differences of experience create a state of disequilibrium. This difference can only be resolved when a more *adaptive mode of thought is adopted* resulting eventually in understanding/ knowledge (Lawson 1994).

Piaget's equilibration theory involves three mental processes: "assimilation", "accommodation" and "equilibration" (Lawson, 1994, p.136–137). Incidentally, the mental processes of the information-processing model (sensory memory, short-term memory and long-term memory) are similar to those of the equilibration theory. In comparing the two models, it is apparent that two important aspects of the two models – namely "prior knowledge" and "mental models" – contribute to knowledge construction.

So far, the discussion about knowledge acquisition has demonstrated how information is processed (Table 5). However, processing is not the same for all individuals. It depends on the person's existing knowledge and the information coming from the learning situation (since it has already been established that not all individuals have the same knowledge or perceive information in the same way). The information to be processed is also not the same; it differs from one domain to the other. Therefore, its processing will not be the same.

In the light of this, different students will construct knowledge differently owing to their different prior knowledge. Different levels or types of prior knowledge will result in students developing different mental models in their attempt to make sense of the information at their disposal during knowledge construction. The view that knowledge is constructed is based on the following three interrelated aspects of learning (Resnick, 1989, p.1), namely:

- Learning is a process of knowledge construction, not of knowledge recording or absorption. Learning does not occur by recording information, but by interpreting it.
- Learning is knowledge dependent, and people use current knowledge to construct new knowledge. According to Glaser (1984), reasoning and learning are knowledge driven and those with rich knowledge reason more profoundly and elaborate as they study and thereby learn more effectively.
- Learning is highly tuned to the situation in which it takes place. That is, skills and knowledge are not independent of the contexts (mental, physical and social) in which they are practised.

Scientific learning (Glynn & Duit, 1995) is a dynamic construction process involving *building, organising* and *elaborating* on knowledge of the natural phenomena through conceptual models. Conceptual models, which are cognitive representations of a real-world process, are important and, together with prior knowledge, are a prerequisite for knowledge construction. Such models cannot be built if there is no relevant and adequate prior knowledge for them to build on. Conceptual models are therefore the cornerstones of knowledge construction (Glynn & Duit, 1995). However, this does not mean that students' mental models are necessarily valid, but are the product of students' prior knowledge, which is not always based on the science practised by the community. It is knowledge, as the student understands it. A student's conceptual models, and more specifically mental models, are not necessarily accurate representation of the scientifically valid conceptual understanding.

What is the difference, then, between conceptual models and mental models? Conceptual models (Norman, 1983), are 'tools' used to understand physical systems while mental models are "what people really have in their heads and what guides their use of things"(p.12). The difference between these models (Figure 2) can be attributed to students' different interpretations of learning material as a result of their prior knowledge. Ideally, a conceptual model and a mental model should be identical. The quality of prior knowledge determines the degree to which the student's mental model corresponds to the scientifically valid conceptual models learned (Glynn & Duit, 1995). Understanding conceptual and mental models of knowledge construction can be an effective tool for both the lecturer and students to apply during learning. The lecturer may use conceptual models to bridge the gap between conceptual models and mental models during learning. The student may use the gap to reflect on his or her limitations in understanding a concept.

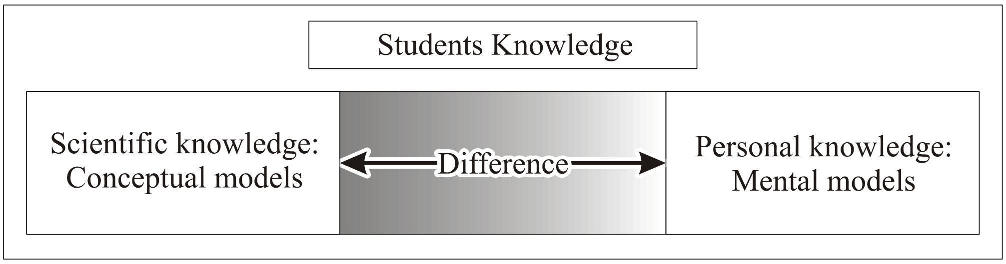

Figure 2: Students' personal mental models and/or scientifically valid conceptual models (Adapted from Glynn & Duit, 1995).

The discussion on conceptual and mental models earlier brings the research questions of this study into perspective: The aim was to establish the student's existing knowledge (first sub-question) in order to relate it to its relational use in practical work activities (second sub-question). The use of knowledge does not occur in the absence of mental or conceptual models. Meaningful learning (Glynn & Duit, 1995), especially in science – involves the active construction of conceptual models by relating existing knowledge to new experiences. Relations are formed between existing knowledge and the incoming information. However, this is hampered to a large extent by how students acquired their knowledge. This is most apparent where students have learned information without understanding it, or where information was learned by rote (Glynn & Duit, 1995).

2.4.2 All meaning is relational.

In the construction of conceptual models Glynn and Duit (1995) stress the importance of the relationship between existing knowledge and new experience. This relationship implies that constructing understanding and generating meaning cannot happen in a vacuum: One should have foundational knowledge in the form of prior knowledge from which to formulate relations. Pines (1985) retorts that there are relations between objects and events in the world and between concepts and propositions that denote these objects and events, without which relations, understanding and meaning would be difficult, if not impossible, to construct.

In fact, Glynn and Duit (1995) believe that a basic goal of scientific instruction is to be able to understand and explain the meaning of fundamental scientific concepts. The view, which follows from research questions in this study, is that understanding how students explain the meaning of concepts will enhance the lecturer's ability to understand students' mental models and how this resulted in the construction of concepts and their understanding of the relevant subject matter (acids and bases in this study).

2.5 Origin, nature and learning of science

The main purpose of teaching is to enhance and facilitate learning by students. However (Bodner, 1986), this is not always the case. There are many variables that interfere with the teaching and learning processes. In this study some of these factors and variables are investigated, specifically in relation to the learning of science. The variables have been found to have both a negative and positive effect on the teaching and learning processes (Dochy, 1992). Despite the fact that a variety of teaching methods and/or strategies (which include practical work commonly found in the teaching of science) were used, the problems with science learning are still difficult to overcome. One factor that was found to interfere with science learning is its "unique" nature (Ware, 2001).

2.5.1 The nature of science.

The nature of science is characterised by its origin. Science is rooted in two traditions (Mason, 1953), namely the "technical" and the "spiritual" traditions. In the technical tradition, practical experiences and skills were handed on and developed from one generation to the next (Mason, 1953); whereas in the spiritual tradition human aspirations and ideas were passed on and augmented. The origin and nature of science (Figure 3) show some parallelism with Millar's (2004) two domains of knowledge (the domain of real objects and observable properties and events, and the domain of ideas). The two domains illustrate and reflect on the role practical work plays in the teaching and learning of science.

In the late Middle Ages and in early modern times, the two traditions (Mason, 1953) converged, resulting in a "new tradition" of science (Figure 3). In this new tradition, the technical tradition appears to have dominated most of the scientific endeavours. This dominance is apparent in many discoveries made by craftsmen (Mason, 1953). Therefore, science was and is still viewed as more practical than most fields of study. This has consequently led to practical work being an important "tool" by which students could learn science. (The importance of practical work as a teaching strategy will be highlighted later in this discussion.).

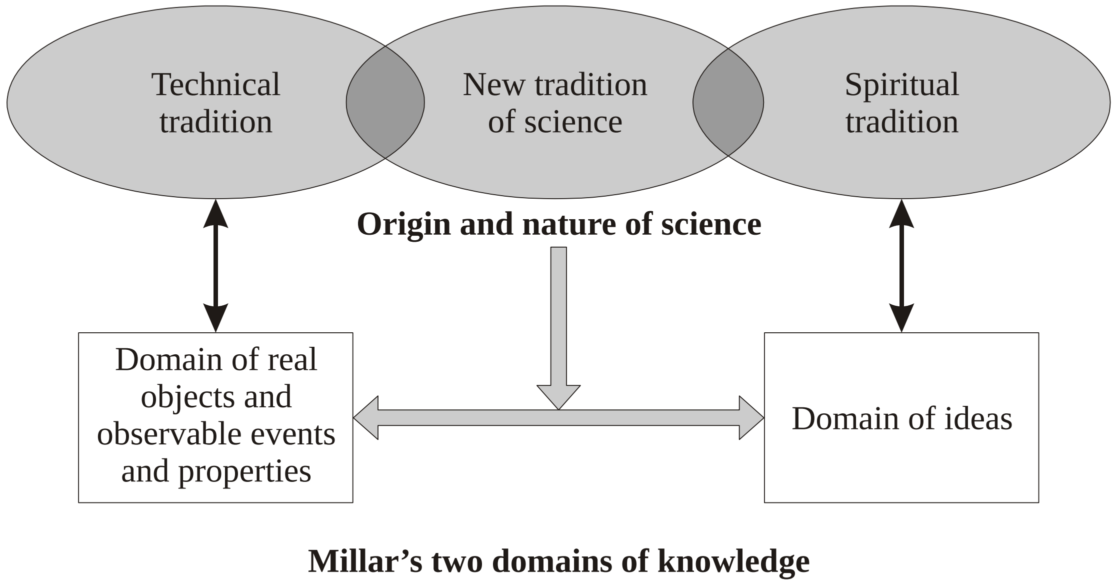

Figure 3: Parallelism between the origin and nature of science and Millar's two domains of knowledge.

