First-year students' use of prior knowledge in the learning of acids and bases

by

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Abstract

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Science has been perceived as difficult to learn because of its nature and the methods by which it is usually taught. Most first-year science students entering higher education in South Africa today come from disadvantaged teaching and learning backgrounds. These students bring different "knowledge, skills or abilities" into the learning process. This knowledge, referred to as prior knowledge – or what the student already knows – is the single most important factor influencing learning (Ausubel, 1968). It is on the basis of this influence of prior knowledge on learning that the focus in this study is on understanding its manifestation in learning. Prior knowledge has both facilitating and inhibiting effects in learning. However, the focus in this study was only on *inhibiting effects* of prior knowledge on learning. To better understand prior knowledge qualitative methods (interview, observation, document review and the prior knowledge state test) were used. The aim was to specifically establish how students used their understanding of selected acid-base concepts and processes to *construct understanding* and to *generate meaning* of new concepts and/or knowledge. The study managed to highlight important aspects of the quality of prior knowledge and their manifestation in learning. The findings generally indicated that:

- The quality of the knowledge that students possessed was in most instances incomplete. That is, in their description of concepts, students preferred to use *summary* and *informal* descriptions without understanding the meaning of the concepts they were describing.
- The quality of knowledge (e.g. incomplete knowledge) affected their ability to construct understanding and/or generate meaning as this knowledge

was insufficient to access for the construction of scientifically valid meanings of concepts.

- The quality of students' knowledge impeded their ability to *reflect* and/or to be *aware* of the knowledge they possessed. This made it difficult for students to access knowledge and to restructure it in order to construct new knowledge or prevent errors in their learning.

The study culminated in the development of a framework that may in future be used to assess prior knowledge and enhance meaningful teaching and learning based on the quality of students' prior knowledge.

<u>Key terms</u>

Prior knowledge; inhibiting effects; knowledge construction; generate meaning; quality of knowledge; incomplete knowledge; knowledge restructuring; accessing knowledge; error prevention; and types of knowledge.

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This project is dedicated to my children, Kgosietsile and Omphile, and to my wife Ntombikayise, who tirelessly supported me, persevered and tolerated my absence from their lives. I would also like to dedicate this project to my late parents, Theophilus and Sinah, and to all my brothers.

Signature:

T. D. T. Sedumedi.

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CHAPTER ONE

General orientation of the study

All we come to know is our own construction (Bettencourt, 1993, p.39).

1.1 Introduction

With the dawn of democracy in 1994 South Africa was accepted in the global community of nations. This new era has also brought about many societal challenges. One of the challenges facing the new democratic society was the limited knowledge and skills of the majority of its citizenry to engage with other nations in a competitive, technologically advanced and ever-changing political, economical, social and cultural environment. In an attempt to address this challenge, the new government introduced legislation such as the South African Qualifications Act, 1995 (Act 58 of 1995); the Skills Development Act, 1998 (Act 97 of 1998) and the Higher Education Act, 1997 (Act 101 of 1997), and other plans aimed at addressing the level of knowledge and skills of its citizens.

In its endeavour to further enhance the knowledge and skills of society, especially at school level, government began developing a new curriculum. The objective of the new curriculum, according to the *Revised National Curriculum Statement* (Department of Education, 2002a), was to take up the challenge posed by –

- the scale of change in the world (i.e. the growth and development of knowledge and technology and the demands of the 21st century, which required students to be exposed to different and higher level skills and knowledge than those required by the former South African curriculum); and
- the fact that South Africa had changed (the new South Africa required revision to reflect new values and principles based on the Constitution).

What does it mean to expose students to different and higher level skills and knowledge? How would a curriculum accomplish this?

The development of a new curriculum cannot be sufficient if it is not accompanied by the development of resources – both human and physical – to enhance higher-level skills and knowledge. According to Spady (1994) to successfully implement a curriculum to enhance skills and knowledge, that curriculum should focus on and organise everything around what is "essential for all students". This he said is to enable successful learning at the end of their learning experience. It also needs sufficient *resources* if students are to learn successfully. Resources here mean both the *physical* and the *human* resources required to enhance teaching. "Physical resources" are, for example, well-equipped classes, laboratories, libraries, etc. "Human resources" refer to administrators and lecturers who are qualified in their respective fields to contribute to successful learning. In the case of teaching, lecturers should not only be qualified, but also knowledgeable in the art of teaching a specific subject matter content.

This means lecturers should understand the content of their subject matter and the pedagogy to teach it successfully. Successful teaching is teaching that results in meaningful learning or understanding. Understanding something according to Wandersee and Griffard (2002) is "to explicitly connect it to one's prior knowledge and experiences in a non-trivial way" (p.29). Meaningful learning can therefore be enhanced when the lecturer has sufficient and relevant knowledge to understand how students use their prior knowledge during learning. To enhance meaningful learning the lecturer should be in a position to demonstrate 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, Mulhall & Berry, 2004, p.370). In fact, the knowledge described by Loughran *et al*., (2004) above is what Shulman (1986) termed "pedagogical content knowledge" (p.9). It is an understanding of the relationship between knowledge of content and teaching and learning, and enables the lecturer to represent and formulate the subject in a manner that makes it comprehensible for the student (Shulman, 1986; 1987).

The qualified and knowledgeable lecturer should not only have pedagogical content knowledge to succeed in his or her teaching. In addition, the lecturer should also understand the students' background and the factors contributing to students' learning. According to Ausubel (1968), the main factor contributing to learning is one's existing knowledge. The definition of understanding cited earlier highlights the important role that the individual's existing knowledge plays in learning and especially in understanding: One needs to connect newly acquired information to what is already known (referred to as one's "prior knowledge" in this study) in order to understand.

But what is prior knowledge? Different people have defined prior knowledge differently. Jonassen and Grabowski (1993) define it as "knowledge, skills or ability that students bring to the learning process” (p. 416). Dochy and Alexander (1995) describe it as "the whole of a person's knowledge" (p.228). What students bring to the learning process is therefore what they would use to acquire new knowledge. Based on these definitions, the rationale is that understanding students' prior knowledge would enrich lecturers’ teaching and learning planning of their lectures before engaging in teaching. On the whole, the lecturer should have an understanding of a student’s learning weaknesses and strengths on the basis of his or her prior knowledge. This understanding would help the lecturer in the planning of relevant and effective teaching and learning activities.

The purpose of this study is therefore to explore and understand students’ use of prior knowledge to construct understanding and generate meaning of selected concepts and processes on the topic of acids and bases. The study was based on first-year students studying towards a National Diploma in Analytical Chemistry at the Tshwane University of Technology in South Africa. For ease of reference, the topic on acids and bases would generally be referred to as "chemistry" where it is not specifically stated.

1.2 Background and rationale

Education and higher education institutions in particular, especially in South Africa, are faced with the challenge of adapting their programmes and curricula to satisfy the needs of an economy that has to compete in the global community. These institutions therefore have to produce graduates with the knowledge, abilities and skills that will ensure their competitiveness at all levels of the local and international economic landscape in which they participate. The economy for which today's institutions of higher learning (universities and universities of technology) are required to prepare their graduates can be grouped into three interrelated categories that cannot function separately (Castells, 1996). These categories are –

- an economy in which productivity and competitiveness are based on knowledge and information;
- a global economy which has the capacity to work as a unit in real time on a planetary scale of core activities; and
- an economy with technological, organisational and institutional capacity.

Undeniably, the kind of economy Castells describes here relies on *knowledge* and the individuals' capacity to create new knowledge. Individuals aspiring to participate in such an economy must therefore have the capacity to create new knowledge since knowledge in this economy changes as fast as it is created. This knowledge changes as fast as it does because (Castells, 1996) "new information and communication technologies allow fast processing and distribution of information throughout the entire realm of productive activity" (p.2). Institutions of higher learning, especially those in developing countries such as South Africa must therefore develop teaching and learning strategies, whose application would produce graduates capable of independently generating relevant knowledge. With this knowledge graduates would engage productively in the economy Castells describes above.

