CHAPTER FIVE

Findings, conclusion and recommendations

… (I) f we can understand meaning and, by doing so, improve our understanding of meaningful learning, then we will be in a position to improve education. (Pines, 1985, p.103)

5.1 Introduction

Science has often been perceived as being difficult to learn owing to its nature and the methods by which it is usually taught (Gabel, 1999). In fact (Johnstone, 1991a) it is usually taught without any effort to understand the students and the nature of the subject matter being taught. It is against this background that in this study an attempt was made to understand how students use their existing knowledge of the subject matter to construct understanding and generate meaning of concepts during learning.

There are generally two types of learning, namely "rote" learning and meaningful learning. Meaningful learning is learning in which students understand the constituent parts of concepts and can use them to generate meaning and make sense of the phenomena under study. As understanding is influenced by what the individual already knows (Gunstone & White, 1992), the emphasis of the study was to understand students' use of their prior knowledge to construct understanding of concepts during learning. "Prior knowledge" (Ausubel, 1968) refers to what one already knows.

Among factors contributing to students' abilities to construct understanding of concepts are previous teaching and learning environments, the socioeconomic situation, prior knowledge, language and cultural backgrounds of students. Prior knowledge was singled out for this study because it is considered the major factor influencing or determining the outcome of learning (Ausubel, 1968). The rationale in this study was that if what the student already knows (in terms of the subject matter content) is understood, most problems associated with the learning of that subject matter could to some extent be alleviated and his or her learning enhanced. Since it would have been practically impossible to study all aspects of students' prior knowledge, a research question was posed to focus the study. The main question was therefore phrased as follows to focus the study:

Main question

How do first-year chemistry students use prior knowledge in the learning of chemistry concepts?

Earlier in this study (Dochy & Alexander, 1995), knowledge or prior knowledge in particular was described as dynamic in nature, available before a certain learning task, structured, existing in multiple states, explicit and tacit and containing conceptual and meta-cognitive components (see subsection 2.9.1). The findings in this study were described through the three states or types (declarative, procedural and conditional) in which prior knowledge exists. Prior knowledge referred to in the main question is the knowledge specific to the learning of concepts (acids and bases) in chemistry, although other types of knowledge may have been used in the learning of concepts.

For a better understanding and for practical purposes, the research question of the study was further subdivided into two sub-questions, each focusing on particular aspects of prior knowledge. The subsidiary questions were aimed at eliciting specific knowledge students possessed at the time of the study. For example, the first sub-question relates mainly to whether students possessed the particular knowledge that was sought. The second sub-question on the other hand relates to the use of that knowledge in practical situations (e.g. during practical work activities). The knowledge elicited from the two sub-questions was categorised in the findings according to the three types of prior knowledge mentioned earlier.

The quality of declarative knowledge for example was established when students were probed to *specify* concepts (see subsection 4.2.2). The quality of procedural knowledge was established when students were observed and probed on the basis of their manipulative actions of the apparatus during practical work activities. Conditional knowledge, which is inherent in the declarative and procedural types of knowledge (Schunk, 1991), was determined from the *decisions* they made in their responses of the prior knowledge state test (PKST) and when they were probed to use the concepts according to their understanding of such concepts.

The sub-questions were phrased as follows:

Sub-question 1

What is students' understanding of selected chemistry concepts and processes before engaging in a first-year practical work activity?

The responses to this question established students' prior knowledge or understanding of certain concepts mainly by way of a prior knowledge state test. The test was conducted before students engaged in practical work activities. The researcher further probed understanding of students' understanding of concepts by simultaneously observing and interviewing them during practical work activities.

Sub-question 2

How do students use prior knowledge of selected chemistry concepts and practical work processes to construct understanding and generate meaning during learning?

This question was answered mostly by responses from students during practical work activities. Students were observed and interviewed based on the researcher’s inference of their activities (manipulation of apparatus). The aim, as is apparent from the question, was to establish how students used their prior knowledge or understanding to manipulate information in response to the demands of practical work activities.

5.2 Description of the analysis framework

The findings in this study are the product of a process to understand how students constructed understanding and generated meaning in the learning of concepts in chemistry on the basis of their prior knowledge. Individual findings were not necessarily responses to individual research questions or parts thereof. The nature of the subject of research for this study (being "prior knowledge") is such that individual research questions could not be directly responded to by individual findings. This is so because of the fluid, interactive and dynamic (Alexander, *et al*., 1991) nature of knowledge in general and prior knowledge in particular. Knowledge varies between individuals as well as within individuals as a result of personal, task or contextual variables (Alexander *et al*., 1991).

The findings are based on the analysis of information from all the research questions individually and/or in their interaction. In other words, the findings are a product of knowledge interaction as understood and used by individual students in their attempts to understand concepts and generate meaning. The information from each student was individually analysed because of the variations in knowledge between individuals as well as within individuals (Alexander *et al.,* 1991). The findings were however based on the synthesis of information from all three cases.

In order to better facilitate the analysis of students' prior knowledge within the scope of the three types of knowledge, a framework (Figure 13) was developed.

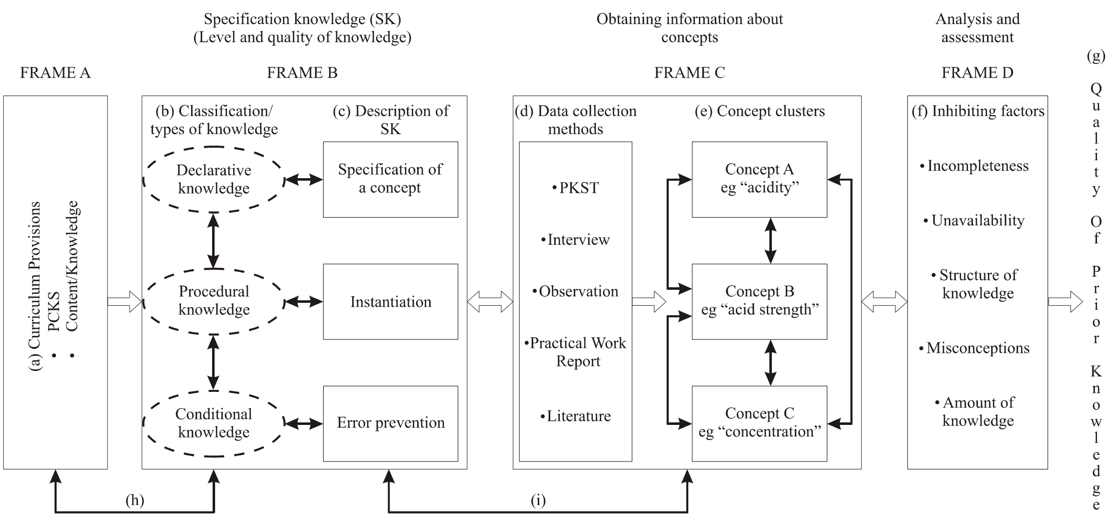

Figure 13: Framework for assessing prior knowledge and its usage.

This framework was based on Treagust's (1995) development of a diagnostic instrument for identifying students' conceptions in specific scientific content areas. Treagust's process comprised ten steps within three broad areas namely; *defining the content*, *obtaining information about conceptions*, and *developing a diagnostic instrument* (see sub-section 3.3.1). The framework

(Treagust's) was adapted for this study to indicate the following areas: specific curriculum provisions; PCKS; content/knowledge (FRAME A); *specification knowledge* (FRAME B). Specification knowledge assists in the determination of assessment criteria of knowledge supposed to have been learned (based on contents of FRAME A); *obtaining information about concepts* (FRAME C) and classifying it into concept clusters; and *analysis and assessment* (FRAME D) of the quality (inhibitors of prior knowledge used here as reference of quality) and how students construct understanding and generate meaning from their conceptions.

- *Specification knowledge* (FRAME B)

For an accurate analysis of concepts as appropriate knowledge and functionally useful building blocks of knowledge, it was important to first specify these concepts. The concepts were specified as specification knowledge (see section 3.4.4). Students' prior knowledge was therefore analysed within the realm of specification knowledge to determine its quality in relation to what was supposed to have been learned as prescribed by the curriculum and assessed according to specific criteria (i.e. PCKS or content knowledge). This was done to establish whether the knowledge students possessed before teaching was relevant and/or sufficient to enable them to construct understanding and generate new meaning during learning (see subsection 2.9.2).