Figure 3 demonstrates that science is a complex phenomenon. But what is science? There are many definitions: The *Concise Oxford English Dictionary* (2006) describes science as "the intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical world through observation and experiment"(p.1287). *Science for All Americans Online* (2007) describes science as a development and validation of ideas about the physical, biological, psychological and social worlds. According to this view, scientists share certain basic beliefs about what they do and how they do it in terms of the nature of the world and what can be learned about it. In fact, it asserts that –

- the scientific world is understandable in the sense that things and events in the universe occur in consistent patterns that are comprehensible through careful systematic study, and the universe is a vast single system in which the basic rules are the same everywhere;
- scientific areas are subject to change, i.e. science is a process of producing knowledge, and this process depends both on making careful

observations of phenomena and on inventing theories for making sense of those observations;

- scientific knowledge is durable (although this is the case scientists still reject the notion of attaining absolute truth and accept uncertainty as part of nature). The modification of ideas rather than their outright rejection is the norm in science; and
- science cannot provide complete answers to all questions, as there are many matters that cannot usefully be examined in a scientific way (for example, beliefs by their nature cannot be proved or disproved).

Science is organised into different fields. One of these is natural science. The fields are organised further into disciplines (such as physics, biology, chemistry and astronomy). These disciplines are interrelated in many cases. This study focuses on natural science – "the systematic study of the structure and behaviour of the physical world through observation and experiment" (The *Concise Oxford English Dictionary*, 2006, p.1287) with an emphasis on chemistry (acids and bases) – the study of the properties of materials and the changes that materials undergo (Brown, *et al*., 2006).

2.5.2 Nature of chemistry.

The term "nature", according to the *South African Concise Oxford Dictionary* (2006) describes the basic or inherent features, qualities or character of a person or thing. To claim to understand chemistry would therefore require that its inherent features and qualities form part of that understanding. Understanding chemistry could then lead to a variety of problems regarding the teaching and learning of chemistry being solved. These problems are not only confined to lecturers who attempt to explain and demonstrate chemistry as a phenomenon, but also to students who attempt to understand the relationships between objects and events and the meanings of these relationships.

However, this definition of nature does not indicate what the nature of chemistry is. Earlier in this discussion chemistry was defined as the study of the properties of materials and the changes that materials undergo. In order to study and understand chemistry would therefore entail understanding the properties of materials and the changes they undergo. The nature of chemistry is embedded in these properties and changes. Johnstone (2000a) uses a triangle (Figure 4) with different levels to describe the character of chemistry. These levels are –

- a *macroscopic* level, which describes what can be seen, touched and smelt;
- a *sub-microscopic* level, describes atoms, molecules, ions and structures of chemical compounds; and
- a *symbolic* or *representational* level, which describes the symbols, equations, molarity (c = n/v where c = concentration, n = number of moles, v = volume of solution), mathematical manipulation and graphs.

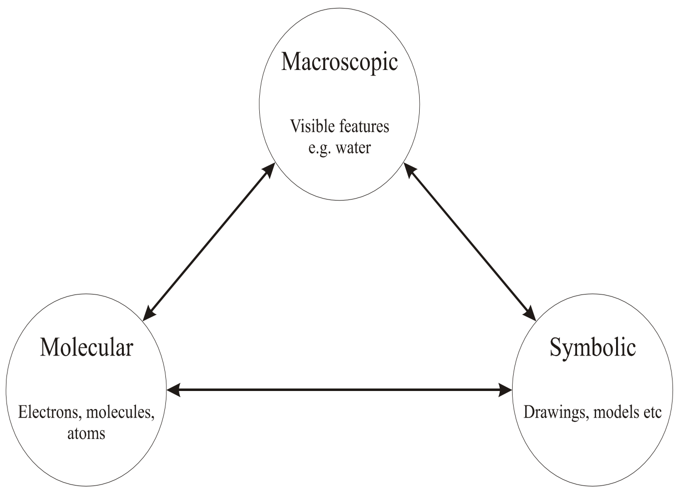

Figure 4: The triangular representation of the forms of matter in chemistry (Adapted from Johnstone, 1982).

In this form (Figure 4) chemistry becomes difficult for most students to comprehend – especially those with limited or less developed prior knowledge in a particular knowledge domain (Johnstone, 2000a). These students generally have an impoverished teaching and learning background, and a lack of previous exposure to relevant resources of learning. They find it difficult to comprehend and differentiate between the different forms of chemistry. The difficulty to comprehend chemistry leads to an information overload and ultimately to failure to understand concepts or processes in chemistry (Johnstone, 2000a).

Furthermore (Johnstone, 2000a), the difficulty students (especially first-year students) have in understanding chemistry is exacerbated by the fact that the three forms of chemistry are simultaneously introduced to students during teaching, leading to the overload of the "working space" in the students' memory. For example, the sub-microscopic level is not visible and students (especially those with inadequate/less developed relevant prior knowledge or experience) cannot visualise it or develop mental models to understand it at this level (Chittleborough, Treagust & Mocerino, 2002).

An appropriate approach to learning should therefore be sought to overcome this effect on student learning. In this study constructivism is viewed as the relevant learning theory to overcome problems associated with the learning of chemistry.

2.6 Learning science: A constructivist view

As mentioned earlier, the main purpose of teaching is to enhance student learning. This however depends on the outcomes that the lecturer envisages for his or her students to achieve. These envisaged outcomes are again dependent on the learning environment, which comprises but not limited to what is to be learned and who the student is. The lecturer has a choice of learning perspectives regarding how the outcome is to be achieved. The view here is that the outcome of scientific learning should enable a student to actively apply the knowledge acquired productively in his or her field of expertise.

To achieve this requires an appropriate theory of learning to serve as a referent. Constructivism was chosen as a referent in this study. According to Ishii (2003) the main tenet of constructivism is its recognition of people as constructors of their own understanding of the world. It focuses on the importance of the individual in the learning situation. Therefore the successful enhancement of learning science lies in the understanding of the student. In other words, the factors that affect the student should be better understood if meaningful teaching is to be achieved. The aim with this study is therefore to understand how students with diverse teaching and learning backgrounds receive information and use it to construct understanding and/or generate meaning. Based on Bodner's (1986) contention that teaching does not necessarily result in learning, the view is that this is the case because each student brings into the learning situation different prior knowledge, which they would use to interpret information and construct new knowledge. It is the difference in quality of prior knowledge that influence if learning does or does not take place during teaching. It is therefore imperative for lecturers to understand students' diverse knowledge backgrounds if they are to succeed in their meaningful teaching.

In the light of what constructivism is and how it can be used, could it be said that it contrasts fields such as mathematics and science, where knowledge is viewed as true facts, principles, theorems and laws? Ishii (2003) retorts that constructivism does not question the interpretation of simple arithmetic or the notion of gravity, but merely contends that each person comes to construct his or her own conclusions and conceptions. Ishii further contends that these individually constructed conceptions are personally valued, whether or not they are consistent with what the field deems acceptable. The aim here is therefore to understand these personally constructed conceptions through their usage during learning.