However, students entering the higher education system are different in terms of their individual learning abilities. Most of these students come from a schooling system of limited teaching and learning resources. In most instances these students' prior knowledge is less developed. Consequently they find it difficult to engage productively in higher-order cognitive learning. For example, in South Africa (Nkomo (1990), the majority of these students are the products of an inferior education system. They come into higher education studies with poor quality prior knowledge. Nkomo (1990) further argues that the segregated education system deliberately subjected Africans, Coloureds and Indians to intellectual underdevelopment. According to Nkomo (1990) this education system was meant to provide the then government with "an ideological cornerstone for the social segregation, economic exploitation and political oppression of these groups calibrated according to their location on racially hierarchical social system" (p.1).

In fact, most students who lack the capacity to learn meaningfully are products of teachers who themselves are the products of an education system that promoted an intellectually underdeveloped (mostly black) society. The teachers also studied under a system where resources were deliberately minimised for the three racial groupings mentioned earlier, while maximised for their white counterparts. As a result, schools and higher learning institutions meant for these communities could not develop teachers and other professionals at the competency level of their white counterparts. The "gap" between what was taught and learned by white and black citizens in South Africa was (and still is) apparent in different areas of the society. More significantly, the “gap” is apparent in the socio-economic, education and skills spheres.

Table 1: Mathematics and physical science performance by group, 1991 (Kahn, 2005).

	AFRICAN	COLOURED	INDIAN	WHITE
Mathematics				
Candidates (HG)	10 519	1 127	3 436	15 399
Passed (HG)	1 052 (10%)	715 (63%)	2 731 (80%)	13 543 (89%)
Physical science				
Candidates (HG)	10 6409	1 308	3 952	15 642
Passed (HG)	1 698 (16%)	1 033 (79%)	3 277 (83%)	12 769 (82%)

HG = Higher Grade (There are other grades, i.e. SG = Standard Grade; LG = Lower Grade. HG is weighted more than the two in terms of their difficulty.)

The statistics (Table I) provide what Kahn (2005, p.140) referred to as "some feel for the extent of the inequalities" in education under the apartheid education systems. These exclude statistics of what was happening in "independent homelands" in terms of education. In Mehl's (1990) words, "… this is an imbalance which any future government will need to address as an urgent priority" (p. 383) if any teaching and learning is to prepare students for what Gravett (2004) regards as the world of "super-complexity"(p.22). The world of super-complexity (Barnett, 2000; Barnett & Hallam, 1999) is the world that is rapidly changing; a world without stable meanings and a world in which the handling of uncertainty, ambiguity and contestability come to the fore. If this is the world students have to face when they enter their careers, a meaningful way should be found to prepare them for it.

In fact, in their study Howie and Pietersen (2001) highlight the state of teaching and learning in South Africa in terms of Grade 12 students' performance in the Third International Mathematics and Science Studies (Table 2). According to their report, the performance of South Africa's top students was not that well compared to that of the top students from other countries; they performed the same as average students from other countries. South African grade 12 students were the worst performers in the selected group.

Table 2: South African grade 12 students: Mathematics literacy compared to selected countries (Adapted from Howie & Pietersen, 2001, p. 10).

COUNTRY	MATHEMATICS LITERACY	OVERALL LITERACY
Netherlands*	560 (4,7)	559 (4,9)
Sweden	552 (4,3)	555 (4,3)
Canada**	519 (2,8)	526 (2,6)
New Zealand	522 (4,5)	525 (4,7)
Australia	522 (9,3)	525 (9,5)
Russian Federation	471 (6,2)	476 (5,8)
Czech Republic	466 (12,3)	476 (10,5)
USA*	461 (3,2)	471 (3,1)
South Africa*	356 (8,3)	352 (9,3)
International mean	500	500

( ) Standard errors appear in brackets
* Unapproved sampling procedures and low participation rates
**Did not satisfy guidelines for sample participation

Studies such as this one show the need to enhance students' learning abilities in order to improve performance. This will help to avoid such performances as described above (Howie & Pietersen, 2001; Kahn, 2005). With the legacy described and illustrated above, how does higher education and science education in particular take up the challenges of the "new economy" described earlier by Castells?

Some approaches to overcome these challenges are suggested. For science education at higher education institutions to equip graduates to compete in the new economy requires a holistic approach. Such an approach is characterised by the belief that the teaching and learning in general, and of science in particular, should be based on and influenced by factors surrounding the environment in which learning takes place. The environment includes, but is not limited to teaching and learning facilities, the student, the lecturer and the learning content.

There are many factors (cultural, social, economical, linguistic, the nature of learning content and the prior knowledge of both the student and the lecturer) that affect teaching and learning. However, not all of these factors can be studied in detail or at the same time in one study or within a limited prescribed time. Only students' prior knowledge of science and more specifically their prior knowledge of concepts of acids and bases and related practical work processes are the focus in this study.

The motivation to focus on prior knowledge was prompted by the fact that first-year students entering higher education for the first time bring into the learning situation established ideas and notions inconsistent with those of lecturers and scientists. In addition, this knowledge is insufficient and irrelevant and/or littered with 'misconceptions' since (Erduran & Scerri, 2003) teaching still continues to reinforce a 'rhetoric of conclusions', "a tradition that perpetuates the learning of conceptual outcomes while neglecting the learning of strategies that enable knowledge growth in different fields of scientific enquiry" (p.7); making learning science meaningfully, difficult (De Jong, 2000; Gabel, 1998; Johnstone 2000a; Taber 2000).

Furthermore students at this level have not yet been assimilated into the culture of learning at a higher level and the learning culture of the institution they are studying at. For a better assimilation of new first-year chemistry students factors that contribute to their poor and/or good performance such as prior knowledge must be understood to reduce the inhibiting effects of other factors such as culture of learning on their performance. Prior knowledge of students was also identified as the area of focus because successful construction of knowledge is knowledge-dependent (Glaser, 1984) and that prior learned concepts (Reif, 1985) are "logically the building blocks of the knowledge used to deduce important consequences, make predictions and solve problems" (p.133).

How then do students with limited or a lack of prerequisite knowledge engage in higher order cognitive learning processes in chemistry? To answer this question, an attempt was made to understand how the specific prior knowledge of concepts and their relationships or lack thereof manifested in students' abilities to learn and apply these concepts in practical learning situations. The rationale was therefore that understanding *how* students use these concepts would help lecturers develop strategies that would enhance students' ability to engage in higher-order cognitive learning processes and prepare them for the world of "super-complexity" (Gravett, 2004) and the "new economy" (Castells,1996).

1.3 Purpose statement

The main purpose of teaching is to facilitate and enhance learning by students. However, teaching often has limited success in guiding students from their pre-instructional conceptual frameworks to new understandings (Bodner, 1986). That is, teaching does not always result in the lecturer's intended learning. This is so because of the complexities surrounding teaching and learning. The failure to achieve intended learning outcomes in some instances could be ascribed to the limited understanding of lecturers and instructional designers of factors that affect teaching and learning.

According to von Glasersfeld (1995) lecturers too often prepare their teaching strategies and procedures from "the naive assumption that what we ourselves perceive and infer from our perceptions is there ready-made for the students to pick up, if only they had the will to do so" (p.5). This attitude makes it even more difficult for students to learn in general and to learn chemistry in particular; especially students coming from poorly resourced teaching and learning backgrounds. This attitude (based on the practice not to assess students' prior knowledge before teaching) is prevalent in most schools in South Africa. In addition (Gabel 1999), students encounter problems learning chemistry because of the many abstract concepts in chemistry. Students are sometimes taught without the use of analogies or models. This makes chemistry difficult to understand and learn. The abstract nature of chemistry is further compounded by assumptions that lecturers make about the levels of students' knowledge and their ability to learn in a particular domain. How, then, do we overcome the effect of the legacy of poor teaching and learning resources, especially in science learning?

Questions occupying most instructional designers' and lecturers' minds, are *what* factors affect successful teaching, *how* they do that, and how they could be *overcome* to achieve intended outcomes of teaching? The different knowledge bases that students (i.e. first-year students) bring into the learning situation is what instructional designers and lecturers especially chemistry lecturers need to understand if they are to answer the question: *How do I help my students to learn if I do not know what they know, how they know it and how they learned it?*

The purpose of this study is therefore to understand how students construct understanding and generate meaning during learning. Understanding students' learning in this study was based on von Glasersfeld's (1996) view of learning. According to this view learning is a constructive activity in which students themselves carry out knowledge construction. Within this perspective the lecturer does not dispense knowledge but provides students with opportunities and incentives to build knowledge. With this understanding of learning, some of the questions asked about understanding students' knowledge construction may be answered.