The 'accurate' assessment or analysis of students' knowledge would only be possible if the required knowledge is specified. That is, there must be correlation between curriculum provisions, content/knowledge and specification knowledge (see (h)). Therefore, it was important to specify prior knowledge (before analysis or assessment) in terms of the type of knowledge (see (b)), the level of understanding and how that knowledge was supposed to have been described and used (see (c)) by students in their learning activities. In fact, for accurate analysis of prior knowledge, there needs to be a *frame of reference*. Specification knowledge provides this frame of reference.

- *Obtaining information about concepts* (FRAME C)

In this frame information was collected within the confines of the specification knowledge requirements (see (i)) using qualitative methods. The choice of a qualitative approach, in which the PKST, interview, observation and practical work report were used to collect data (see (d)), was influenced by the nature of the reality in which the study was conducted and the approach's ability to elicit information from written, spoken and observable activities (Taylor & Bogdan, 1998).

Once information on students' learning activities was collected, it was analysed to reveal how they constructed understanding and/or generated their meanings. As the framework was meant to analyse students' conceptual understanding, it was imperative to develop concept clusters (see (e) in FRAME C) which would elicit this information. These clusters were formed on the assumption that concepts are (Reif, 1985) "logically the building blocks of knowledge used to deduce important consequences, make predictions and solve problems" (p. 133). In addition, students constructed understanding from their established conceptual structures in their knowledge bases. The knowledge that students possessed (as indicated by their responses) was part of their conceptual infrastructure hence the construction of concept clusters from these responses.

In fact (Alexander *et al.*, 1991), all forms of knowledge are interactive (see broken lines in (b), FRAME B). The presence or activation of one form can directly or indirectly influence the other. Information in one concept cluster can thus be used to make sense of the student's understanding or meaning in another concept cluster. The meanings derived in the concept clusters should therefore be ‘seen’ as derived from the interaction between the types of knowledge (understanding of concepts) as described by the three components of the specification knowledge (i.e. there is a direct *link* between specification knowledge and meanings or understandings constructed within concept clusters; see (i)).

- *Analysis and assessment of prior knowledge* (FRAME D)

With prior knowledge specified and classified, it was now possible to analyse and/or assess the quality of students' prior knowledge. FRAME D (inhibiting qualities of prior knowledge) was used as a *point of reference* to analyse and assess the quality of students' prior declarative, procedural, conditional knowledge and/or their interaction in use. In determining the quality of knowledge and its use, the interactive nature of prior knowledge (see Figure 8) also was taken into consideration. That is, individual types of knowledge as distinct or isolated pieces were not the only ones analysed, but also the understanding of concepts, their use and their subsequent effect (see Figure 9) were. The framework was used on specific elements of texts in the form of concepts, meanings, thoughts (by inference), language and interpretations as presented by students. The knowledge demonstrated by students was analysed and assessed against factors (see (f)) that could inhibit learning (see subsection 2.9.2). (Details on how prior knowledge was analysed or assessed are given later when specific examples are discussed.).

5.3 Synthesis and explanation

The findings are categorised according to the three types of knowledge sought (see (b) in FRAME B of Figure 13) in line with the research questions. That is, they are described within the specification knowledge – *specification of a concept, instantiation* and *error prevention* (see (c) in FRAME B of Figure 13). The rationale is that understanding a concept in terms of the ways it is described and/or used may promote meaningful future learning. The findings therefore focus on the *understanding* and *use* of concepts. The findings are reported on interactively to demonstrate that all forms of knowledge are interactive in that one form of knowledge can directly or indirectly influence any other (see section 2.9.2).

5.3.1 Finding 1: Specification of a concept

This finding is assumed to describe students' understanding of concepts at the declarative level of prior knowledge (see FRAME B, Figure 13). The extent of understanding as required by the specification knowledge is determined in relation to the six factors (see subsection 2.9.2) that, according to Dochy (1995), may inhibit learning. The quality of prior knowledge was based on the assessment (FRAME D, Figure 13) of how the student described concepts based on 'inhibiting' factors of prior knowledge. For example, a concept that is described using a *summary description* and/or *informal description* would not have the same amount of relevant and/or in-depth information as that described by procedural specification (not to be confused with procedural knowledge). The view here is that the more detailed and accurate the description is, the more alternatives one has in terms of information to use for constructing and generating valid understanding and meanings during learning.

Procedural specification of a concept (see subsection 3.4.4) on the other hand is a more detailed way of describing a concept. Based on this finding and the limitations of summary and/or informal descriptions, procedural specification should be a preferred way of specifying or describing a concept. It is not surprising though that the ability to describe a concept (as indicated by summary and informal descriptions) does not necessarily mean that one understands it. According to Gunstone and White (1992) "a valid measure of understanding a concept involves eliciting the *full set of elements* the person has in memory about it" (p. 6). This is possible through *procedural specification*. The full set of elements in this study is therefore described in the description of specification knowledge (see subsection 4.3.1, (i)). A valid description of a concept, a principle or fact should therefore (Reif, 1985) be by way of explicit rules to ensure that it is unambiguously identified. This may be achieved through procedural specification, which in turn can lead to clearly interpretable scientific knowledge.

The students' ability to specify concepts in terms of amount, relevance and depth of information varied when describing the five concepts under study. The extent of their description of concepts represented the amount of prior knowledge they had about the concepts. The conclusion drawn from the analysis of students' responses was that their specification of concepts was mostly through summary and informal descriptions. As indicated earlier (Reif, 1985), summary descriptions are *compact* and *easy to remember*. The fact that they are easy to remember could be the reason why students preferred to use them instead of procedural specification. Informal descriptions, on the other hand, specify the essential meaning of a concept without undue precision or excessive detail. With this description, attention is selectively focused on a few salient features of a concept (Reif, 1985).

To demonstrate the use and effect on learning or construction of understanding and generation of meaning, responses to the concepts of acidity (Exhibits 4.1, 4.5 and 4.9) and acid strength (Q.4.2.2 in Exhibit 4.2, and Q.4.6.1 in Exhibits 4.6 and 4.10) were used. The responses are assumed to represent the students' understanding of the concepts and related terms, since all meaning is relational (see subsection 2.4.2). The exhibits (concept clusters) were based on the fact that conceptual relations are constructed on "organised networks of related information, not as lists of unrelated facts" (see subsection 2.9.2). The responses to Q.4.1.1 (Exhibit 4.1), Q.4.5.1 (Exhibit 4.5) and Q.4.9.1 (Exhibit 4.9) are typical illustrations of both summary and informal descriptions:

<u>Illustration 5.1</u>

Q.4.1.1: Differentiate between an Arrhenius and a Bronsted-Lowry acid.

S: Arrhenius' acids ***increase the concentration of H^+ ions*** when dissolved in *water,* while Bronsted-Lowry's acids are proton donors.

Q.4.5.1: Differentiate between an Arrhenius and a Bronsted-Lowry acid.

S: Arrhenius: Acid, when reacts liberates/releases ***hydrogen ion H^+.***

Bronsted-Lowry acid: Acid is a proton donor/it donates ***protons***.

Q.4.9.1: Differentiate between an Arrhenius and a Bronsted-Lowry acid.

S: Arrhenius acid is a substance that ***increases H$^+$ ions*** in aqueous solution whereas with Bronsted-Lowry acid it is a proton donor.

In their attempts to differentiate between the two acids (Arrhenius and Bronsted-Lowry), the students' attention was selective to three salient features (high, H$^+$ and proton). In their responses the students did not pay attention to the precision required by the question. The description of the concepts illustrated that the students' prior knowledge was *incomplete*, as some elements constituting the specification of the concepts were omitted. Their answers were constructed by way of an incomplete list of related facts. Part of the responses was correct but incomplete. Some elements of their prior knowledge were apparently *unavailable* or nonexistent and were therefore *inaccessible* (see subsection 2.9.2). It was therefore not possible for students to construct concepts which could be unambiguously identified. Another example where students described a concept with summary and informal descriptions is the description of "acid strength". In Q.4.2.2 (Exhibit 4.2) and Q.4.6.1 (Exhibits 4.6 and 4.10), the students managed to describe a 'strong acid' according to the Bronsted-Lowry concept of a strong acid.