The domain of chemistry (acids and bases) was chosen as the focus of this study owing to the variety of problems encountered by both lecturers and students in this field (De Jong, 2000; Johnstone, 2000a; Johnstone, 1991b and Taber, 2000). These teaching and learning problems are not confined to any level of learning, but are encountered at all levels, including university. In his article, "Crossing the borders: Chemical education research and teaching practice", De Jong (2000) identified problems at both school and university level. Some of the identified problems especially at school level included students viewing chemistry as a "dirty discipline" with difficult concepts to understand; and teachers finding repeated explanation and demonstration ineffective and frustrating to both themselves and students.

At university level, De Jong (2000) found that students complained that laboratory courses (such as chemistry) involved many boring "cookbook" problems instead of challenging tasks for exploring new areas, while lecturers complained that many students were not able to connect lecture courses with laboratory courses and therefore could not apply theoretical knowledge in a practical context. In addition, De Jong cites problems with the curriculum. According to his study, the curriculum was overloaded with factual material; the course structure was vague and lacked modern topics. All these problems underlie the fact that meaningful learning cannot be achieved in the process. But what is the fundamental problem?

The fundamental problem in learning lies in factors pertaining to the whole learning process. Since there are many views on the teaching and learning of chemistry, including the researcher's view, there will also be many views on the sources of the problems faced. In fact, Johnstone attributes poor chemistry learning on how it is “transmitted”. The difficulty in learning chemistry lies in the failure to successfully "transmit" it. This failure he adds is due to three things: the transmission system (the methods used and the facilities available); the receiver (student) and the nature of their learning; and the nature of the message itself (chemistry). Johnstone further argues the merits of his assertions as follows (1991b, p.76):

- A great deal of effort has been expended on the techniques of transmission without asking too many questions about how young people learn.
- Not enough thought has been given to the message itself.
- The significance of the message to the learners has not been clarified for them.

Johnstone's arguments are significant relevant to this study. However, some views in this study differ fundamentally from Johnstone's. For example, how knowledge is acquired. The view here is that knowledge is not transmitted but is constructed (as set out by Resnick (1989) and summarised earlier in this discussion). The "message" that Johnstone (1991b) refers to here would be chemistry (acids and bases in the case of this study), and its nature and clarification would takes place when students construct understanding and generate meaning, with the lecturer's facilitation during learning.

The recognition of the *context* in which students learn, *how* they learn and *what* they learn should be viewed as vital for clarifying the “message” if meaningful learning is to be achieved. Meaningful learning refers to learning with understanding. Understanding, according to Perkins (1993), is a complex concept that goes beyond knowing. It requires one not only to regurgitate facts and demonstrate routine skills, but also to deal with a topic in a variety of thought provoking ways. In fact, Bailey and Garrat (2002) are of the opinion that "our graduates need to know their subject so that they can *explain, exploit* and *extend* it; universities need to provide a triple X experience"(p. 40).

It is on this basis that constructivism was identified in this study as the appropriate referent for the learning of science. In order to provide a "triple X experience", especially in chemistry, we must understand the nature of chemistry before engaging in the process of explaining how chemistry knowledge is constructed. This understanding should be seen as a prerequisite to the effective and successful teaching of science.

2.7 Teaching science

The two main theories of teaching and learning that focus on student activity are phenomenography and constructivism (Biggs, 2003). "Phenomenography" is based on the idea that a student's perspective defines what is learned, not what the lecturer intends should be learned (Marton, 1981). Therefore the student's perspective needs to be understood if teaching is to be effective and meaningful. Constructivism, on the other hand, emphasises the importance of what the student has to do to create knowledge (Steffe & Gale, 1995). It considers the activities performed by the student in a learning situation as important to constructing their understanding.

What the student needs to do, requires that the lecturer "knows" the student's prior understanding so as to prescribe relevant activities for the learning process.

In fact, Gelman and Greeno (1989) suggest three components needed for a theory of instruction to be considered meaningful teaching, namely –

- a theory of the knowledge that the lecturer wants students to acquire;
- a theory of the initial knowledge state of the learner; and
- the desired state of knowledge to be achieved by the instructional setting.

To have meaningful teaching requires answering what Glynn and Duit (1995) refer to as the frequently asked question: "How can I help my students to learn meaningfully?" (p.3).This question could be answered by helping students understand what they are being taught; and by helping students meet the two criteria for understanding, namely "connectedness" and "usefulness in social contexts" (Smith, 1991).

"Connectedness", which is initiated when an idea is understood to the extent that the student can appropriately represent it and connect it with his or her prior knowledge and beliefs in social contexts, describes "the structure of a person's knowledge". "Usefulness", which describes "the function of the person's knowledge", is when an idea is understood to the extent that the student can use that idea in successfully performing significant tasks appropriate to the social context in which it occurs (Smith, 1991). Based on these descriptions of the criterion, how then is the lecturer supposed to help students learn?

First, the lecturer should understand how the *structure* and *function* of student knowledge link during learning. Dunkin and Biddle (1974) suggest a model (Figure 5) to help understand the interaction between processes and factors that intervene in the teaching and learning situation. Understanding this interaction should help students to learn more meaningfully. Successful teaching or its failure depends to a large extent on the factors that intervene in learning, particularly the learner's prior knowledge. In fact, Dochy (1992) believes that the knowledge the learner already has, appears to exercise a considerable influence on the manner and degree to which new information is understood, stored and used.

Dunkin and Biddle (1974) suggested a three-phase model to explain the factors that affect learning:

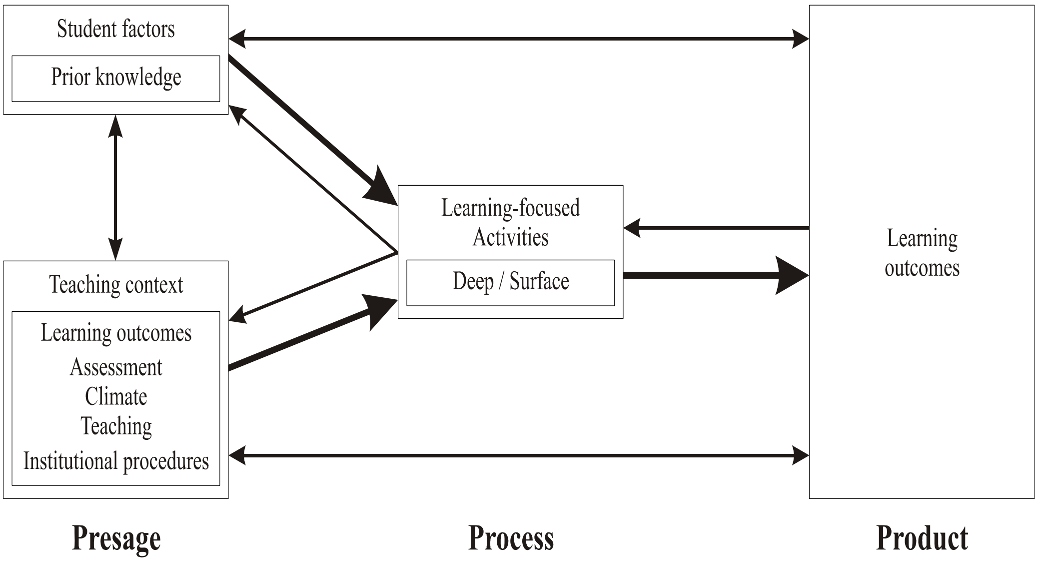

Figure 5: The three-phase model of teaching and learning (Adapted from Dunkin & Biddle, 1974).

They present these three factors (in Figure 5) as "presage", "process" and "product". Presage is the stage before learning takes place. It describes the student's interest in the topic, his or her ability to engage in the topic, and so on. This stage is student-based and describes in the case of this study the *relevant prior knowledge* the student has or does not have about the topic. The process stage refers to the time when learning takes place. This stage is teaching-context-based. It describes what is intended to be taught, how it will be taught and assessed, the expertise of the lecturer, the climate of the classroom, and so on. Product refers to the outcome of teaching and learning. In the context of this study, product would refer to the outcome of learning as a result of how students used their prior knowledge to construct understanding and generate meaning of concepts. In other words, it represents the personal knowledge of the student as derived from his or her prior knowledge, irrespective of the quality of the prior knowledge from which this new knowledge was constructed.

One of the purposes of teaching is to enable students to productively apply the knowledge they acquire in their fields of study and careers. This could be achieved if we understand how students from diverse learning backgrounds receive information and construct meaning from this information to acquire knowledge. Learning in general does not require understanding, but learning of a particular subject field such as chemistry does. It is therefore imperative that how students' learn or use their prior knowledge in learning should be understood, because (Glynn, Yeanny, & Britton, 1991) "no two students learn exactly the same thing when they listen to a lesson, observe a demonstration, read a book, or do a laboratory activity" (p.6).