1.4 Research question(s)

Major question

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

Research sub-questions

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

(ii) *How do students use their prior knowledge of selected chemistry concepts and processes to construct understanding and generate meaning during learning?*

1.5 Aims and objectives of the study

The aim in this study was to understand how students use prior knowledge in constructing understanding and generating meaning of concepts and processes during the learning of acids and bases. To achieve this (students' knowledge construction), an attempt was made to answer research questions posed earlier. These questions were answered by establishing:

- *Students' understanding of selected acid-base (chemistry) concepts and related processes in a first-year practical work activity.*

Acid-base equilibria or "acids and bases" are a common topic in many first-year chemistry curricula. Acids and bases are, according to Brown, Le May Jr, Bursten and Murphy (2006) "important in numerous processes that occur around us, from industrial processes to biological ones, from reactions in the laboratory to those in the environment" (p.669). In the light of this it was important that concepts mostly considered ‘confusing’ among many first-year chemistry students had to be studied in order to enhance their understanding and their subsequent usage by students. These concepts were *acidity* (or *aqueous acidic solution*), *acid strength, concentration, equivalence point* and *endpoint.*

- *Students' use of prior knowledge of selected acid-base (chemistry) concepts and processes to construct understanding and generate meaning during learning*.

Titration is a process commonly used (e.g. by chemists) to determine the concentration of solutes in a solution. It (titration) involves combining a sample of the solution with the reagent solution of known concentration. Titrations are conducted using any of the acid-base, precipitation or oxidation-reduction chemical reactions (Brown *et al.,* 2006). In the teaching of chemistry, concepts selected for this study contribute significantly in the understanding and performance of acid-base titrations. Understanding these concepts would therefore enhance the students' meaningful learning of acid-base concepts and the titration processes involved.

In conclusion, understanding (by lecturers) how students construct understanding and generate meaning of concepts and/or processes as building blocks of knowledge, will according to Gravett (2004) go a long way to help in "getting the 'ordinary' students enrolled at higher education to engage in higher-order cognitive learning processes that the more academic students tend to engage spontaneously" (p.23). In the light of this, the outcomes of the study would enhance lecturers' understanding of the quality of students especially those with less developed prior knowledge and its manifestation in their construction of knowledge during learning.

With this understanding lecturers will be in a position to help students adapt to their new learning environments because (von Glasersfeld, 1996) one can hope to induce changes in students' ways of thinking only if one has some inkling as to their domains of experience, their concepts and the conceptual relations they possess at that time.

1.6 Significance of the study

Generally the study was to explore and understand students' background in terms of prior knowledge and how this manifested in new learning of science and, more specifically, selected acid-base (chemistry) concepts. In the light of this its significance was that:

- It could bring a rich understanding and more knowledge to lecturers, curriculum developers and researchers about what Dochy (1992) referred to as the "student model". According to Dochy this model is an instrument used to gain a clear understanding of the students' prior knowledge in order to make hypotheses about their perceptions and reasoning strategies employed in achieving current knowledge.
- It could also help the lecturer to enhance the learning of science by a better course design and instructional support, using information from students' prior knowledge and their application of this knowledge in practical situations (Dochy, Valke & Wagemans, 1991; Dochy, 1994; Dochy & Kulikowich, in press). The results of the study could also inform the development of frameworks to accommodate understanding between the student and the lecturer in terms of the objectives of teaching and learning.

1.7 Literature review

The focus of the literature review was on aspects of teaching and learning with specific emphasis on chemistry (acids and bases) teaching and learning. As the study leaned more towards the constructivist view of learning, knowledge, its quality and usage were areas focused on in this literature review. The review on prior knowledge emphasised three important aspects namely –

- prior knowledge as a major factor in learning;
- prior knowledge as a barrier towards meaningful learning; and
- prior knowledge as a facilitator of meaningful learning.

(i) Knowledge as a major factor in learning.

Since this study was conceived within the constructivist view of learning, it was important to review knowledge in general and from the constructivist perspective in particular. This knowledge (Glaser, 1984), is the source from which new meaning/knowledge is constructed. Understanding knowledge was therefore paramount as it is the outcome of learning and at the same time guides new learning.

(ii) Prior knowledge as a barrier towards meaningful learning.

One of the characteristics of knowledge (or prior knowledge) is that it inhibits learning. This is the case when one has incomplete, not well-organised and inaccessible knowledge. Inaccessible knowledge cannot be utilised (Dochy, 1992). For this study, it was important to understand this characteristic in order to enhance the understanding of students' learning (and/or their prior knowledge).

(iii) Prior knowledge as the facilitator of meaningful learning.

A facilitating effect (Dochy, 1992) of prior knowledge is mostly recognised as contributing positively to learning. Three types of the facilitating effects of prior knowledge were identified. They are (1) the direct effects of prior knowledge, which facilitate the learning process and leading to better results; (2) the indirect effects of prior knowledge, which optimise the clarity of the study material; and (3) the indirect effects of prior knowledge, which optimise the use of instructional and learning time. Although these characteristics were not the focus of the study, it was important to understand them, as they are part of an individual's knowledge infrastructure.

The review also focused on the origin of science and its nature, with particular emphasis on the nature of chemistry. As the study deals with teaching and learning (knowledge construction), it was also important to highlight areas of teaching and learning in general, and teaching and learning of science, particularly chemistry. As far as teaching and learning in general and teaching of chemistry are concerned, the foci of the study were on the following:

- Understanding learning and knowledge ‘acquisition’;
- Origin, nature and learning of science; and
- Practical work in science teaching and learning.

(i) Understanding learning and knowledge acquisition.

For purposes of understanding the importance of learning and the context in which it occurs it was imperative to explain *what* learning and knowledge were and *how* knowledge is acquired. There are many views on learning, but three views (behavioural, cognitive and constructivist) were considered relevant to and are briefly discussed later in this study.

(ii) Origin, nature and learning of science.

Science, relative to other subjects, is not easy to learn (Gabel, 1999) because of its nature. With this in mind, it was important to discuss the origin, nature and the learning of science. This is done in an attempt to show how students and lecturers respectively conceptualise it.

(iii) Practical work in science teaching and learning.

Practical work or laboratory activities have had a distinctive and central role in the science curriculum. Science educators have suggested that many benefits accrue from engaging students in science laboratory activities (Lunetta, 1998). Therefore, practical work is discussed to demonstrate its importance in science learning and in helping in the facilitation of this study. The literature review also focuses on how education, and science education in particular, contributes or should contribute and could contribute to learning to equip graduates with relevant knowledge and skills for the 'new economy'. The literature therefore focuses on factors that affect teaching and the complexity of learning, especially the learning of chemistry.

1.8 Research methodology

It is apparent from the discussion above that the qualitative method would be appropriate for the study. Qualitative research methods (Denzin & Lincoln, 2003) are situated in activities that locate the observer in the world. That is, they study things in their natural setting in an attempt to make sense of, or to interpret, phenomena in terms of the meanings people bring to them (p.4-5). In this study the natural setting was a chemistry laboratory and the phenomena under study were prior knowledge of concepts and their use in constructing understanding and generating meaning during learning.

1.8.1 Research design.

The design of a research project plays a major part in the outcomes of an empirical study. According to Denzin and Lincoln (2003), a research design describes a flexible set of guidelines that connect theoretical paradigms to: (1) strategies of inquiry and (2) methods for collecting empirical material. In fact Janesick (2003) regards a research design as the 'spine' on which the researcher must rely in his/her research project. The spine is elastic; therefore the research design should also be seen in the same light. That is, as being elastic in terms of which strategies and methods should be employed at any given time of the study.