Illustration 5.2

Q.4.2.2: What is the difference between a strong and a weak acid?
S: Acid that dissociates or ***ionises completely*** is an ***aqueous solution.***

Q.4.6.1: In terms of the Bronsted-Lowry definition of acids and bases, what is a strong and a weak acid?
S: A strong acid is acid that ***ionises completely*** in water. Weak acid is acid that ***ionises partly*** in water.

Q.4.10.2: In terms of the Bronsted-Lowry definition of acids and bases, what is a strong and a weak acid?
S: A strong acid is an acid that ***ionises completely in aqueous solution***; weak acid is a weak electrolyte that exists ***mostly as molecules in aqueous*** solution.

The students' descriptions (in Illustration 5.2) were not *complete* when answering questions asked, since some elements required for constructing unambiguously scientific terms were missing. They were based on summary or informal descriptions, and some elements were omitted (see subsection 4.3.1 for an explanation of the specification of knowledge). The effect of the incompleteness in the definitions and/or the students' knowledge as presented in both examples were demonstrated when the students had to *instantiate* their understanding in the second finding. The responses were assumed to represent students' prior knowledge, which students would use to construct new understandings or generate new meanings. But was this knowledge *adequate* and *relevant* to construct understanding and generate new meanings unambiguously?

5.3.2 Finding 2: Instantiation

Instantiation (Reif, 1985) or the ability to apply a concept in a variety of instances depends on the quality of one's prior knowledge. The quality and basis on which this ability could be identified and assessed was the *specification of a concept*. An analysis of the quality of "a concept specification" (Finding 1) indicated that the students' prior knowledge was mostly incomplete. The reason for the incompleteness, as indicated earlier, was their apparent emphasis on describing concepts through summary and informal descriptions (e.g. Q.4.1.1 (Exhibit 4.1), Q.4.5.1 (Exhibit 4.5) and Q.4.9.1 (Exhibit 4.9). Incomplete knowledge hampers or inhibits instantiation, as sufficient information is required to construct understanding, generate meaning and construct new knowledge unambiguously. The students' understanding and/or construction of concepts related to acidity (Q.4.1.2 in Exhibit 4.1, and Q.4.9.2 in Exhibit 4.9) and their generation of the meaning of acid strength (Q.4.2.1 in Exhibit 4.2, and Q.4.6.4 in Exhibit 4.6) best illustrate the effect of *incomplete* prior knowledge in the descriptions of a concept:

<u>Illustration 5.3</u>

Q.4.1.2: You are told that an aqueous solution is acidic. What does this mean?
S: It means the solution has a ***high concentration of H***$^{+}$ *ions.*

Q.4.9.2: You are told that an aqueous solution is acidic. What does this mean?

S: It means that it contains ***hydrogen ions.***

Illustration 5.4

Q.4.2.1: Why is ethanoic acid considered a weak acid?

S: It is a weak acid … CH_3COOH is not ***ionised completely*** because there are ***still*** H^+ ***ions*** within the CH_3COO^-.

Q.4.6.4: Demonstrate how a weak acid ionises ***"incompletely".***

S: … Not all H^+ ions have ionised … there are ***still three*** H^+ ions in the CH_3COO^- ion.

From the two descriptions (Illustration 5.3) of an aqueous acidic solution it is apparent that the students' focus was on the *release and concentration of* H^+. As explained earlier (Finding 1), the students' attention was generally selectively focused on a few salient features of the definition of an acid. The meaning was derived from the definition of an acid, which was limited, and defined according to an informal description. The students could not describe *all the features* of a concept because their prior knowledge was insufficient and/or inaccessible (see "specification of a concept") to construct the meaning of an aqueous acidic solution. This could have been caused by the *limited* information of the concepts (e.g. definitions of acids), from which the new concept or knowledge had to be constructed. In their responses the students demonstrated that they lacked adequate elements within their descriptions of related concepts to construct a viable meaning of an acidic solution. Instead, students attempted to use their definitions of acids, such as in Q.4.1.1 (Exhibit 4.1) and Q.4.9.1 (Exhibit 4.9) to describe acidity.

Illustration 5.4 further shows the *effect* of poorly defined concepts to construct understanding of concepts related to acid strength. The description here is typical of descriptions that are inadequate to help construct understanding or generate meaning. They could not contribute to knowledge that could assist in the construction of new knowledge and/or future learning. In their responses to Q.4.2.1 (Exhibit 4.2), Q.4.6.1, Q.4.6.2 and Q.4.6.3 (Exhibit 4.6) and Q.4.10.3 (Exhibit 4.10), the prior knowledge demonstrated in their descriptions could not be applied meaningfully, since it was incomplete in the first place, and lacked meaning. For example, in Q.4.2.1 the student could not demonstrate what "complete ionisation" meant. If the description of a weak/strong acid was at least followed by the use of an equation (symbolic representation) for example, the meaning could have been different and hopefully understandable.

The effect of incomplete knowledge is that a misconception was initially created from the student’s meaning of "complete ionisation". In the response, "incomplete" apparently referred to ‘decomposition’. The response indicated the importance of procedural description of concepts in teaching. When a ‘weak acid’ is described it should be accompanied by a demonstration of the three ways (macro, micro and symbolic) in which matter could be represented. This could assist in *reducing* or eliminating any *ambiguity* in the description of concepts. The students’ inability to instantiate their knowledge could also have been a result of the information having been acquired through memorisation. That is, without understanding.

In conclusion, it is apparent that the incomplete prior knowledge in the description of concepts made it difficult for students to *restructure* knowledge in order to construct new knowledge. It was not possible for the students to generate meaning of an “aqueous acidic solution” and “acid strength” from their available knowledge, which was limited or incomplete (compared to the specification knowledge as described in subsection 4.3.1).

5.3.3 Finding 3: Error prevention

In order to prevent errors or use one's conditional knowledge one must have adequate and relevant knowledge to do so. A person should also be aware of the knowledge that he/she possesses. One should have what Santrock (2001) refers to as the ability to monitor and reflect on one's current or recent thoughts, which include both factual knowledge and strategic knowledge. This ability is derived from meta-cognitive knowledge. This knowledge should not only be relevant; it should be complete, well-organised, available, accessible and of a sufficient amount. In the case of this study, students' error prevention abilities or conditional knowledge was inadequate. This was demonstrated by responses to Q.4.1.3 (Exhibit 4.1) and Q.4.5.2 (Exhibit 4.5). The students' prior knowledge was incomplete (as inferred from Finding 1), and it was also unavailable and poorly structured (as inferred from Finding 2).

Accessibility is (Barsalou, 1993) a *critical factor* underlying which knowledge features are retrieved to construct meaning of a concept on a particular occasion. The discussion above (Finding 1 and 2) demonstrated the quality of students' prior knowledge in terms of completeness, accessibility and availability, and the organisation of their knowledge bases. The quality of their prior knowledge made it difficult (and impossible in some instances) for them to reflect and prevent errors. New information is interpreted in terms of what one already knows (Prawat, 1989). If what a person already knows has limitations (such as incompleteness) accurate interpretation will be negatively affected, resulting in the student's inability to prevent errors during problem solving and purposeful thinking (Santrock, 2001).

The reliable interpretation of a concept requires adequate knowledge to prevent errors (Reif, 1985). The knowledge of concepts of the students in this study was generally inadequate for this purpose. It was therefore unlikely that the students, with their inadequate knowledge, would interpret concepts reliably and prevent errors. In order for persons to access or use their intellectual resources (for example their prior knowledge), that knowledge should be well organised (Prawat, 1989). In addition, people need a sufficient amount of reflective awareness to be able to restructure or reorganise their prior knowledge to assist in preventing errors or detecting them if they have been committed and to correct them. The responses to the questions, as indicated in the discussion earlier, indicate that students' prior knowledge was not sufficient to prevent errors.