2.7.1 Understanding the process stage of teaching.

Learning was described earlier in this study as being an active and complex process in which key cognitive processes interact. The end product of these processes facilitates the construction of conceptual relations. The purpose as illustrated by the research questions here is to understand this construction of conceptual relations. According to Glynn *et al.*, (1991, p.6–7), this "construction of conceptual relations" means the learning of concepts as organised networks of related information, not as random lists of unrelated facts. This process is carried out through cognitive processes that construct relations among elements of information.

The process of establishing conceptual relations is cognitive and depends on the individual's prior knowledge, expectations and preconceptions. Therefore, it could be expected that students from different academic backgrounds would respond differently to the information they receive during learning. Students exhibit differences because of what they already know, which affects the outcomes of their meaning construction. These differences, according to Champagne and Bunce (1991), stem from the fact that students relate new information, ideas and experiences to the most appropriate existing knowledge. However, existing student information is not always what the lecturer believes. This means that it does not always facilitate learning. In fact, it has the potential to impede learning. As has already been indicated, learning is a very complex matter. How then can it be explored and understood? This study attempts to understand what happens during teaching by reflecting on the equilibration theory of Piaget and the information-processing model.

According to the equilibration theory (Lawson, 1994), organisms respond differently to environmental pressures because of their genetic make-up. In a teaching and learning situation this could be compared to the different responses students from different academic, cultural, social and economic backgrounds students exhibit during teaching and learning. Students with different teaching and learning backgrounds will have different prior knowledge and will respond differently to teaching. According to the equilibration theory, students also reorganise prior knowledge differently. Understanding the teaching and learning process (process stage) by way of the equilibration theory would enable the lecturer to actively engage, both mentally and physically, with the students (Lawson, 1994). A lecturer who is knowledgeable about the developmental pathways of students could therefore produce the environmental pressures (learning activities) that enable students to construct understanding and generate meaning of more complex and adapted thought processes. In other words, the lecturer could be an instigator of disequilibrium and can provide pieces of the intellectual puzzle for the students to put together (Lawson, 1994, p.135–139).

The information-processing model, which is also a three-stage process, could be useful owing to its dependence on students' prior knowledge for the interpretation of incoming information. In processing the information, the observed information prompts students to perceive what they are observing. The interpretation and comparison of information by the student is dependent on prior knowledge. During the interpretation stage, misunderstanding (disequilibrium) between prior knowledge and new information becomes apparent. This misunderstanding occurs in the short-term memory. According to Lawson, disequilibrium or misunderstanding occurs when "a mismatch exists between the poorly adapted mental structure and sometimes mental behaviour" (Lawson, 1994, p.138).

This mismatch is not confined to a misunderstanding of the content; other factors, such as the culture of science, the language of science and the language of teaching also play a role. Understanding the culture of scientific teaching, the language used to teach science and the language of science are of the utmost importance if any meaningful teaching and/or learning is to be achieved.

2.7.2 Culture of science teaching.

A definition of culture in the context of this study is necessary. Different people depending on the context in which they wanted to use it have defined culture differently. For this study, culture is defined in relation to learning so that its manifestation can be better understood. Culture also needs to be understood in terms of the way students learn chemistry, and how students respond to learning based on their cultural backgrounds. In fact, Cobern and Aikenhead (2003) see learning as making meaning within a cultural milieu. Within that cultural milieu this study poses the question as to how students use their prior knowledge (which is a part of their cultural knowledge background) to generate meaning, especially considering their diverse cultural backgrounds.

An appropriate definition of culture is therefore essential to highlight its effects on learning. Culture in Geertz's (1973) view is "an ordered system of meaning and symbols, in terms of which interaction takes place" (p.5). On the basis of this definition, students entering any learning environment would bring their own culture into a different culture (the culture of chemistry education in the case of this study). The definition of culture above allows for many different aspects. The "system" has different attributes: Cobern and Aikenhead (2003, p.41) list communication (psycholinguistic and socio-linguistic); social structures (authority, participant interactions); skills (psychomotor and cognitive); customs; norms; attitudes; values; beliefs; expectations; cognition; material artefacts; technological know-how; and the worldview as constituting this culture. Similarly, Maddock (1981) sees culture as an accumulation of attributes such as beliefs, attitudes, technologies, language, leadership and authority structures. All these attributes are subcultures of a larger culture of learning (Cobern & Aikenhead, 2003).

The subculture and attributes of a student's culture will influence the way he or she views and responds to learning. Students' culture is usually different to or in competition with the culture that they are expected to embrace (in this case, chemistry). According to Cobern and Aikenhead (2003) students' successful or failure in learning will depend on whether the subculture of chemistry (which the student must learn) is in harmony or not with their everyday culture and whether it supports their view of the world. If this subculture (chemistry) is at odds with their world, the instruction tends to disrupt the students' view of the world. This forces the student to reconstruct a new meaning, which – in most cases – is not valid or what the lecturer intended. The influence of culture on students' prior knowledge should also be considered when assertions or conclusions about the quality and effect of their prior knowledge on the outcomes of learning are made.

2.7.3 The language of science and the language of scientific teaching.

In addition to prior knowledge and culture as factors that influence chemistry learning, the language of communication is also important. Language here refers to chemistry as having its own language and to English (which is a second language for the majority of students*)* as a medium of instruction in many schools and universities in South Africa. Students have to engage in many interpretations before the content of chemistry could be understood. Understanding here means eliciting the full set of elements that a person has in memory about what is to be learned (Gunstone & White, 1992). Understanding also involves the use of different parts to construct conceptual relations. It is only through the understanding of the *message* (chemistry and its constituent parts) that meaningful construction can take place.

Understanding of the message or what is taught depends on whether the sender of the message and the receiver of that message understand each other (Figure 6). In a teaching and learning situation, and particularly in a chemistry laboratory or classroom, the student (receiver) should understand the message and the language that the lecturer (sender) uses to communicate. The language of chemistry in this study refers to the representations (three levels of matter: macro-, micro-; and symbolic levels) used in chemistry. The message is the content and form passed to the receiver by the sender (Freysen, Briel, Potgieter, van Graan & van Niekerk, 1989).

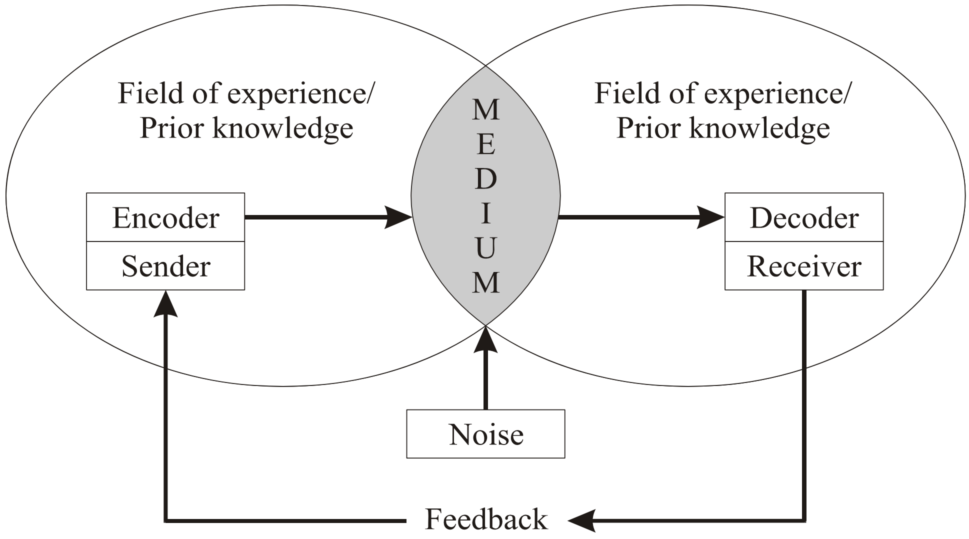

Figure 6: The communication model (Schramm's adaptation of Shannon's model).