As this study was to be in-depth three *instrumental case studies* were used. An instrumental case study (Stake, 2003) provides insight into an issue or redraws a generalisation. With the three case studies an attempt was made to provide insight into students' construction of understanding and generation of meaning from their prior knowledge during learning. To better understand students' use of prior knowledge during learning the constructivist-interpretive design was used to elicit information from students engaging in the learning of 'acids and bases' concepts and/or processes through practical work activities. This paradigm was selected on the basis that the nature of the reality within which the study was conducted was multiple, constructed by human interaction, holistic and divergent (Patton, 1990).

1.8.2 Instrumentation.

Instrumentation (Fraenkel & Wallen, 2003) involves the whole process of preparing to collect data; where the selection or design of the instruments, the procedures and conditions under which the instruments are to be administered are important. The process of data collection is therefore important as it affects the data collected. In a research study such as this one, it is important to know what the study's intent is and how we intend doing it. To guide the procedures and conditions that may be "ideal" for conducting a study, Fraenkel and Wallen (2003) suggest questions that, when answered correctly in relation to the objectives of the study, may yield desired outcomes (see Table 3).

Table 3: Instrumentation questions

Question to researcher	Answer from this researcher
Where data would be collected? (**Population of interest**).	From first-year chemistry students during practical activities at the Tshwane University of Technology.
When would data be collected? (**Time).**	At the end of the semester, when topics that are practically and theoretically relevant to the study have been covered.
How would data be collected? (**Data collection methods**).	Prior knowledge state test, interview and observation.
Who would collect the data? (**Research instrument).**	The lecturer responsible for practical work (in this case, the researcher).

Since a research design (Denzin & Lincoln, 2000) situates researchers in the empirical world and connects them to specific persons, sites, groups, bodies of relevant interpretive material, etc.-responding to these questions would indicate –

- the population of interest;
- the time period at which the study would be conducted;
- the methods and instruments that would be used to collect data; and
- the instrument(s) for data collection.

(i) Data collection methods.

A population must be identified for data to be collected. Fraenkel and Wallen (2003) describe a population as "the group of interest from whom the researcher would like to generalise the results of the study" (p.97). In this study, "population" refers to all first-year chemistry students studying towards a Diploma in Analytical Chemistry at the Tshwane University of Technology. Since not all members of this population were practically accessible, the sample was selected from students who volunteered for the study. However, it should also be stated that generalisation was not intended.

The quality of research data depends to a large extent on the appropriateness of the selected data collection methods. In this study, only qualitative data collection methods were used. Marshall and Rossman (1995) list four methods relied on for qualitative data collection, namely participation in the setting; direct observation; in-depth interviewing; and document review. However, for the purposes of this study, observation, interviews and a practical work report were used and complemented with a prior knowledge state test.

(ii) Data collection process.

Social collaboration between individuals (Tobin, 1990) fosters the understandings to be clarified, elaborated, justified and evaluated. The rationale is that, in this social collaboration, any differences of opinion between individuals would be an "ideal" environment for individuals to construct understanding and generate meanings of concepts and processes in a practical situation. The differences in opinion (if any) would enable the researcher to capture the conversation and collect data. In fact, the prior conceptual understanding would be established from translating or interpreting students' talk to their object manipulation or vice versa. The existence of relevant prior knowledge students have when engaging in practical activities would therefore be established through their discussions of practical work activities.

Data collection involved the formation of dyads. Each dyad was provided with a practical work task. It was also important that students understood the purpose of the practical task. The task was a 'mixture' of closed-ended and open-ended tasks. According to Hofstein (2004), students conduct experiments on specific instructions in a closed-ended task, while in an open-ended type task they are involved in "experiences such as asking relevant questions, hypothesizing, choosing a question for further investigation, planning an experiment, conducting the experiment (including observations) and finally analyzing the findings and arriving at conclusions" (p. 253). For this study, the task had features of both types of tasks. In some instances they were provided with information and in some instances no structure or guidelines for the task were provided.

The reason for using a mixed-task approach was necessitated by the experience of the *pilot study*. In the pilot study it was apparent that students at first-year level were not ready to engage in an exercise that demanded higher order cognitive skills, owing to their academic background and lack of experience in discovery inquiry exercises in practical work. During a pilot study students spend most of the practical activity asking for explanation of the aspects of the practical work activity. Most of the time was therefore occupied by explaining practical work aspects to students.

According to Piaget (1964), the ability to design and carry out an open-ended inductive experiment depends on the student's ability to carry out formal reasoning operations. In fact, Kirschner and Meester (1988) indicate that this ability is possessed by only a *third* of students starting university. This means that two thirds of first-year university students lack this ability. The mixed-task approach (or "divergent laboratory approach", according to Kirschner & Meester, 1988, p.90) where some parts of the experiment are predetermined and standardized for all students was found *ideal* for this study. With this approach, students are expected to interact both physically (by object manipulation) and mentally with objects to achieve the goals of the task.

The empirical study process involved four data collection methods described earlier. The type of data collected depended on the sequencing of the methods (see Figure 1). For example, it was important for students to write the prior knowledge state test before performing practical work activities. This was done so that students' responses in the prior knowledge state test could guide the framing of questions for the interview and observations during practical work activities.

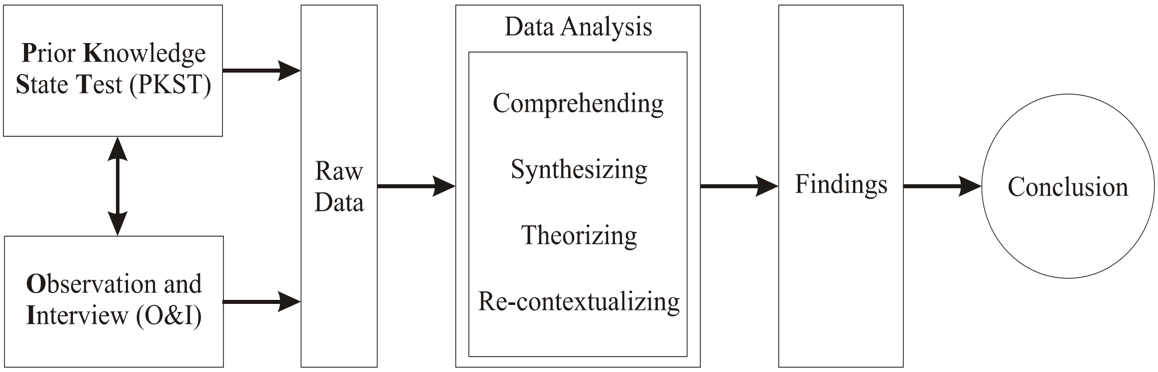

Figure 1: The empirical study process.

Information collected during the interview and observation stage of the process was used with data collected from the prior knowledge state test. The prior knowledge state test elicited students' *initial* understanding of concepts. It elicited information about how students interpreted concepts that they used for reasoning during practical work activities. A relation could therefore be established between how students constructed understanding and generated meanings on the basis of their prior conceptual understanding.

(ii) Data management and analysis.

The challenge of data analysis, especially qualitative analysis is to make sense of massive amounts of data collected (Patton, 1990). This is done by reducing the volume of information through the identification of significant patterns emerging from the information, and the construction of a framework that can later be used to communicate research outcomes. Morse (1994) lists four cognitive processes (Figure 1) that are integral to data analysis in qualitative research. They are: comprehending; synthesizing; theorizing; and re-contextualizing. "Comprehending" refers to learning about the setting before the study begins. "Synthesizing" is merging several stories, experiences or cases to describe a typical composite of behaviour or response. "Theorizing" is the constant development and manipulation of malleable theoretical schemes until the "best" one is developed.

"Re-contextualizing" is the development of an emerging theory so that it may be applied to other similar settings and to other similar populations (p.25-34). Some aspects of the four processes were used for analysis in this study.

(iv) Addressing issues of trustworthiness.

In any research study it is important that a researcher is able to defend the findings of his or her research. In qualitative research this is not an easy task, as the method is value-laden. According to Janesick (2003), the researcher is an instrument whose background about the research topic plays a major part in the credibility of the findings. Because of the importance of the credibility of the research instrument, it is important therefore that in qualitative research attention is paid to issues relating to the trustworthiness of this instrument (the researcher) as far as its ability of conducting the study is concerned.