A preference for summary and informal descriptions (Illustration 5.2), as demonstrated by many of the responses, was highlighted. These kinds of descriptions reduce the number of alternative sources of information in the students' knowledge bases to enable them to construct valid scientific knowledge during learning. The more alternatives one has in terms of available or accessible knowledge (Dochy, 1992), the more chances there are that one's knowledge will be enhanced. Enhanced knowledge helps one to perform tasks successfully. According to Reif (1985), the successful performance of tasks is facilitated by one's *awareness* of likely *errors* and pitfalls.

Unfortunately for the students in this study, awareness was hindered by prior knowledge that was limited and apparently of poor quality. The quality of the students' knowledge was such that it could not be used to reflect. In fact, their knowledge appeared to have been obtained through memorisation instead of active construction. It was therefore not understood or usable. For example, a student could describe a concept (although not in detail, but understandably), but unable to use this description to answer related questions (see Exhibit 4.6). In fact Ware (2001) asserts that students do not fully comprehend the concepts that they can use in algorithmic problem solving.

The findings in this study confirm Gabel's (1999) contention that many concepts studied in chemistry are abstract and inexplicable if learned without the use of analogies or models. Without the use of these, students tend to resort to learning by memorisation. Memorisation or "rote learning", according to Edmondson and Novak (1993), is when new information is acquired without specific association of existing elements in an individual's conceptual structure. The new information is not linked to existing concepts and integrated into what the student already understands. In this form, knowledge or information cannot be used, as it is not understood. The students could not use their declarative, procedural and conditional knowledge in a fluid, dynamic and interactive way. Their knowledge bases consisted of bits of isolated information. Knowledge that is conceived through memorisation is, in most instances, in a form that makes it *unavailable* or *inaccessible.*

All of this underlines the importance of understanding students' prior knowledge in the learning process. In fact, it emphasises the notion that knowledge is "fluid, dynamic and interactive", and the notion (Norman, 1982) that the learning process is constituted by three overlapping phases, namely –

- accretion of new information and its chunking and elaboration and connection to existing knowledge;
- its restructuring, whereby knowledge organisations are formed, usually to replace or reformulate old concepts and relations; and

- Tuning or adaptation and practise of knowledge structures in particular uses.

The learning process was demonstrated by the interactive relationship between the students' specification of a concept, its instantiation and error prevention. In fact, the process of knowledge acquisition (Norman, 1982) determines to some extent how knowledge is organised in the individual's cognitive structure. This in turn determines the ability of the individual to have access to this knowledge and reflecting on it when it is required for future construction of understanding or generation of meaning. For example, the three students in this study in some instances had relevant knowledge, which was known and could be defined and/or described without understanding. The knowledge was in some instances relevant, because most of the questions posed were intended to elicit understanding that could be reflected on in other questions. Yet, the students could not reflect on this knowledge in their responses and use it when it was required to generate viable meanings of other concepts.

In conclusion, the quality and use of students' prior knowledge demonstrated how important it is for lecturers in general and science lecturers in particular to understand prior knowledge as a factor in knowledge acquisition before any teaching can be undertaken. In addition to understanding how prior knowledge is used and how it affects learning, the study highlighted the importance of the depth at which teaching and assessment should be done if meaningful learning of science concepts is to be achieved. What does this mean in terms of *instruction, instructional design* and *assessment* of science and concepts in chemistry in particular?

5.4 Significance for instruction, instructional design and assessment

The main objective of engaging in research is to contribute new knowledge in the area of study. In the process, this new knowledge could have implications (intended or unintended) on the everyday practices in the field of such research. In the case of this study, the findings on the quality of students' prior knowledge and its use in constructing understanding and generating meaning of concepts would have far-reaching implications on meaningful instruction and/or appropriate learning.

Appropriate learning is learning that enhances meaningful learning and ensures competent performance by students (Kemp, Morrison & Ross, 1998). The important question for teaching, in terms of the findings in this study, is whether students' prior learning as demonstrated by their responses was appropriate. Based on the findings these students' prior learning was inappropriate in most instances of the study.

As the study was conceived within a constructivist view of learning, knowledge and understanding, the implications of the findings on instruction, instructional design and assessment would emphasise the notion that learning is a product of knowledge construction. The importance of prior knowledge in learning should therefore focus on explaining the implications on the educational process. It is on the basis of the constructivist view of knowledge that "instruction" should be a systematic process in which every component (including prior knowledge) of the learning environment is crucial to successful learning (Dick & Carey, 1990).

In the case of this study, the learning environment included the lecturer, students, teaching and learning material, and the students' *prior knowledge*. The study also has implication for instructional design. "Instructional design", according to Kemp *et al.,* (1998), is the systematic method to ensure *achievement* and *competent performance* by students. Instructional design should be based on what is known (in this study, prior knowledge) and consider instruction from the perspective of the student rather than the content (Kemp *et al*., 1998). The effect of the student's prior knowledge should therefore be fundamental to instructional design and should be described for the design of relevant instructional activities.

The findings would also have implications for assessment. Assessment has been deliberately separated as part of instruction in this discussion in order to emphasise its importance as a major factor in the learning process – particularly where the quality of knowledge plays a role in what is learned. Assessment for the purpose of understanding the implications of this study could therefore be described (Shavelson, Ruiz-Primo, Li & Ayala, 2003) as a systematic procedure for *eliciting*, *observing* and *describing* students' activities, both physically and mentally in the learning process. The "activity" here refers to the activity of *constructing understanding* and *generating meaning* during learning. The study would also have implications on *what* type of knowledge (declarative, procedural and/or conditional) is assessed and *how* it is assessed to enable both the student and the lecturer to enhance meaningful learning in the teaching and learning process.

What are the specific implications of understanding students' prior knowledge and its manifestations in the construction of understanding and generation of meaning? The specific implications of students' prior knowledge on *instruction, instructional design* and *assessment* (as derived from the findings of the study) are discussed within three broad areas of knowledge, namely the understanding of –

- the student (and/or his/her prior knowledge);
- different types of knowledge; and
- the nature of the subject matter.

(i) The understanding of the student

A clear understanding of the student's prior knowledge is needed in order to make hypotheses about his or her conceptions and the reasoning strategies employed. This understanding is what Dochy (1992) calls the "student model". The findings about students' declarative, procedural and conditional knowledge and its use have revealed valuable information for understanding *how* students construct understanding and generate meaning in their attempt to learn. This understanding will be useful to the lecturer before instruction, because it will establish three significant components required by the theory of instruction.

According to Gelman and Greeno (1989), the theory of instruction requires a theory of –

- the knowledge that we want students to acquire;
- the initial prior knowledge state of the student; and
- the process of transition between the initial state and the desired state of knowledge to be achieved in instructional settings.

How these requirements can be achieved will further be elaborated on when the framework for enhancing meaningful learning of chemistry concepts (Figure 14) is discussed in section 5.5.

(ii) The understanding of different types of knowledge

This entails an understanding of different types of knowledge (e.g. declarative, procedural and conditional), both in a *student's knowledge base* and in *subject or content knowledge*. The types of knowledge here refer to knowledge in the student's knowledge base specifically relating to the domain of chemistry. The understanding of the type of knowledge is important for both the lecturer and the student in preparing for their teaching and learning respectively. Understanding the types of knowledge and what each entails will enable the lecturer to identify this knowledge in the student's knowledge base for assessment and quality of instruction. Lecturers will need specific knowledge of what they are teaching and/or assessing. Teaching will then not be haphazard. For a student, understanding what knowledge they have to learn will provide an understanding of *how* and *when* to use such knowledge. For example, understanding what procedural knowledge is will immediately indicate to the student that it is knowledge that enhances application. Students will then be able to identify such knowledge and use it appropriately in their learning to enhance their procedural knowledge. Understanding knowledge types will also help students organise or adapt their learning according to a particular type of knowledge (see (b) FRAME B Figure 13).