The process by which information reaches the intended recipient is demonstrated in Figure 6. Two individuals with different experiences and prior knowledge engage in the process of learning at different levels of knowledge. They communicate through the content of what is taught. Noise interferes with understanding. Different levels of knowledge, the language of communication and the language of science are all regarded as noise (Freysen *et al*., 1989). In a situation where there is a lot of noise there would not be understanding.

Noise is present in communication if the sender (lecturer) sends the message in a form that is unintelligible to the receiver (student). The student is then not able to relate what the lecturer is saying to any of his or her prior knowledge, or it is not in a well-structured form that may be related to previous knowledge. If the information fails to reach the student in an intelligible form, the student will be unable to construct new knowledge – even if he or she has relevant prior knowledge. The power of perception would then fail. How do students then engage in learning in such situations, especially if they have to perform a practical work activity? How do they engage actively, based on their prior knowledge, in key cognitive processes? These are some of the questions that an attempt was made in this study to answer them.

2.8 Practical work in science teaching

Practical work as part of the teaching of science has a long history, and has gone through many changes. Many research studies and reviews (Hofstein & Lunetta 1982; Woolnough & Allsop, 1985) have elucidated conflicting views of what practical work can and cannot do as far as enhancing learning of science. In this study, however, the focus is not on whether or not practical work can enhance learning. Practical work, in this sense, is regarded as an integral part of scientific teaching and learning, since it promotes the active participation of students in their own learning. In fact, practical work was used in this study to access students' thought processes (their use of prior knowledge during meaning construction).

Practical work plays a critical role in the understanding of the empirical component of this study. It would not have been possible to explore and understand how students construct knowledge from their prior knowledge and experience in the learning of chemistry without the use of practical work. The reason for this is that some of the students' decisions could be inferred from their practical activities. In order to understand these inferences, one has to understand what is meant by practical work as a teaching strategy in science learning.

According to Hegarty-Hazel (1990), teaching strategies are "highly complex instructional procedures, which reflect the overall approach employed by the teacher or course" (p. 4). The emphasis here is an *encompassing activity* that includes techniques, methods and tactics. In other words, strategy is broader than techniques, tactics and methods. It is important that the meanings of these terms are not confused as this may lead to situations where strategies are compared to tactics, or methods to techniques, or different methods to each other –with ambiguous results.

People define practical work differently, depending on the environment in which practical work is conducted. Practical work in this study is defined on the basis of where it is conducted. That is, in a laboratory. The definition of practical work relevant to this study is therefore that of Hegarty-Hazel (1990), which states that practical work is "the work taking place in a purposely assigned environment where students engage in planned learning experiences, and interact with materials to observe and understand phenomena" (p.4). The terms in this definition relevant to this study are emphasised: it is about *observing* students *engaging* in practical activities that have a certain *purpose*. It is also about students constructing understanding from the phenomena they themselves observe and generate meanings with the help of their prior knowledge and experience.

The main concern of any scientific teaching endeavour should be to enhance active learning. Practical work is one of the teaching strategies that aim to achieve this goal. It promotes learning by engaging students in practical activities, both physically and mentally. Potential users of this strategy should ask whether it does indeed enhance learning. How it enhances learning should also be established. In order to answer these questions one first has to find out what "enhancing learning" means and which kind of learning is involved. In other words, the aim of practical work should be clear to students, lecturers and curriculum developers.

2.8.1 Aims of practical work.

Practical work has been used for different purposes in different teaching settings. Most teachers claim to use it to enhance conceptual understanding and develop procedural skills in the application of science. The conflicting outcomes yielded by practical work could point to the fact that the *aims or purposes* may not have been the same, or practical work may have been used incorrectly to achieve these aims and purposes. Understanding the purposes of practical work may help in planning and attaining consistent objectives. Understanding the purpose should also help students with diverse prior knowledge and experience to apply these experiences to their understanding or what is required of them. It is also important that in determining the aims of practical work that we understand the student's readiness and the environment for achieving those aims. Clearly defined purposes for practical work should enhance the achievement of outcomes.

Earlier in this discussion, Driver and Bell (1986) listed factors that affect learning; this include learning through practical (see section 2.3). These factors underline the importance of the *individual* student and the *clarity* of what the exact *purpose or aim* of practical work (a particular task) is in a given learning environment. In an attempt to illustrate how different outcomes of practical work may be achieved, Klainin (1991) reported about the different approaches to the use of practical work over time. Prior to the 1960s, practical work was primarily used to demonstrate or confirm factual and theoretical aspects of the science course. In the curricula of the 1960s and 1970s, it was used as a tool for raising problems, developing enquiry skills and providing opportunities for *discovery*, while in the 'new' curricula it has been assigned a role in the learning of scientific enquiry and for developing cognitive abilities of the student.

With so many aims it is not surprising that practical work as a teaching strategy has attracted such diverse views as to its effectiveness or lack thereof in enhancing learning. As this study is about understanding how students construct understanding and generate meaning in learning, this study was guided by Ausubel's view that "the laboratory gives the students appreciation of the spirit and method of science … promotes problem-solving, analytic and generalization ability … (and) provides students with some understanding of the nature of science" (Ausubel, 1968, p. 345).

In addition to the guide provided by Ausubel, some classification of the goals of laboratory instruction in science education proposed by Shulman and Tamir (1973) can reinforce understanding of how students construct understanding and generate meaning by way of practical activities. These include –

- arousing and maintaining interest, attitude, satisfaction, open-mindedness and curiosity in science;
- developing creative thinking and problem-solving abilities;
- developing aspects of scientific thinking and the scientific method (e.g. formulating hypotheses and making assumptions);
- developing conceptual understanding and intellectual ability; and
- developing practical abilities (for example, designing and executing investigations, observations, recording data, and analysing and interpreting results).

The goals of practical work described above highlight the aim in this study; namely understanding the influence a students' prior knowledge has in learning new things in a particular field of study. It should also be stressed that it is not only the student's prior knowledge that is important in a learning situation, but also the lecturer's knowledge of the student's level of readiness. This is especially true for the learning of chemistry through practical work, if one considers the limited exposure to practical work most students in developing countries (such as South Africa) had in the past.

2.8.2 Practical work as a teaching strategy.

In order to understand practical work as a teaching strategy, one must first clarify exactly *what* needs to be understood, *when* it needs to be understood and *where* it needs to be understood. In other words, we need a holistic understanding of practical work as a teaching strategy. Earlier in this study, it was indicated that research into practical work has yielded conflicting conclusions about its effectiveness owing to unclear understanding of terms. Lunetta and Hofstein, in their 1982 review of research in practical work, concluded that previous studies on practical work were narrow in their approach. They elicited narrow findings on techniques, lecturer and student characteristics, and learning outcomes. The two researchers also listed specific weaknesses of past research studies, indicating where they were too narrow in their approach. These included:

- Selection and control variables: Important *variables* describing student *abilities* and *attitudes* were not examined. Researchers failed to note the kind of prior laboratory experience students had.
- Group size: Researchers used comparatively small groups. Studies lacked diversity in the form of less able or more able students.
- Instrumentation: Researchers were more concerned with the nature of the treatment than with the *validity* of the instruments used to measure outcomes.

These shortcomings should serve as a guiding light for this study. The researcher should acquaint himself with recorded failures and successes in practical work as teaching strategy on the basis of cognitive goals (intellectual development, creative thinking and problem solving), practical goals and affective goals (attitude and interest).

2.8.3 Cognitive goals: intellectual development.

One of the reasons practical work fails to enhance cognitive abilities during learning (Woolnough & Allsop, 1985) is because lecturers attempt to use practical work to explain theoretical concepts to which it is ill-suited, instead of concentrating on developing basic processing skills, a feel for natural phenomena and problem-solving skills. According to the researchers, the fact that students doing introductory science courses have not developed the capacity for "formal" thinking, which the abstract content of these courses require, is the main contributor to this failure.

In addition, Bennett and O'Neale (1998) explain that practical work sometimes fails to enhance creative thinking and problem solving because students often engage in practical work mechanically (carrying out the manipulations without understanding them). Students perform actions without understanding their meaning and how outcomes are arrived at. This is illustrated by the passive manner in which students are often expected to engage in practical work activities with no understanding of what they are doing. This is especially true if lecturers dominate the interaction between themselves and students. According to Llewellyn (2002), the lecturer's dominance focuses learning on changing behaviour rather than promoting understanding.