In an attempt to enhance trustworthiness in this study, only factors relating to credibility and confirmability were addressed. Credibility (Hoepfl, 1997) is the extent to which findings accurately describe reality. Credibility was established through 'triangulation' of sources of data. The sources of data were: (1) observation and the interview report sheet (2); the prior knowledge state test answer sheet; and (3) the practical work report. Data collected was interpreted and compared to determine if data from sources had convergent meanings. The iterative nature of the study (in data collection methods) also played an important role in establishing credibility and confirmability. For example, responses from the prior knowledge state test were used to confirm students' understandings during observations and the interview. Reviews by peers on students' understanding were also sought and used to confirm the findings.

(v) Delimitations and limitations of the study.

Not everything can be researched at a given time and place. It is also not possible in research to avoid aspects that limit the effectiveness of a research project. It is therefore also important to indicate the delimitations and limitations within which this study was conducted.

- Delimitations.

As this study was about prior knowledge, which was earlier described as pervasive (Dochy & Alexander, 1995), it was important to indicate the delimitations within which it was to be conducted. The study was specifically on "inhibiting effects" of learning by way of the three types of prior knowledge. The three types of knowledge are *declarative knowledge*; *procedural knowledge*; and *conditional knowledge*. According to Marzano and Kendall (2007) "declarative knowledge" is the knowledge of vocabulary terms and facts. A vocabulary term according to these authors refers to a word or phrase about which one has an ‘accurate’ but not necessarily a deep level of understanding. Facts, on the other hand, are seen as presenting information about specific persons, places, things and events. "Procedural knowledge" (Shuell, 1985) and "conditional knowledge" (Alexander, Schallert & Hare, 1991) refer to the individual's ability to do various procedures necessary to complete some task and the understanding of *when* and *where* declarative and/or procedural knowledge is applicable respectively. Any subject, including chemistry, according to Marzano and Kendall (2007) can be described in terms of how much of these three types of knowledge it comprises.

The study was conducted at the Faculty of Sciences of the Tshwane University of Technology. Since the faculty is located at three different campuses and constitutes different fields of study and departments, students of the Department of Chemistry were chosen from one campus, namely Ga-Rankuwa. This campus was chosen because it is where the researcher is stationed and most of the students on this campus are from provinces, which are historically rural, with limited teaching and learning resources in schools.

- Limitations of the study.

The following were significant limitations of the study:

- o Prior knowledge by its nature is pervasive. There are different definitions of prior knowledge. Studying prior knowledge therefore requires consistency of definitions and descriptions. In this study, the limitation was that only three types of prior knowledge could be described. Studying prior knowledge is therefore limited by its nature.
- o Studying knowledge has the limitation that knowledge is not static; it changes between individuals and within an individual as fast as it is acquired. In this way, the results of the study cannot be replicated. Hence generalisation is not possible.
- o Sampling of participants is difficult, as one cannot select an ideal sample for the project. This is so because it could not be predetermined how participants would fare during the study.
- o There was limited choice in the selection of the sample as the choice was confined only to those students who volunteered to participate in the project. However, this limitation did not have much impact on the sample composition in terms of gender, geographical location of the students' previous schooling (i.e. provinces) and their performance on the prior knowledge state test.
- o As the focus was on students with previously disadvantaged academic backgrounds (generally these are students with poor quality prior knowledge), this became inhibitive, as some participants had inadequate experience to engage sufficiently in discussions between members of the dyad. A detailed discussion on the limitations is provided in Chapter 5.

1.9 Summary

This chapter orientates and highlights the background of the study, the rationale for the study and the specific purpose of the study. The chapter introduces the literature to be covered (in Chapter 2) It also illustrates *what* methods and *how* the methods the researcher intends on using (Chapters 3 and 4). Finally, the orientation explains the significance of the study (in Chapter 5) within the socio-economic and educational realm in which this study is conducted.

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.

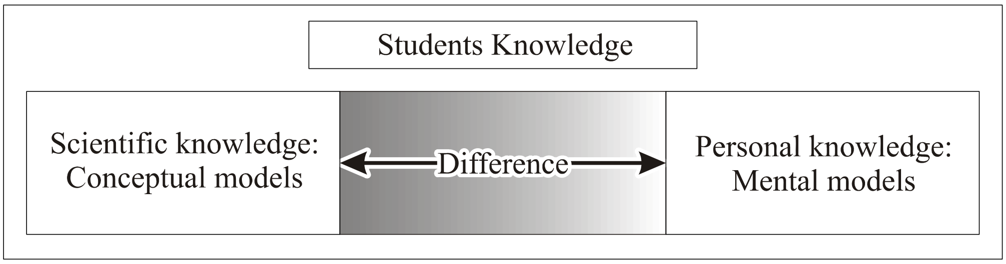

Figure 2: Students' personal mental models and/or scientifically valid conceptual models (Adapted from Glynn & Duit, 1995).

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.).

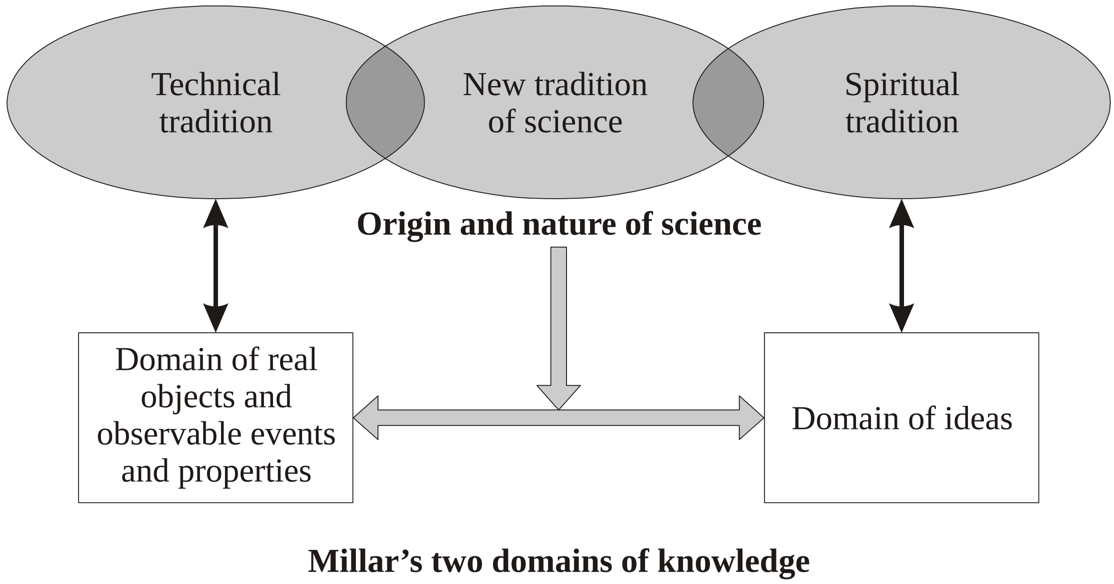

Figure 3: Parallelism between the origin and nature of science and Millar's two domains of knowledge.

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.

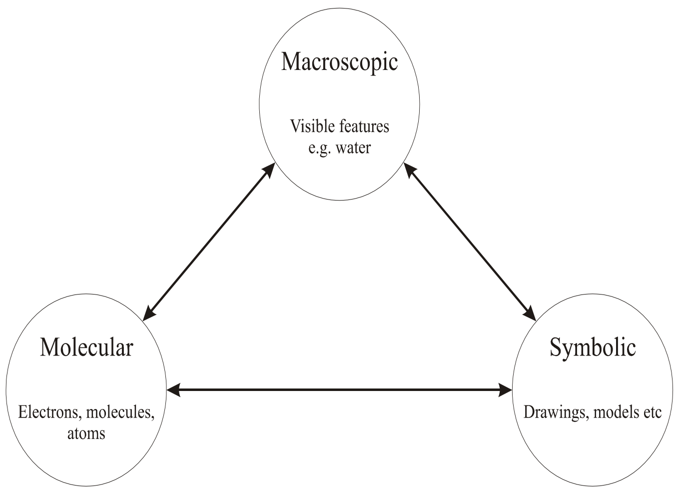

Figure 4: The triangular representation of the forms of matter in chemistry (Adapted from Johnstone, 1982).