(iii) The understanding of the nature of the subject matter

There are different subjects being taught to the same student. Each has its own characteristics, which influence how it is taught and/or learned. In this study the subject taught or learned is chemistry. Chemistry deals with matter and its changes. The nature of matter has an effect of both inhibiting and facilitating learning (Johnstone, 1991b). This however depends on a student's prior knowledge about that subject. This includes understanding how the subject matter could be taught and assessed to make it comprehensible to students, especially students whose prior knowledge has limitations such as “incompleteness” and “misconceptions”. The nature of the subject matter has been singled out for understanding because it was apparent from students' responses (in this study) that it is a crucial factor in determining the quality of students' knowledge. How will understanding of the nature of the subject and the other understandings discussed earlier enhance meaningful learning of chemistry?

The three broad areas of knowledge discussed earlier will be further elaborated on within a framework (Figure 14) to explain how understanding prior knowledge and knowledge interaction in learning could enhance meaningful learning and/or the use of knowledge to construct understanding and generate meaning that is scientifically valid.

5.5 Framework for understanding prior knowledge for meaningful learning.

Students’ learning, unlike instruction, is in most instances (Kemp *et al.*, 1998) haphazard. This characteristic was apparent in the analysis of students' responses during the empirical study. It does, however, not necessarily mean that all of the students’ responses did not make sense. What it means is that students' prior knowledge, in whatever form, needs to be understood if planning for meaningful instruction is to be achieved. What does it mean to understand students' prior knowledge for meaningful learning?

The lecturer should have an instructional design process that recognises the quality of prior knowledge as a factor in the outcomes of teaching and learning. The process should ensure that what a student already knows is a source of information from which to plan teaching for meaningful learning. Since, in this case, the *source* of the information is students' *prior knowledge;* students should also be *active* participants in the teaching and learning processes if meaningful learning is to be achieved. Teaching and learning involves for both the lecturer and the student interpretation of information about content and the knowledge to be constructed. Interpretation depends on knowledge one already possesses (Glaser, 1984); therefore, its quality will determine the quality of the interpretation and the knowledge constructed. Understanding prior knowledge in the teaching and learning environment will therefore enhance a lecturer's ability to help students in their learning, since they will be aware of the quality of the students' prior knowledge before engaging in learning.

A framework (Figure 14) is here therefore suggested to help students' and lecturers to use prior knowledge enhance meaningful learning. This framework is an extension of the theoretical framework discussed earlier (Figure 13) to assess the quality of students' prior knowledge (which was used to arrive at the findings of this study).

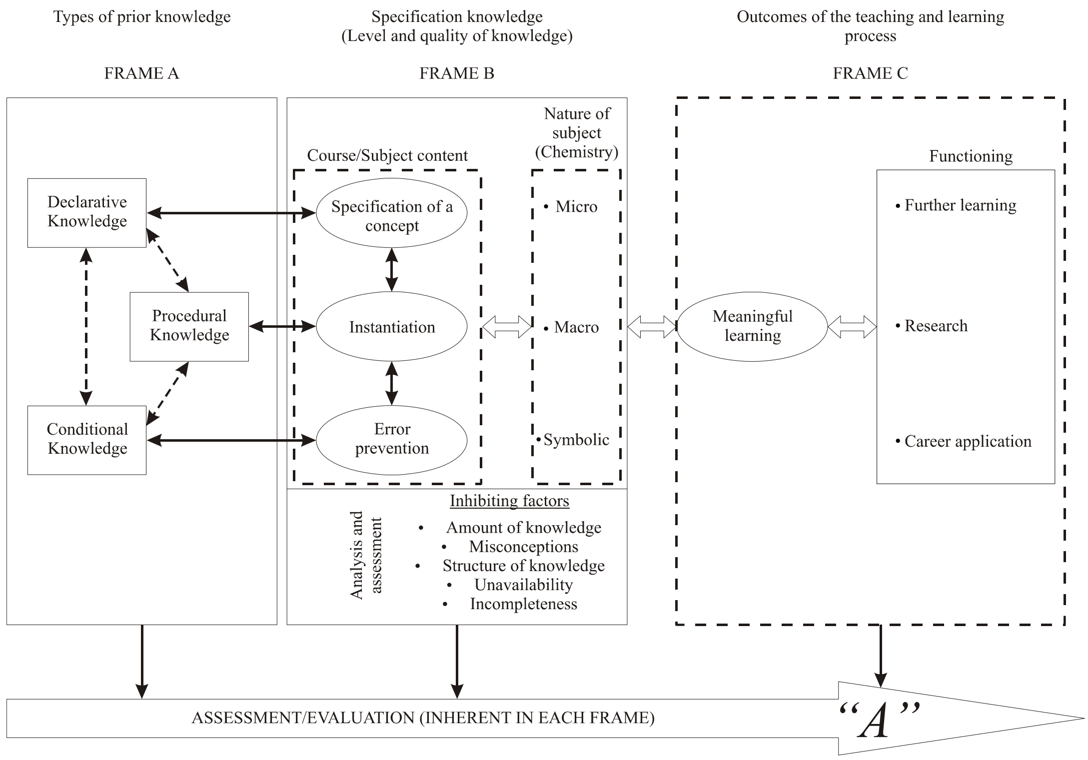

Figure 14: Prior knowledge framework for enhancing meaningful teaching and learning of chemistry concepts.

In order to understand how the framework could be used in the teaching and learning process it is important to first understand its structure. The framework has three broad areas, namely –

- the types of prior knowledge and how they relate (FRAME A). (This is students' prior knowledge as assessed from Figure 13.);
- the quality of knowledge, which is described within the specification of knowledge (FRAME B); and
- the outcomes of teaching and learning (FRAME C).

What does each of these areas mean in the teaching and learning process? The description of the three areas is based on the constructivist view of learning. According to this perspective (Tobin, Tippins & Gallard, 1994), learning is a social process in which the construction of understanding or the generation of meaning depends on one's extant knowledge. The social interaction refers to the interaction of a student with other students and the lecturer. The extant knowledge is a student's prior knowledge, of which the quality needs to be known and understood by the lecturer in order to enhance his or her meaningful learning. The other knowledge that this framework focuses on is the lecturer's knowledge.

In this learning process, the lecturer is the facilitator, and as such should have the knowledge of the subject matter and of teaching the particular subject matter (see FRAME B, Figure 14). In addition, as one of the role-players in the learning process, it is also important that the student should have an understanding of his or her own knowledge and the subject matter. Understanding the source of learning (prior knowledge) by both the student and the lecturer will provide a learning environment with a common understanding or *common language* for better communication (see subsection 2.7.3). Better communication here would be enhanced when both the student and the lecturer have the same understanding of the framework (Figure 14). That is, the framework should be understood by both the lecturer and the student before it could be used.

(i) *Types of prior knowledge* (FRAME A)

Earlier in this discussion, Kemp *et al.,* (1998) described student learning as being haphazard and teaching as a planned process. The rationale is that planning can only be successful when one has an understanding and/or knowledge of what to plan *for* and what to plan *with*. In the case of traditional teaching and learning, understanding the types of prior knowledge had generally (from the researcher's experience) not been part of teaching and learning.

In this framework, both the student and the lecturer should have an understanding of the types of knowledge (declarative, procedural and conditional knowledge) they are supposed to learn and teach respectively before any teaching or learning could take place. In other words, they will have to understand the types of knowledge that have to be taught and learned and the meaning and importance of the interaction of different types of knowledge. This understanding will be derived from the prior knowledge analysed and/or assessed earlier for each student (see section 5.2, Figure 13) and categorised into the three types of knowledge during learning.

(ii) *Specification knowledge (quality of knowledge)* (FRAME B)

In this frame, the focus is on *what* knowledge will be required for a particular level of understanding (described by specification knowledge). It is also about *how* knowledge is used or should be used to generate new knowledge (when the three types of prior knowledge interact). Therefore, the knowledge described in this frame would mostly be influenced by the quality of knowledge demonstrated by students in the initial analysis of their prior knowledge (this is the prior knowledge in FRAME B, Figure 13). The knowledge required by students to demonstrate their understanding is therefore specified in this frame. Not only is its content specified; the level of understanding at which this knowledge should be demonstrated is also described in the three components of the specification knowledge (specification of a concept, instantiation and error prevention). These components are specific descriptions of the three types of prior knowledge (within the course/subject content).