This researcher concurs with Llewellyn (2002) that learning should be more cognitive and not based on the direct transfer of knowledge from the lecturer to the student. Students are ‘unique’ and their responses to or construction of learning should be viewed as unique because of the differences in their domain-specific prior knowledge and experiences. That is, students' knowledge is the product of their own construction. In fact, Novak (1991) believes that in order to educate students it is important that students and lecturers "seek to share their meanings in classroom and laboratory experiences". Novak further stresses the fact that learning is the responsibility of the individual student and that it cannot be shared (p.64).

2.8.4 Creative thinking and problem solving.

It has been reported (Fensham, 1991) that creative thinking is enhanced if students engage in open-ended, process-oriented practical activities. This, it is argued, is possible if students are presented with a problem for which no standard solution method is immediately shown, thus necessitating a creative problem-solving response. In addition, Reif and St John (1979) credit practical work with the potential to develop higher level skills, such as applying a theory to solve a problem, modifying a practical task to find a different quantity and predicting the effect of an error in a practical procedure.

In their 1999 study, Vianna, Sleet and Johnstone found that some practical tasks place a high load on students' working memories, resulting in them becoming ineffective. This, they add, is because students have to recall theory and techniques, make observations, follow instruction and interpret results. The researchers blame this "load" for students resorting to following recipes with little understanding of the work being done. In light of this, how do students with limited prior knowledge of chemistry and practical work experience "cope" with learning new material? Hart, Mulhal, Berry, Loughran and Gunstone (2000) found that "laboratory work often achieves little meaningful learning by students" (p.655) as the fundamental concern of many students in the laboratory is to complete their task. According to these authors (Hart *et al*., 2000) this may be valid because students do not fully comprehend the purpose of practical tasks

2.8.5 Practical goals

Practical work, according to Fensham (1991) can "enable students to integrate their experiences with materials and with phenomenon of science to conceptual aspects of these activities, and also to more formal schemes and models for practical investigations". This should involve both manual and intellectual abilities (p.198–199). But this is not always achieved, since lecturers do not always take the students' level of readiness into consideration before they engage in practical activities. In addition, in a 1999 article, Leach found that it is often assumed that students and lecturers share common epistemological and ontological ideas about the purpose of the investigation; the ways in which scientific models or theories are used to explain the behaviour of material objects and events; and the ways in which data are collected, analysed and used in drawing conclusions. This contributes to students not having enough relevant information to help them adjust their thinking towards the tasks at hand. In fact, (Leach, 1999) there is sufficient evidence to suggest that students do not share lecturers' assumptions about issues, except through direct teaching.

2.8.6 Affective goals: attitude and interest.

There have been numerous positive reports on the results 'affective goals' have on enhancing learning of practical work (e.g. Raghubir, 1979). According to Hegarty-Hazel (1991), lecturers need to have "knowledge about students' readiness to undertake laboratory work of certain kinds, their interests, motivations and career aspirations"(p.9). In other words, students' needs should be understood if their learning is to be enhanced through practical work or any other teaching strategy.

The brief discussion on the positive and negative aspects of practical work above affirms the view in this study that there is a need to focus on a holistic understanding of practical work as a teaching strategy. Understanding the influence of the major factor (prior knowledge) on the outcome of learning may be the start to understanding practical work as a teaching strategy. If the focus of understanding is through information-processing, it would shed light on the effect of information "load" on the process of physical and mental engagement and the resulting construction of understanding and generation of meaning during learning.

2.9 Conceptual framework

Many research studies[1] have been conducted on student learning in science. The focus of the studies was on conceptual understanding, misconceptions and practical work as a strategy in the teaching and learning of chemistry. In this study, however, the intention is not to reinvent the wheel; but to, in a way, heed Tobin's (1990) call for better questions and answers for improving learning. The focus in this study is therefore on the use and effect of students' prior knowledge on their learning. The intention is to explore students' understanding of chemistry concepts and how this understanding is used in practice.

Research into prior knowledge, especially in scientific learning, is still in its infancy stages compared with other research areas (Pines & West, 1986). The reason it was chosen as the focus in this study is because of the many learning problems that students encounter in the learning of chemistry. Many students, especially first-year students, find it difficult to learn chemistry concepts especially at the sub-micro and symbolic level (Harrison & Treagust, 2002). To address the many problems associated with learning, especially the learning of chemistry, it was important to understand the nature of the subject and the academic background of the individuals learning the subject.

Understanding individual students encompasses understanding the factors that affect their learning. Three factors are, according to this researcher, fundamental in influencing learning: language, culture and prior knowledge. However, it would not be possible to address all three factors sufficiently in this study; therefore culture and language were briefly discussed earlier in this study. These two factors cannot be isolated from the learning individual. They are inherent in his or her make-up in the way that they influence learning. The main focus of this study, therefore, was on *prior knowledge*. Prior knowledge has a powerful influence (Ausubel, 1968) on the knowledge learners attend to during learning. "Attending to knowledge" (Alexander, 1996, p.89) refers to how new information is perceived, what

[1] Bodner (1991), Champagne, Gunstone & Klopfer, (1985), Krajcik (1991), Smith (1991) and Gunstone and White (1992)

students judge to be relevant and important and what they understand and remember.

How students perceive new information, how they judge what is relevant and how they understand and remember it is only possible if their prior knowledge and its application is known and understood. Students' understanding of certain concepts and their application during learning and more specifically during practical work in chemistry is affected by their prior knowledge.

2.9.1 Mapping prior knowledge.

Prior knowledge, to a large extent, contributes to whether an individual acquires new knowledge or not. However, it is not enough to only know this. How this prior knowledge affects learning is more important, since this would allow lecturers to understand its effects. But this understanding is complicated by the fact that there are different types of prior knowledge affecting learning. In addition, prior knowledge is not the same for every individual. Different people have different types and 'amounts' of prior knowledge (therefore the effect would be different).

A clear definition of what exactly is meant by prior knowledge has to be drawn up to better understand our intentions. Dochy and Alexander (1995), in an article, highlighted some problems in educational research literature associated with the use of prior knowledge terminology. Their view, which this researcher concurs with, is that the inappropriate use of prior knowledge terminology could result in a study lacking specificity with the potential for poor or nonexistent precision in the way the researcher articulates and operationalises the knowledge constructs under study. The improper use of terminology could manifest itself in the questions the researcher asks, the measures he or she develops or the analysis he or she makes in a research study.

Some of the problems associated with the confusion in the use of prior knowledge research have been identified (Dochy & Alexander, 1995). These include the fact that most knowledge concepts used were undefined or vaguely defined, nominal definitions prevailed over real definitions, and different aspects of knowledge were referred to by the same terms or the same aspects of knowledge were referred to by different terms. The intention here is not to elaborate on these problems. Instead, they are used as a guide to avoid their repetition.

Research literature has provided many definitions of prior knowledge, all of which may not necessarily describe the same thing. A common denominator in these definitions however, is that prior knowledge is "what the learner already knows" and what the learner brings into the learning situation. For example, in their 1986 article, "Conceptual understanding and science learning: An interpretation of research within a sources-of-knowledge framework", Pines and West describe knowledge in terms of its source. They distinguish two types of knowledge – spontaneous knowledge and formal knowledge. "Spontaneous knowledge" refers to the knowledge that individuals (children) acquire spontaneously from their interactions with the environment. "Formal knowledge" on the other hand is described as knowledge acquired in a formal fashion through the intervention of teaching (school).

Spontaneous knowledge could also be classified as prior knowledge, since it is acquired informally before teaching or task of learning. According to Pines and West (1986), spontaneous knowledge is a product of efforts to make sense of the environment influenced and tempered by interactions, other people and influences such as television. This type of knowledge is brought into the learning situation as real and believed. It is knowledge that can affect learning in one-way or another. In their definition, Jonassen and Grabowski (1993), use two constructs to describe prior knowledge as knowledge that constitutes prerequisite knowledge. These two constructs are "prior achievement" and "structural knowledge". Prior achievement indicates the "amount of knowledge" an individual possesses, and could be determined or assessed through content tests (which determine the individual's entry-level knowledge and skills related to a specific content domain). Structural knowledge is an understanding of the constituent concepts and the relationship between them in a given content domain. In fact, Posner (1978) describes prior achievement as declarative knowledge (the knowledge of facts, the meaning of symbols and the concepts and principles of a particular field of study). Anderson, Reynolds, Schallert and Goetz (1977) refer to structural knowledge as procedural knowledge (i.e. knowledge of action, manipulation and skills).