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:

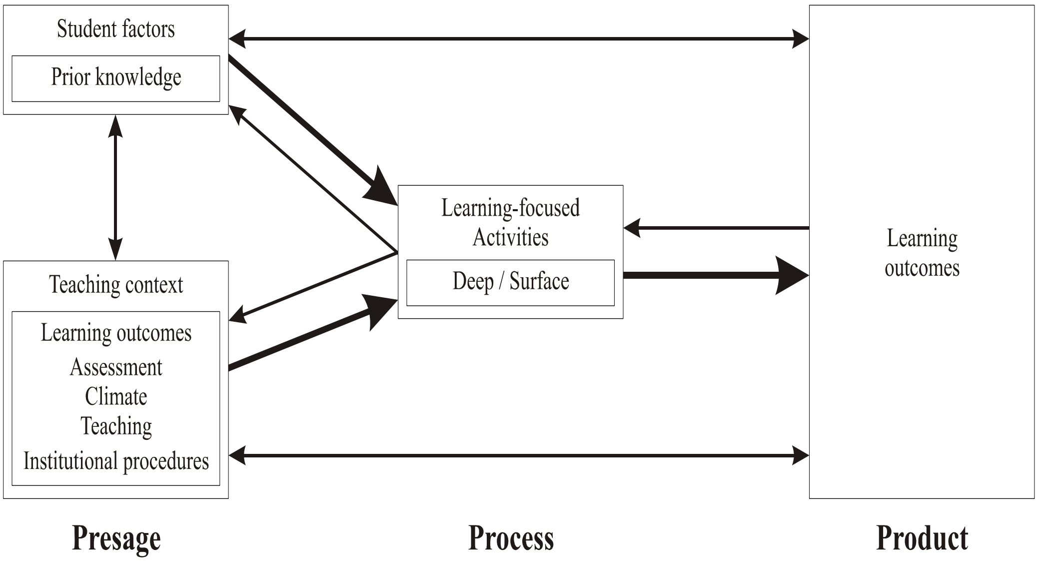

Figure 5: The three-phase model of teaching and learning (Adapted from Dunkin & Biddle, 1974).

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).

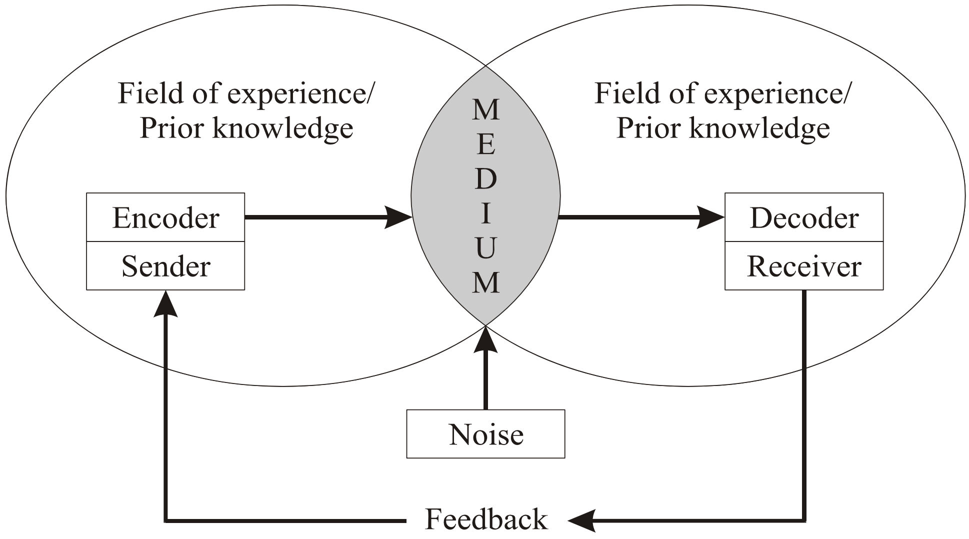

Figure 6: The communication model (Schramm's adaptation of Shannon's model).

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.

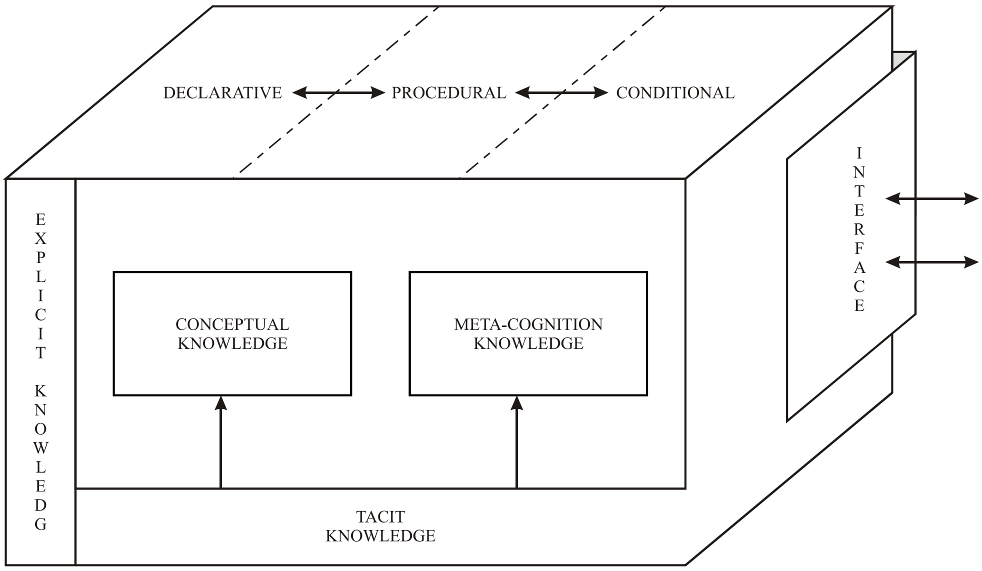

Figure 7: A conceptual map of prior knowledge (Adapted from Dochy & Alexander, 1995).

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).

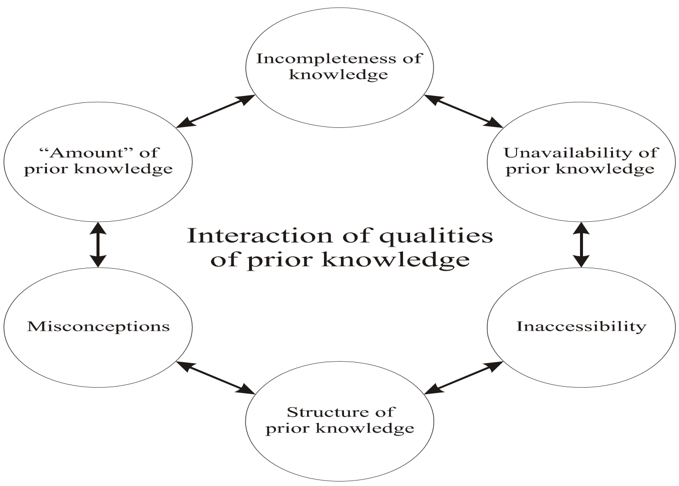

Figure 8: Interaction of qualities of prior knowledge as they affect learning.

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).