The nature of matter, which has a bearing on how knowledge is structured and used, is also described in this frame. For this study, which focused on the learning of chemistry, the quality of knowledge of chemistry is in most cases affected by its triangular (macro, micro and symbolic) nature (as analysed in Figure 13). Finally, the quality of students' knowledge is analysed and/or assessed throughout learning (see arrow “A”) using as reference the six factors or characteristics of prior knowledge (see subsection 2.9.2) that may inhibit learning.

(iii) *Outcomes of the learning and teaching process* (FRAME C)

The outcomes of teaching and learning for this study would be that students are able to construct understanding and generate meaning from their prior knowledge as a result of the intervention in FRAME B. This ability would demonstrate that students have learned meaningfully and are in a position to use their knowledge according to the specifications as described by the specification knowledge (see FRAME B). The *quality of knowledge* constructed will enable the students to use this knowledge in future learning, since it would not be knowledge derived from memorisation (without understanding) or learned haphazardly (because it is continuously assessed in all the frames). This ability to use knowledge will depend on what the lecturer considers as relevant content to construct understanding and generate meaning when specifying the knowledge to be learned.

How will this framework (Figure 14) enhance *meaningful learning* and effective *functioning* of students' future learning? Meaningful learning means to promote the *facilitating effect* of prior knowledge. According to Dochy (1992), this "facilitating effect" contributes positively to learning. Three effects are identified, but not all of them are a direct result of prior knowledge:

- Direct effect which facilitates the learning process leading to better results;
- Indirect effect which optimises the clarity of the study materials; and
- Indirect effect which optimises the use of instructional and learning time.

The framework (Figure 14), based on the facilitating effects of prior knowledge will enhance meaningful learning as follows:

- Both the student and the lecturer will establish understanding of the knowledge (declarative, procedural and conditional) they are supposed to have before any teaching and learning takes place. It introduces a *common language* (see illustration 5.5 hereafter) between the student and the lecturer on the basis of what is to be taught and learned. The students will, on the basis of what the framework prescribes in terms of the knowledge to learn and the quality expected (FRAME A and B, Figure 14) understand what their lecturer's intention or purpose is with learning of particular concepts. In this way, the framework *optimises the clarity* of the subject and the type of knowledge to be learned. In addition, a student's role as an *active participant* (see illustration 5.5) in the learning process is elevated.

Illustration 5.5: Tacit explanation of a classroom interaction where the framework is a referent.

Lecturer (**L**): In terms of the Bronsted-Lowry definition of acids and bases, what are strong acids and weak acids?

Student (**S**): A strong acid is acid that ionises completely in water. Weak acid is acid that ionises partly in water.

L: With that response I will allocate you only 50% of the total mark!

S: But Sir, I do not understand. My response is correct.

L: No … your response shows that your knowledge is incomplete (*Finding 1*).

S: I do not understand, Sir.

L: Remember what we discussed at the start of the lecture on this topic. We agreed on the *types of knowledge* that we were going to learn and emphasised the importance of *accurate and adequate* specification of knowledge. Your response is only a *summary description* of what is expected according to the prescribed specification knowledge (see *Finding 1*). We agreed to always, where possible, use *procedural specification* as it gives us more alternatives to answering questions because it is a detailed description of a *concept.* It enhances the *completeness* of our knowledge.

S: I remember now, Sir.

L: Okay, let's continue. Is acetic acid a weak acid or a strong acid?

S: Acetic acid is a weak acid because it ionises *incompletely* in water.

L: What does it mean to ionise incompletely?

S: Err … I don't know, Sir. (See *Finding 2*.)

L: But you have just said it. Okay, demonstrate how a weak acid ionises incompletely.

S: Not all ions have ionised … there are still three H^+ ions in the CH_3COO^- ion (*Finding 2*).

L: Do you still remember what we said about the importance of the three aspects of the specification of a concept and the nature of matter (macro, micro and symbolic)?

S: You mean … err … ensuring that I know the types of knowledge and focusing on the completeness of my descriptions as specified in the specification knowledge at all times, Sir?

L: Yes … but your responses are not of the quality as specified.

L: Okay, let's try again. You are told that an aqueous solution is acidic. What does this mean?

S: It means that every acid is in the form of water molecules? (*Finding 3*).

L: Your responses clearly indicate you did not study according to what the specification knowledge required. You cannot use your knowledge to *reflect* on your errors. Your poorly structured knowledge makes it difficult for you to be *aware* of the errors you commit.

S: Yes … Sir … I will start *using* my framework when I study. It appears to *simplify things* as one will always know *what to expect from the lecture.*

This illustrates how the framework may be used as a “common language” through which the lecturer and his or her students can communicate.

- It can be a "manual" or a guide for students to prepare themselves before teaching takes place. The framework provides the student with an understanding of the quality of prior knowledge required in advance (see Illustration 5.5). With this information, the student has the advantage of elevating his or her level of knowledge to meet the requirements of the “specification knowledge”. Students can only improve on their knowledge if they are aware of the detailed specification knowledge provided (see subsection 4.2.2). This framework provides a detailed specification knowledge (see description of specification knowledge), which focuses on the three types of knowledge (through specification of a concept, instantiation and error prevention). In addition, the nature of the subject matter to be learned is included as part of specification knowledge. Understanding specification knowledge is an indirect effect of prior knowledge *to optimise the clarity of the study material* and *the use of instructional and learning time*.
- Assessment (baseline/diagnostic, formative and summative) is an important component of the teaching and learning process, and is inherent in the framework (see arrow “A” in Figure 14). Both the student and the lecturer have an assessment role to play in the process of teaching and learning. Based on the specification of knowledge provided by the framework, both students and lecturers will be able to assess learning at the same level with the same focus. A lecturer's assessment will be that of the knowledge that students bring into the learning situation. The next phase of assessment will be an assessment of the progress of students' learning. The student's assessment will be of the level and quality of his or her knowledge before learning, and the assessment of what knowledge is required to achieve the outcomes. Students can, with this framework, for example assess the extent of their specification of a concept, since the quality requirements (specification knowledge) would be indicated in the curriculum and the measure of quality would be indicated by whether it is

complete, well organised, available, etc (see subsection 2.9.2). Finally, the framework can be a “tool” for both the lecturer and students to continuously assess different types of knowledge at all stages of teaching and learning (see Illustration 5.5). Continuous assessment of knowledge improves its quality, resulting in the direct effect of prior knowledge to "facilitate the learning process" (not hindering it) and leading to better result (see Figure 9). In the case of this study, the effect will lead to meaningful learning with the potential of students being functional in future learning (see Figure 14).

- For knowledge to be complete, it has to be a distribution of ‘all’ types of knowledge within the subject content. In the case of this study, the distribution should be among the three types of knowledge. The framework, with its initial assessment of prior knowledge, affords a lecturer the opportunity to assess how students' knowledge is distributed between the three types of knowledge. With this information the lecturer is able to identify in what form students' knowledge is structured and/or organised in terms of the types of knowledge discussed earlier. The lecturer can then "optimise the use of instructional learning time" by preparing teaching or study materials relevant to the form in which students' knowledge is structured or organised.
- For meaningful learning to occur students’ prior knowledge should meet the requirements of the “specification knowledge”. The quality of knowledge must be reasonable, complete and correct, of reasonable amount, accessible and available and well structured (see subsection 2.9.2). The framework affords lecturers an instrument that can help them assess the qualities of the three types of knowledge individually and how these interact during use in terms of the characteristics listed earlier.