Dochy and Alexander (1995) demonstrate the pervasive nature of prior knowledge in their definition. They describe it as "the whole of a person's knowledge" (p.227). At this stage it is difficult to imagine or understand what the term "whole" means. Dochy and Alexander (1995) describe prior knowledge as dynamic in nature; available before a certain learning task; structured; existing in multiple states (for example, declarative, procedural and conditional); explicit and tacit in nature; and containing conceptual and meta-cognitive components. In the context of this study, these characteristics are ideal.

Some of the above definitions serve no purpose in this study. For example, the limitation of Jonassen and Grabowski's definition is its apparent quantification of the individual's knowledge. Knowledge is not static; it changes with the passing of time and is constituted by different and interacting types of knowledge. Is it possible to measure the amount of knowledge an individual possesses? This question is answered later in this discussion when the conceptual mapping of prior knowledge is described. In Posner's (1978) definition, the limitation lies in equating prior achievement with declarative knowledge. Does this mean that achievement is an indicator of declarative knowledge or the interaction of all knowledge? These are just some of the questions highlighting the lack of consistency of the definitions and show what nominal definitions can do in terms of understanding concepts and/or their use.

Among the many definitions of prior knowledge above Dochy and Alexander's (1995) definition is appropriate to guide this study. One concern with this definition though, is the use of the term "whole" which appears ambiguous. In an attempt to bring clarity and uniformity to the understanding of prior knowledge, Dochy and Alexander (1995) proposed a conceptual map of prior knowledge, which demarcates prior knowledge into an array of subsidiary and interrelated concepts (Figure 7). This demarcation some extent, eases the concern expressed earlier.

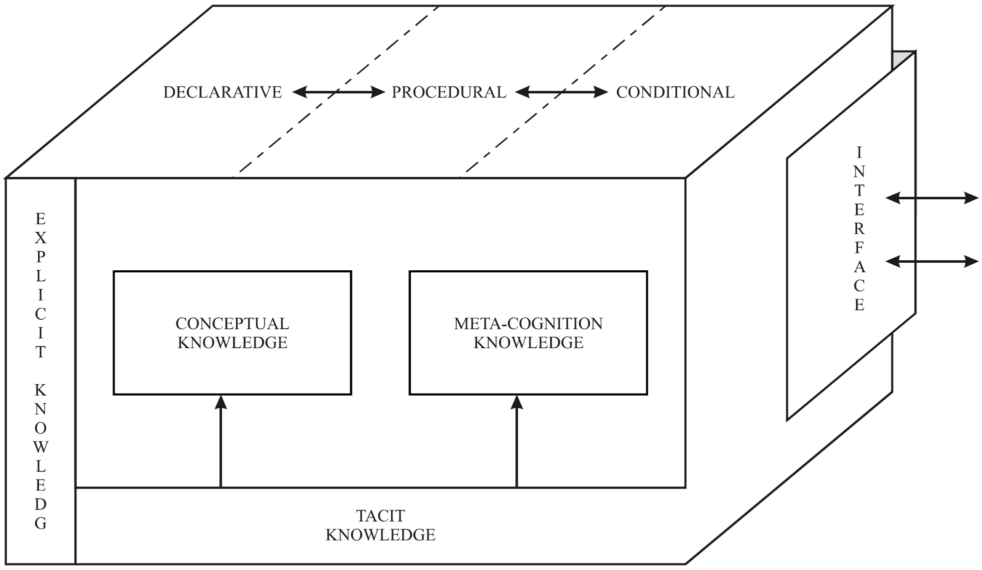

Figure 7: A conceptual map of prior knowledge (Adapted from Dochy & Alexander, 1995).

The figure (Figure 7) above illustrates the different components of prior knowledge. It does however not indicate the dynamics of the individual student's prior knowledge or the interactive nature of his/her knowledge. Therefore, Dochy and Alexander (1995) recognise that –

- individual knowledge is continually and significantly impacted on by its context and this should be considered in the interpretation of information;
- the figure is meant to be a conceptual map of prior knowledge terminology and not a processing model of knowledge use;
- the forms of knowledge represented in the map are *fluid* and *dynamic* (Not only do these forms vary between individuals, but also within individuals. In other words, the state of knowledge within the individual changes from one moment to the next and *cannot be adequately captured* in a one-dimensional or even multidimensional display.);
- the relative shape, size and positions of knowledge terms are largely arbitrary and are not intended to approximate the quality or quantity of each knowledge; and

- all forms of knowledge are *interactive*. The presence or activation of one form of knowledge can directly or indirectly influence any other (see Figure 8).

Because prior knowledge changes with every passing second and since the change happens so fast, the knower should have *sufficient* and *relevant* knowledge. The view here is that the rate of change in prior knowledge has a proportional relationship to the *amount and relevance* of the student's prior knowledge. In fact, Alexander (1992) asserts that what the student already knows (misconceptions or alternative conceptions), cannot easily be eliminated by simply adding a fact or formula to his/her existing knowledge base. They do not exist as isolated pieces of information, but as networks of related information. In light of the pervasive nature of prior knowledge and the difficulty to capture it (prior knowledge), the focus would be on conceptual and meta-cognitive aspects of prior knowledge at the declarative, procedural and conditional levels.

The conceptual component (Dochy & Alexander, 1995) is a convenient way of discussing the dimensions of prior knowledge that roughly corresponds to the individual's knowledge of ideas (since it entails ideas that are both formally and informally acquired). These concepts are domain-specific (concerned with one particular field of study, e.g. chemistry) and domain transcending in nature. In addition, the relationship between conceptual knowledge and meta-cognitive knowledge is considered within the conceptual map for better understanding of prior knowledge and its manifestation in learning. The relationship between conceptual knowledge and meta-cognitive knowledge should attend not only to the concepts that individuals know but also to the understandings that permit individuals to *monitor, assess*, and *regulate* these concepts.

So far it has been illustrated that prior knowledge is complex; which makes its understanding in terms of learning fundamental. There should therefore be an understanding of the inherent relationship between prior knowledge, teaching and learning – the effects of prior knowledge on teaching and learning need to be understood. In addition it should be understood that prior knowledge has both enhancing and inhibiting effects on teaching and learning.

2.9.2 Prior knowledge as a bridge and/or barrier in learning

Referring to prior knowledge as a "bridge" or "barrier" emphasises the importance thereof for learning and more specifically for meaningful learning. Prior knowledge should be seen as a bridge that allows one to achieve his or her learning goals. "Goals" here are the outcomes set for teaching. If there is no bridge, it means that there is a barrier (or something that prevents the achievement of certain outcomes or objectives). For example, (Johnstone, 2000a), the nature of chemistry is a barrier for students to learn it with understanding.

The constructivist view (which is the referent in this study) on learning and understanding involves the learner attempting to construct knowledge of some part of public knowledge (Pines & West, 1986). When a student constructs knowledge, his or her prior knowledge guides the type of knowledge being constructed. Therefore, to teach meaningfully one needs to understand prior knowledge, since it has the potential to inhibit (be a barrier) or enhance (be a bridge) knowledge acquisition. The way in which lecturers attempt to influence learning should stem from their understanding of the factors impacting on learning: how students learn, which factors influence their learning. How it influences their learning is vital if meaningful learning is to be successfully enhanced.

(i) Prior knowledge as a "bridge" towards meaningful learning

Dochy (1992) defines a facilitating effect as the effect most widely recognised as contributing positively to learning. There are three types of facilitating effects, but not all of them are a direct result of prior knowledge. These effects are –

- a direct effect of prior knowledge which facilitates the learning process and leads to better results;
- an indirect effect of prior knowledge which optimises the clarity of the study material; and

- an indirect effect of prior knowledge that optimises the use of instructional and learning time.

The effects of prior knowledge on learning depend on the quality of the individual's prior knowledge. This becomes apparent when students with limited prior knowledge are unable to understand what is being taught (as compared with those with relevant prior knowledge). Weinert (1989) as cited in Dochy (1992) adds that prior knowledge not only affects subsequent achievement directly but also indirectly as a result of intermediate instructional parameters. Dochy (1992) maintains that certain characteristics or qualities must be present for prior knowledge to have this effect on learning and its outcomes. For prior knowledge to be effective it must be –

- reasonable, complete and correct;
- of a reasonable amount;
- easily accessible; and
- available and well structured.