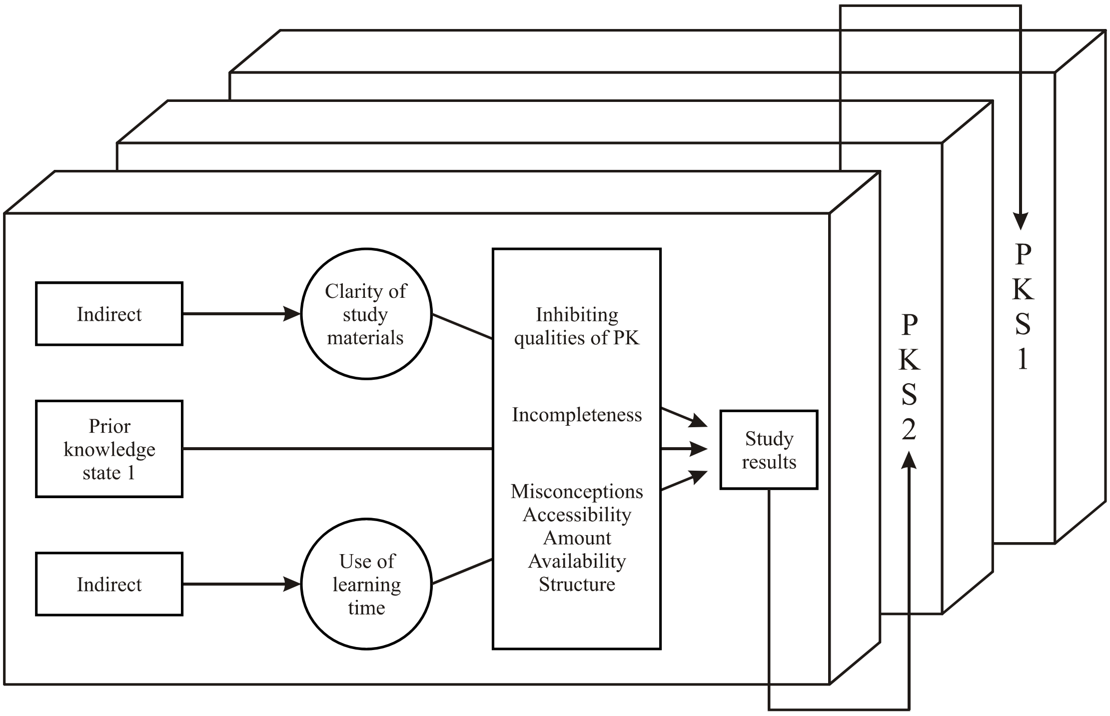

Figure 9: Interaction of inhibiting qualities and the facilitating effect of prior knowledge on learning (Adapted from Dochy, 1992).

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.

CHAPTER THREE

Research methodology and design

If you want people to understand better than they otherwise might, provide them with information in the form in which they usually experience it (Lincoln & Guba, 1985, p.120).

3.1 Introduction

The outcome of a research project depends to a large extent on the quality of its design and methodology. The main concern of a researcher in any research project is to yield valid and reliable findings. In this section of the research report, the research methodology, design and methods used to carry out the empirical processes are described. The practical processes described here aim to explore students' understanding of selected concepts and their relational use during the learning of concepts and processes in chemistry (acids and bases). More specifically, this chapter reports about procedures used to collect information in the form in which students' learning activities may shed light on how they construct understanding and generate meaning of concepts and/or processes in the learning of acids and bases.

3.2 Research methodology

As indicated earlier (Chapter 1, subsection 1.8.1), the study would be qualitative in nature. The qualitative approach was chosen on the basis of questions posed and the "reality" in which it was to be conducted. The reality referred to here (Burns, 2000), is a social reality that is "a creation of individual consciousness, with meaning and the evaluation of events seen as a personal and subjective construction" (p. 3). In addition, the qualitative approach was chosen because of its ability to elicit information from written, spoken and observable activities (Taylor & Bogdan, 1998). This ability was deemed appropriate for exploring students' understanding and use of concepts during learning.

According to Avis (2005) a qualitative research approach assists researchers to "capture social events from the perspective of the people being studied" (p.4). Thus, qualitative research enhances researchers' understanding of the subjects of research. The subjects of research are understood from their own frame of reference and their experiencing of "reality" (Taylor & Bogdan, 1998). The reality of teaching and learning was for this study viewed from Vanderstraeten and Biesta's (2006) perspective.

In their view, reality is the "educational situation" that is "constituted though, not determined by, the interaction between the educator and the student" but results from the difference between the partners in education (p. 7). The educational situation for this study therefore includes the level and quality of prior knowledge which students bring into the learning situation as opposed to that required by the community of practice. The education reality differs from student to student because of their different academic, social, economic, and cultural backgrounds.

3.3 Research design

A good qualitative research design should, according to Janesick (2003), be simultaneously open-ended and rigorous if it is to solve complex issues of the social setting under study. As indicated earlier (Chapter 1, subsection 1.8.1), a research design is a set of procedures or guidelines used to answer research questions. In other words, it (Janesick, 2003) guides researchers to make a set of design decisions about what is studied, the circumstances under which it is studied, and the time frame in which it is studied.

This study was a collective case study of the three cases of individual students. A collective case study (Stake, 2003) is an instrumental study extended to several cases. The cases in a collective case study are not necessarily similar or dissimilar. In a collective case study a researcher jointly studies more than one case in order to understand a phenomenon (Stake, 2003). The purpose of this approach was therefore mainly to provide insight into students' construction of understanding and generation of meaning during learning. A collective case study promotes a better understanding of the phenomenon under investigation (Stake, 2003). In this study instrumentation would therefore be on the three cases separately but focusing on the same phenomenon under investigation.

3.3.1 Instrumentation

Instrumentation includes the whole process of preparing to collect data whereby the selection, design of the instruments, procedures and conditions under which the instruments are to be administered are important (Fraenkel & Wallen 2003). In this study it was also important to clarify what the researcher's intentions were and how they would be accomplished. In fact, Miles and Huberman (1994) assert that "you cannot study everyone everywhere doing everything"(p.27).

In order to understand the educational situation from students' own frames of reference and their experience of the reality of learning chemistry, an assessment procedure was developed to assess students' knowledge of concepts on the topic of ‘acids and bases’ and related practical work processes. This assessment procedure was largely modelled on Treagust’s (1995) diagnostic instrument for assessment of science knowledge. According to this model, the instrument for assessment constitutes three broad areas: *defining the content*; *obtaining information about the students' conceptions*; *and developing a diagnostic instrument*. However, in this study these areas were fused into two areas resulting in fewer steps. Instrumentation for this study was therefore based on two broad areas namely: (1) defining the content; and (2) obtaining information about students' prior conceptions and use thereof.

3.3.2 Defining the content.

The conceptual boundaries of the topic pertinent to grade 12 learners (the Department of Education of South Africa) and entry-level chemistry students (Tshwane University of Technology) were defined as the content for this study. Propositional content knowledge statements (PCKS) representing the knowledge considered *adequate* to comprehend the theory and the titration of acids and bases, were identified (Appendix D) and validated by four subject matter experts in chemistry. The propositional content knowledge statements indicate the minimum prior knowledge expected from students at that curriculum level. This is the knowledge guideline students were expected to demonstrate in their prior knowledge state test, interviews and the practical work activities. This was done to ensure that the content and concepts to be investigated adequately represented knowledge at the teaching and learning levels indicated.

3.3.3 Obtaining information about student conception

Obtaining information about student conceptions involved the assessment of students' prior knowledge and its use. Students were subjected to a prior knowledge state test and an unstructured interview as they engaged in practical activities. The two most valued learning outcomes (Slavings, Cochran & Bowen, 1997), namely; (1) the understanding of chemical concepts and (2) the ability to use those concepts to solve various chemical problems or to construct understanding and generate meaning of other concepts were observed within this area of instrumentation. Links between students' conceptual understandings and their use of prior knowledge were established. This enabled the researcher to determine during analyses how students used their prior knowledge and its effect (in all its forms) on the learning of chemistry. Practical work activities were used to infer understanding that could not be established by other data collection methods (e.g. prior knowledge state test).

3.4 Data collection methods and procedures

Data collection procedures used in this study had to identify –

- the population from which the data had to be collected;
- the time at which data had to be collected;
- the methods that were used to collect data; and
- the instrument(s) that were used to collect data.

The researcher, who was also the instrument of data collection, strived to avoid "studying everyone doing everything everywhere" (Miles & Huberman, 1994, p.27) with this instrumentation process.

3.4.1 Data collection methods.

In this section, the actual activities pertaining to data collection were described. In describing these activities, the objectives of the study were linked to each research question. This helped to highlight the relevance of the chosen research methods. The relevance of the approach used in the collection of information is also highlighted. The major methods and instruments of data collection used in the study (Table 6) were observation, interviews, a practical work report (PWR) and a prior knowledge state test (PKST).

Table 6: Research questions, objectives and methods.