What will be essential from the lecturer's point of view to implement the framework (Figure 14)? What are the knowledge, skills and values required to successfully achieve meaningful learning in science teaching, particularly in the teaching of chemistry concepts? In order to use the framework suggested here it is important that a lecturer has relevant knowledge and teaching skills. As knowledge begets knowledge (Resnick, 1989) it is expected that lecturers engaged in teaching should demonstrate sufficient and relevant knowledge to guide learning. The ability to identify students' limitations and/or strengths in their knowledge bases requires a deep understanding of the subject content and pedagogy. Meaningful learning or learning with understanding cannot take place if the facilitator of that learning lacks relevant and sufficient subject content and the pedagogical knowledge to do so. Teaching for meaningful learning should therefore be derived from a lecturer's teaching practice (Loughran, *et al*., 2004), which is informed by relevant knowledge. Teaching for meaningful learning is possible when a lecturer demonstrates the "grasp of, and response to, the relationship between knowledge of content, teaching and the learning in ways that attest to notions of practice as being complex and interwoven" (Loughran *et al*., 2004, p. 370). Shulman (1986, p. 9) describes this ability as "pedagogical content knowledge", that is,

> … the ways of representing and formulating the subject that makes it comprehensible for others … [It] also includes an understanding of what makes the learning of specific concepts easy or difficult; the conceptions that students of different ages and backgrounds bring with them to the learning.

Pedagogical content knowledge as a model for lecturers to understanding teaching and learning (Shulman, 1986) was developed from two components, namely "subject knowledge" and "pedagogical knowledge". This model was later revised (Cochran, De Ruiter & King, 1993) to be consistent with a constructivist perspective on teaching and learning. The revised model was an integration of four components of teacher knowledge, namely "subject knowledge", "pedagogical knowledge", "knowledge of students' abilities" and "prior knowledge of the concepts to be taught". In the framework (Figure 14) pedagogical content knowledge is a basic requirement – without it one may not be effective in his or her facilitation of learning. The understanding of knowledge in general, and prior knowledge in particular, and the inherent assessment/evaluation processes in the framework makes it impossible to use if the user (lecturer) lacks the requisite knowledge (i.e. the knowledge of how specific knowledge such as chemistry is organised and used).

The difference between Cochran *et al.*'s (1993) model (Shulman's revised pedagogical content model) and the prior knowledge framework for enhancing meaningful teaching and learning of chemistry concepts (Figure 14) is that in the former the lecturer dominates the teaching and learning situation. His/her knowledge of teaching, students' abilities and the subject matter (knowledge) are emphasised. The latter on the other hand recognises the student's knowledge of the subject matter and the lecturer's intentions about teaching and incorporates these in the teaching and learning process. The student is as important as the facilitator of knowledge in the learning situation. The emphasis is that the student should be a co-constructor of his or her own knowledge for that knowledge to be meaningful.

The understanding of the learning environment in terms of the main factor (prior knowledge) influencing the outcome of learning by the student and the lecturer makes the framework the common language through which learning can take place. It makes it easier for a lecturer to teach students from different prior knowledge backgrounds, as they will be using the same language (framework) of learning. The framework, unlike the pedagogical content knowledge approach (which emphasises only the lecturer's knowledge), will make the student and the lecturer understand each other better in terms of subject matter, pedagogical knowledge (in case of the lecturer), a student's abilities (e.g. prior knowledge) and what needs to be learned based on the student's abilities.

With the use of the framework, teaching and learning will accommodate students with diverse qualities of prior knowledge. The findings of this study (based on students' responses) have demonstrated that the current approaches to teaching and learning are limited in meeting the goals of understanding in science education (see Tables 1 and 2). With the use of the framework as suggested (Figure 14), learning may be integrated. That is, curriculum, instruction and assessment can be directed toward *meaningful learning*. The framework will not only enhance meaningful learning; it will also promote competent performance by graduates in their respective fields after graduation. It is also a ‘tool’ that may promote reflective and independent learning among students.

5.6 Implications for further research

Research by its nature is aimed at introducing new questions to be probed. As this study attempted to respond to particular questions, it generated more questions that needed further research. As could be discerned from the questions posed, the researcher was generally trying to respond to the problem of the quality of prior knowledge in its use to construct understanding and generate meaning during learning. The rationale is that one cannot construct scientifically valid meanings of concepts without, for example, *complete* knowledge. This argument is based on the fact that one needs relevant and adequate knowledge (Resnick, 1989) to generate new knowledge. The question posed was how students with poor prior knowledge backgrounds constructed their understanding and generated meaning in their attempts to learn, considering the fact that many students entering higher education in South Africa brought diverse and poor learning backgrounds into the learning situation?

The question most likely to occupy lecturers' (and this researcher's) minds – in terms of teaching and the belief that prior knowledge is the major factor that influences learning – is: *How do I help my student to learn if I do not know what they know, how they know it and how they learned it?* The empirical study and the findings attempted among other questions to answer this question. The study managed to establish what the students knew and how they knew it, and to some extent, managed to establish how they learned it. The answer to *how they acquired* their knowledge was only inferred from their responses in the progress of the study. The answer to how students learned the knowledge was a matter for further research. As the focus of the study was on first-year students, how they acquired their knowledge was a matter that needed research at their early years of study (that is, at schooling level). How teachers at lower levels taught concepts in science, and more specifically in chemistry, was also a matter for further research.

The framework for assessing prior knowledge (Figure 13) has the potential to assist further research to monitor and understand how students learn. It can be an instrument for understanding meta-cognition. "Meta-cognition" or "meta-cognitive knowledge", according to Dochy and Alexander (1995), is the knowledge that regulates one's cognition. It is knowledge that controls one's *planning*, *monitoring* and *evaluation* of the performance of a task. The framework can assist lecturers and students in regulating cognition during the teaching and learning process. In addition, it is also a common language, both for further research and for daily use in the teaching and learning process. It can be a common language in that it has the potential of enhancing the focus on a particular aspect. In the case of this study, it focused on prior knowledge as a factor in learning. Prior knowledge can be understood further by way of the framework which looks in all forms and at levels of teaching, learning and research.

5.7 Reflections on the study

The focus on knowledge, and prior knowledge in particular, was intended to contribute new knowledge to what had already been done in the past in terms of prior knowledge as a factor in learning. The study focused specifically on prior knowledge as an "inhibiting factor" in individual student's construction of understanding and/or generation of meaning during learning. The study generally dealt with the quality of prior knowledge of individual students and how this affected the product of learning. The "product of learning" here refers to the understanding of concepts as a result of students' prior knowledge and their use in generating meaning.

Prior knowledge has been described as pervasive (Dochy & Alexander, 1995) and difficult to study. Some of the problems posed by its pervasive nature could be avoided before the study was conducted. For example, the problem of undefined or vaguely defined prior knowledge concepts was attended to before the study. However, this does not suggest that the study did not encounter any problems owing to the nature of prior knowledge. In light of this background, a reflection on the study should be made before concluding in order to highlight some of the problems that could not be avoided. Reflecting on something, according to the *Concise Oxford English Dictionary* (2006, p.1208), means bringing about a "good" or "bad" impression of it. Highlights of the significance and limitations of engaging in the study of this nature will therefore follow.

5.7.1 Reflections on the limitations of the study.

Most of the limitations pertaining to this study were due to the cognitive-psychological element in teaching and learning, and the nature of prior knowledge. In addition, the sampling procedure and the nature of the sample were restrictive. Other limitations included the timing of the study, its reproducibility and limiting the study to inhibiting factors only.

(i) Limitations owing to the cognitive-psychological element in teaching and learning.

Teaching and learning, irrespective of the subject matter being taught or learned, at some point had to deal with the understanding of the cognition and/or psychology of a student. Prior knowledge, which was the focus of this study, resided in many fields of specialisation, such as cognitive sciences, psychology, learning and teaching. As the focus of this study was on understanding the effect of prior knowledge on the learning of concepts in chemistry, with specific reference to acids and bases, it also had to include understanding of learning. Learning, as indicated earlier, inherently had cognitive and psychological elements. The limitation, from a methodological point of view, is the fact that the researcher was not a psychologist, but a chemist teaching chemistry at tertiary level with an interest to understand how chemistry learning is inhibited by prior knowledge.

(ii) Limitations owing to the nature of prior knowledge

Knowledge or prior knowledge cannot be adequately captured. In the case of this study, students' knowledge could not be ‘adequately’ captured as students could not *remember* or *demonstrate* all they knew at the time of the study. Knowledge or prior knowledge depends on time – it changes with every second or minute that passes (Dochy & Alexander, 1995). In attempting to capture knowledge, it is impossible to 'see' the interactive nature of knowledge when students construct understanding or generate meaning. This is only inferred from their actions and responses to related questions. Responses of individual students cannot be compared or generalised, as students have 'unique' circumstances from which their knowledge was acquired.