These variables cause interference that yield appropriate outcomes of learning.

(ii) Prior knowledge as "barrier" towards meaningful learning

Throughout this study, the relevance of prior knowledge to learning is emphasised. Relevant prior knowledge is also shown to yield positive learning outcomes. But prior knowledge also has the potential to inhibit learning. This is the case when prior knowledge is irrelevant (for example, as misconceptions or alternative conceptions). Misconceptions or alternative conceptions are prior knowledge that inhibits the facilitating effect in learning.

Dochy (1992) identified six factors that may inhibit learning, namely:

- *Incompleteness* (when parts of prior knowledge are correct but incomplete);
- *Misconceptions* (when students have the wrong conceptions about learning material);
- *Unavailability* (when students have prior knowledge that cannot be readily used);
- *Inaccessibility* (when prior knowledge is not immediately available as it is not organised in the correct structure for use);
- *Incorrect amount* (when one has prior knowledge in too large or small amounts); and
- *Structure* (when prior knowledge is either highly structured or not structured at all).

These factors are interrelated in their effect on the student's learning. The one affects the others in an iterative manner (see Figure 8).

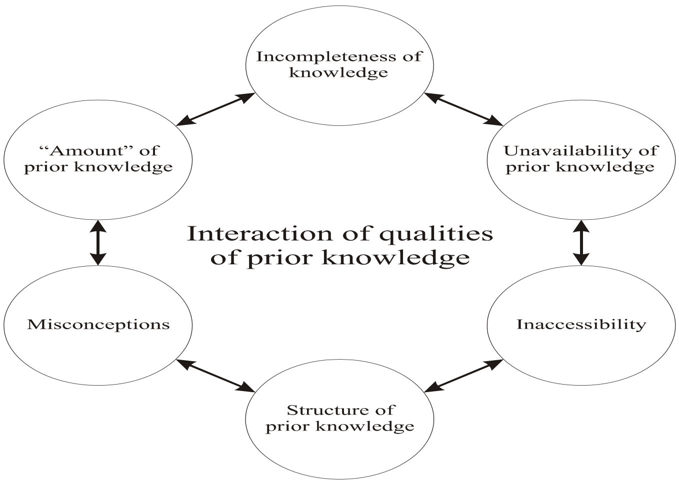

Figure 8: Interaction of qualities of prior knowledge as they affect learning.

For example, if the student's prior knowledge is incomplete (i.e. if parts of his or her prior knowledge are correct but incomplete), construction of understanding and meaning would not be complete – parts of the network of concepts to make meaning would be disorganised. Another example is the availability and structure (organisation) of prior knowledge: Knowledge, which is not well organised or well structured, is not available and cannot therefore, be readily used. Constructing conceptual relations during the learning process should be based on "organised networks of related information, not as lists of unrelated facts" (Glynn *et al*., 1991, p.6–7).

If the qualities mentioned above (Dochy, 1992) differ from the assumed perception, the facilitating effect of prior knowledge would be affected in some way. It would either increase or decrease. Prior knowledge may also be affected by the interaction of the facilitating effect and the inhibiting qualities (see Figure 9).

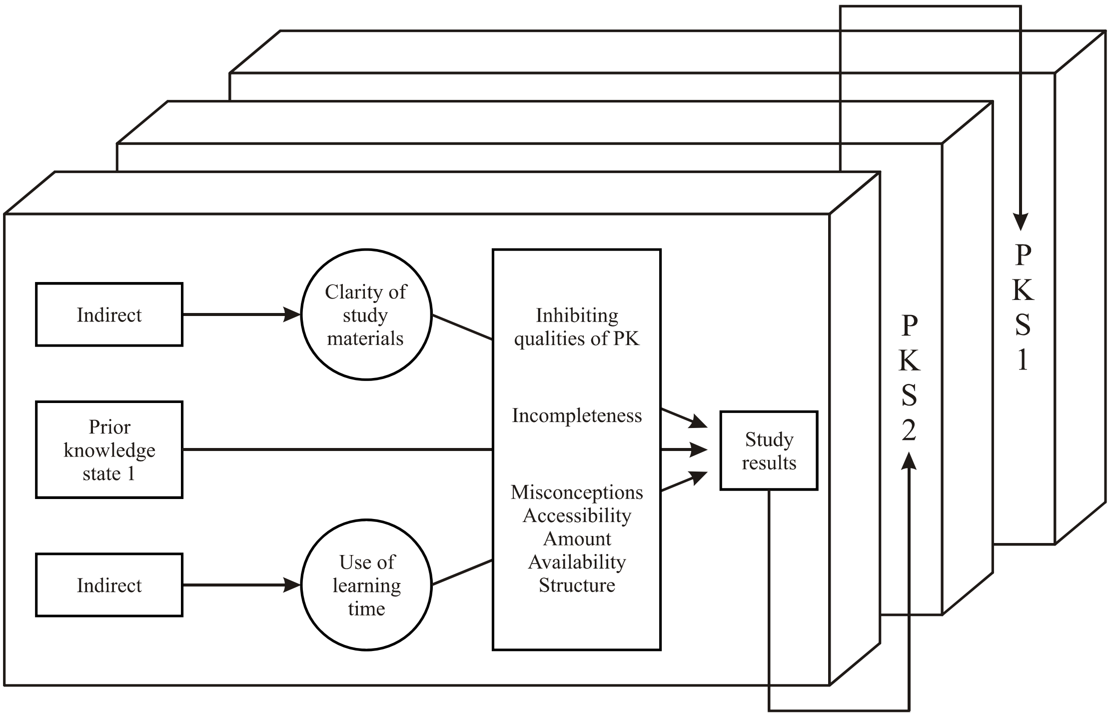

Figure 9: Interaction of inhibiting qualities and the facilitating effect of prior knowledge on learning (Adapted from Dochy, 1992).

The figure above (Figure 9) illustrates the cumulative effects and interaction of prior knowledge on the outcomes of learning. Before any learning takes place, the student is at a particular level of prior knowledge (prior knowledge state 1, or PKS1), which Bransford (1979), refers to as the "current level of previously acquired knowledge and skills"(p.141). As students learn, they move to a new level of prior knowledge (PKS2). During learning, the two factors of prior knowledge (facilitating effect and inhibiting effect) intervene and determine the outcomes of learning. The outcome is the result of teaching and intervention, both positive (e.g. the clarity of learning material and use of learning time) and negative (e.g. the incompleteness of prior knowledge, misconceptions and accessibility) effects of prior knowledge. The resulting learning is what is termed "study results" (Figure 9).

From the description of the effects of prior knowledge above its pervasive nature is apparent. Prior knowledge can affect learning in all spheres and levels of education, such as formal, informal or non-formal education. Prior knowledge is therefore an important aspect of learning and should be treated as such. If students are to be convinced to change the conceptions that inhibit their learning, understanding of their prior knowledge in most of its forms or dimensions and how it is applied in learning should be a priority. This should be accompanied by an understanding of learning and the processes involved during knowledge acquisition. It should also be indicated that the learning referred to in this discussion does not refer to learning in general, but to learning with understanding.

Understanding prior knowledge in its form and amount offers the opportunity to understand the major feature that affect student learning. This understanding (of prior knowledge) would promote teaching and enhance learning among students. In fact, Jonassen and Grabowski (1993) maintain that "the more prior knowledge an individual possesses, the less instructional support is needed; the less prior knowledge an individual possesses, the more support will be needed" (p. 426). This is not necessarily true, unless by "prior knowledge" the authors refer to prerequisite knowledge to the task that is being learned. The prior knowledge students have should be relevant to the specific domain and the task the student is supposed to perform, because not all types of prior knowledge enhance learning (as indicated in (ii) above).

2.10 Summary

The purpose of this chapter was to discuss literature relevant to the study. As this study is concerned with the use and effect of prior knowledge on the construction of understanding and generation of meaning during the learning of science concepts (and acids and bases in chemistry in particular), the literature study focused on topics specific to explaining past research relevant to the objectives of this study (with specific reference to the research questions posed). Topics in the literature specific to this study include: knowledge in general and prior knowledge in particular; learning and teaching in general and learning and teaching of science with particular reference to chemistry; the origins and nature of science; and practical work as a teaching strategy in science. It was also important to discuss practical work as a teaching strategy as it was used in this study to access students' thought processes in order to facilitate the study especially in situations that could not be directly observed.