(iii) Sampling and the nature of the sample

The sample and the procedure to select it contributed to the quality of the outcome. Selection of students (cases) for this study was confined to volunteers. Volunteers are not necessarily the type of sample the researcher envisages for his or her study. However, this limitation did not have much impact on the sample composition in terms of gender, geographic location of the students' previous schooling (i.e. provinces) and their general performance during the study. In addition, it was difficult to pre-empt how the knowledge of participating individuals would manifest in the process of the study. In other words, it was difficult to determine whether volunteering individuals (on the basis of their prior knowledge) have responded and elicited sufficient and relevant information for the purposes of the study.

Students in South Africa enter higher education on the basis of their *prior achievement* at grade twelve examinations levels. Prior achievement, according to Jonassen and Grabowski (1993), indicates the *amount of knowledge* an individual can demonstrate to possess. However, it does not indicate the type of knowledge the student possesses. In this study, it could not have been used to predict at which knowledge (declarative, procedural or conditional) the student performed well or performed poorly. Achievement alone is therefore not a reliable measure of the quality and/or "amount" of knowledge an individual has, especially if it is determined mainly by content tests.

(iv) Reproducibility of the study.

The study's purpose was to provide a contextual understanding of the quality and use of prior knowledge of individual students. As a result the study could not be generalized to a wider population. However this does not mean that the findings in this study (which is qualitative in nature) cannot be applied to a broader range of settings than those of the study (Avis, 2005).

(v) Timing and sequencing of the study.

Timing and sequencing were important aspects in data collection for this study. Students had to engage in practical work and were interviewed only after they had been exposed to the topic of interest (acids and bases). This had to happen towards the end of the semester when students were in the process of preparing for end of semester examinations. It was also important to conduct the prior knowledge test as part of the *routine class test* to enhance the natural setting and improve credibility of the outcomes. In this way, the process of data collection was less flexible. Sequencing (having the test being conducted before the practical work and interview) was important as it was used as a guide for the type of questions asked during interviews and practical work activities.

(vi) Limiting the study to inhibiting factors only.

Facilitating factors were omitted in this study because they could be directly/indirectly affected by and are inherently influenced by inhibiting factors. In other words they cannot be independently studied. The outcome of learning is not only a product of facilitating factors, but also the outcome of the interaction between the two (see subsection 2.9.2 Figure 9). Therefore, it would have been difficult to measure the amount of the interaction to determine the effect of the facilitation factors only.

5.7.2 Reflections on the significance of the study

The decision to embark on studying prior knowledge was motivated by the researcher's experience in teaching chemistry and the perception (Johnstone, 1991a) among first-year chemistry students that chemistry was difficult to understand and/or learn. Prior knowledge was selected because it was the most important factor determining the outcome of learning (Ausubel, 1968). In addition, in order to influence learning one needs to understand this factor. It is apparent from the limitations earlier that understanding prior knowledge was not an easy exercise. However, the limitation to study prior knowledge should not be a deterrent if learning is to be enhanced and education improved. Instead, more studies on prior knowledge should be encouraged because the significance of the findings and the new developments around the findings would benefit learning in general and the learning of chemistry in particular. What was significant about this study in particular?

It was indicated in this study that knowledge (and prior knowledge in particular) could be studied, provided the researcher was focused and took note of the pervasive nature of knowledge (as warned by Dochy & Alexander, 1995). The study was therefore significant because the following could be achieved:

(i) The understanding of the student.

A clear understanding of the student's current knowledge (prior knowledge) is needed to make hypotheses about his or her conceptions and reasoning strategies used to achieve a current knowledge state. In this study it was possible to establish students' prior knowledge and to establish how certain concepts were constructed during learning. This understanding would enhance the lecturer’s understanding of how students manipulated concepts to arrive at meanings they gave to other concepts. In this way the lecturer could gain valuable information on which to plan his or her teaching activities.

(ii) The understanding of different types of knowledge.

An understanding of different types of knowledge (e.g. declarative, procedural and conditional) both in a student's knowledge base and in the subject or content knowledge is important. In this study, the types of knowledge refer to knowledge in the student's knowledge base (and in the domain of chemistry in particular). The understanding of the type of knowledge is important for both the lecturer and the student in preparing for their teaching and learning respectively. In teaching, it should not only be about the content knowledge. The type of knowledge is important as it gives both the students and the lecturer the opportunity to understand what they are learning and teaching respectively. This understanding empowers them to distinguish at which level of knowledge they are learning and/or teaching as individuals respectively.

(iii) The understanding of the nature of the subject matter

There are different subjects being taught. Each has its own characteristics that influence how it is taught and/or learned. The nature of matter has an effect on learning, depending on the student's prior knowledge about that subject. This includes understanding how the subject matter can be taught and assessed to make it comprehensible to students, especially students whose prior knowledge has limitations in terms of, for example, incompleteness and misconceptions. This study managed to some extent to highlight the fact that students did not necessarily engage mental models in their learning and that they viewed matter in its three (macro, micro and symbolic) levels. Their learning is mostly at the macro level and, in some instances, haphazard amongst the three levels.

(iv) New developments around the findings

During this study, an *important* framework was developed and extended. A framework for the assessment of knowledge (Figure 13) was developed from literature and the outcomes of the empirical study. The framework for assessing prior knowledge and its use was developed from the findings on the quality of the three types of knowledge. This framework can be used to analyse the quality of knowledge, based on the six characteristics or qualities of knowledge as described by Dochy and Alexander (1995). In addition, the framework was extended to promote meaningful teaching and learning of chemistry concepts (Figure 14). With this framework, teaching and learning can be guided with all participants being active. The framework is also a language through which the student and the lecturer can communicate at the same level. Lastly, the framework is a meta-cognitive “tool” with which students can monitor and evaluate their learning.

From the study it is apparent that knowledge or prior knowledge in particular is generally difficult to understand because of its fluid, dynamic and interactive nature (Dochy & Alexander, 1995). But understanding prior knowledge can have significant outcomes, such as enhancing meaningful learning (thereby improving education in general and that of science teaching in particular). The nature of knowledge (or prior knowledge) should therefore not be a hindrance; but should be seen as a challenge in the quest for improving knowledge and, more specifically, to enhance the instructional design and facilitation of learning.

5.8 Conclusion

In this study, students' prior knowledge and how it is used during learning, especially during the learning of concepts in chemistry, was explored. The study was specifically aimed at exploring and understanding how students constructed understanding and generated meaning of chemistry concepts. The term "explore" (*Concise Oxford English Dictionary,* 2006) means to travel in an "unfamiliar territory in order to learn about it" (p.502). Indeed, prior knowledge research (and more specifically the understanding of how students use prior knowledge during learning) is still a relatively unfamiliar research area. It needs further exploration if it is to be well understood and used to enhance learning.

"Conclusion", in the context of this study, should not have the common meaning of bringing something to an end or finish. Conclusion should be viewed as the proposition that was reached from given premises. The conclusion in the case of this study is what can be understood in terms of the parameters within which the study was conducted. As indicated at the beginning of the study, the aim was to understand how students used their knowledge. Therefore, it follows that the process could not be the end, as understanding (Gunstone & White, 1992) is never complete and could never be complete.

Based on the limitations of the study, the proposition is that learning is a complex process that requires continual and consistent exploring if it is to be understood. It is affected by many factors, including the prior knowledge of those engaging in it. These factors, individually or as an integrated whole, need to be understood if learning is to be understood and improved. The findings in this study are merely contributory to this objective. This contribution, although limited, will add to the knowledge of understanding prior knowledge as a factor in the quality of learning, especially the learning of chemistry, and in the design and facilitation of learning.

Finally, prior knowledge was understood at a conceptual level of chemistry. This places the study in an important position of enhancing the learning of chemistry because concepts are, according to Pines and West (1985), the building blocks of knowledge. It makes the design of instruction effective as it considers not only the perspective of the content but also the perspective of the student. That is, it considers the readiness of the student and as such will consider the instructional strategies based on the students' prior knowledge (Kemp *et al.*, 1998).