Main research question			
How do first-year chemistry students use prior knowledge in learning chemistry concepts?			
Objective			
The objective in this study is to explore and understand how students with diverse prior scientific knowledge and practical work exposure make sense of their learning during practical work activities.			
Research sub-questions	**Objectives**	**Information gathering methods**	**Time of activity**
What is the students' understanding of selected chemistry concepts and processes before engaging in a first-year practical work activity?	To establish how students with diverse domain-specific prior knowledge understand selected chemistry concepts and related practical work concepts and processes before engaging in practical work activities.	Prior knowledge state test (PKST).	The test was conducted- •before students engaged in practical work activities and •after curriculum sections on 'acids and bases' and 'stoichiometry' were taught and assessed.

How do students use their prior knowledge of selected chemistry concepts and processes to construct understanding and generate meaning during learning?	To establish the relational use of concepts and related processes in the construction of understanding and generation of meaning during practical work activities.	• Observation. • Interview. • Practical work report.	•Observation was done during practical work activities. •The interview was guided but *informal* and conducted while students engaged in activities. •Students submitted individual written reports immediately after their activities.

It is important to explain how each method was used in the collection of information. However, it would be premature to do so before the source from which the information was collected is described. That is, population from which information was collected needs to be clearly defined and described.

(i) Research population

The population for this study was first-year chemistry students studying towards a Diploma in Analytical Chemistry at the Tshwane University of Technology in South Africa.

(ii) Case selection procedure

The study was conducted on three cases. The students were selected towards the end of a semester. This time period was chosen because the relevant subject matter content would have been taught and ‘learned’ by then (since the course was a semester course). In addition, the lecturer (who is also the researcher and the research instrument) and the selected students would have built a "trusting relationship" by then (Denzin & Lincoln, 1998, p.36) especially with regard to having to participate in interviews.

Initially, the intention was to select cases by purposeful sampling. However, this was not possible since the targeted group was not the same as the students who volunteered to participate in the study. The opportunistic sampling approach was used instead, where three cases of individual students were selected from the volunteering group of students. The cases were selected to promote variation among the cases to gather in-depth, rich and varied information from the subjects. The range of variation was based on –

- prior knowledge state test performance (conducted among all first-year chemistry students) -
- gender;
- geographic location of previous school attended; and
- the provincial department of education under which the school operated.

Data used for the study was generated from three cases (students) selected from an original sample of six students who formed the three collaboration dyads. Two of the selected students (one male and one female) were originally from the Limpopo Province and one (female) was from Mpumalanga (see Appendix E). Data collection (or generation) was done in three phases.

(iii) Data collection process.

Phase 1

One of the research questions required an understanding of students' conceptual knowledge of selected 'acids and bases' concepts. Students' own written work was used to capture their conceptual understanding. To better understand students' understanding of the concepts, students had to write a *topic-specific* prior knowledge state test. The test was specifically focused on 'acids and bases', which included questions on the acid-base titration processes.

The objective of the test was not necessarily to determine students' *achievement* (in terms of the mark obtained) in the selected concepts, but to obtain information on how concepts are understood and used. Students' *individual understanding* of concepts (in the prior knowledge test) was used as a "benchmark" to determine how these concepts were applied when engaging in practical work activities. A benchmark, according to the *Concise Oxford English Dictionary* (2006), is "a standard or point of reference against which things may be compared or assessed" (p.125). However, the use of the prior knowledge state test should in no way suggest that captured or recorded information represented the only knowledge students had or that it was the "whole" of their knowledge on the topic. Establishing the whole of an individual's knowledge of a particular type (or domain specific) is difficult if not impossible because of the nature of knowledge. Knowledge or prior knowledge is pervasive and difficult to capture.

Phase 2

In this phase, more information was obtained to supplement the information obtained in the first phase. This was done through "observation", "individual written reports" and "follow-up interviews". This information enhanced a better understanding of students' use of prior knowledge during learning. As not all information could be obtained directly by the above methods, some of the information was inferred from students' practical work activities.

Phase 3

In this phase most of the data generated was used to establish links between the two major types of prior knowledge (conceptual and procedural). Information obtained in phases 1 and 2 were linked relationally (the conceptual knowledge collected through observation of the practical work and responses linked to interview questions posed during practical work). Once all the data had been collected, it was categorised to facilitate analysis (see 'exhibits' in Chapter 4).

3.4.2 Explaining data collection instruments

The quality of research data depends to a large extent on the appropriateness of the methods and instruments selected to collect such data. Instruments for data collection in this study were chosen to effectively collect information that would elicit students' constructed understanding and generated meanings. To effectively collect this data, it was imperative to have an environment where discussions could freely take place. Dyads were therefore formed in which students could engage in discussions or take part in social collaboration during their practical work activities. Social collaboration enables understanding to be clarified, elaborated, justified and evaluated (Tobin, 1990). In social collaboration, conceptual differences between the subjects of study were an *ideal* environment to capture how individual students constructed understanding and generated meaning. The collaboration enabled the researcher to determine how each student used his or her conceptual understanding in speech and/or to interpret this from their object manipulation.

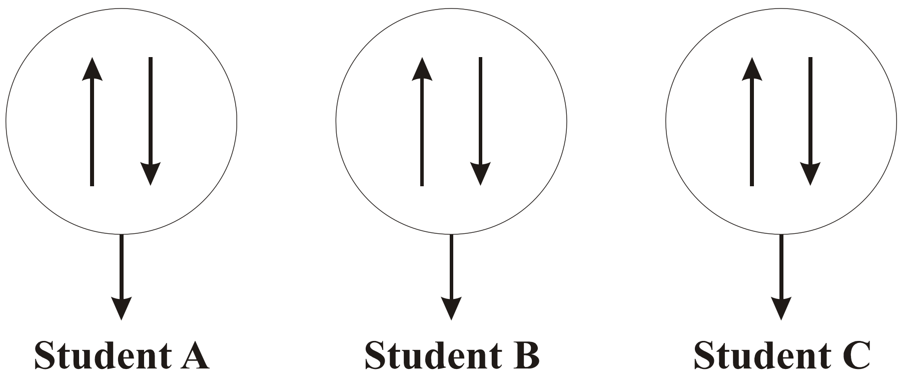

Figure 10: Selection of final sample for the study

Although initially six students were involved (in the three dyads), information from individual responses from only three students were used in data analysis. Data from the three students selected (Figure 10) were used on the basis of the "richness" of the information these three students (three individual cases) generated. To better understand how data were collected, the procedures and/or methods or instruments used and the rationale for their use are explained below.

(i) Prior knowledge state test

Prior knowledge has been identified (Ausubel, 1968) as the major factor that influences learning. It would be difficult to understand prior knowledge if it is not known whether it does exist or not; or the form and extent to which it exists. To understand the *amount* and the *quality* of prior knowledge of students, it is imperative to first determine students' prior knowledge relevant to the topic of interest. A prior knowledge state test (PKST) was therefore used to establish students' knowledge of the subject matter (acids and bases).

As not all the prior knowledge in students' knowledge bases could be determined, PKST was used to approximate the amount and quality of knowledge students had at their disposal on the topic (acids and bases) prior to engaging in practical work activities where this knowledge would be used. The assumption was that students' actions in practice (during practical work and interviews) would to a large extent be influenced or be a product of the amount and quality of the knowledge they possessed at the curriculum level, before engaging in learning activities. Knowledge tested or assessed in the prior knowledge state test was based on the propositional content knowledge statements (Appendix D) at the curriculum level prescribed for first-year chemistry students of the Department of Chemistry at the Tshwane University of Technology in South Africa.

Construction of the prior knowledge state test

A *topic-oriented* knowledge test that, according to Dochy (1992), has direct relevance to the material being studied was constructed to elicit students' understanding of concepts (content knowledge) and practical work processes. Two types of responses were required from students. First it required students to demonstrate their knowledge (conceptual understanding) of the subject content (specifically on acids and bases and their titration processes). Second the test had to elicit students' understanding by requiring them to give reasons and/or elaborate on their responses. In addition, the test items were developed to detect the conceptual understanding (first type) and procedural knowledge (second type) related to the practical work tasks. However, there were instances where the same item tested both conceptual and procedural knowledge, due to an overlap. Knowledge is according to Dochy & Alexander (1995) fluid, interactive and dynamic. In addition to revealing the amount and quality of the two types of knowledge (declarative and procedural), their responses also indicated their conditional knowledge.

Direct answers without elaboration were avoided, as this could have only indicated that a student "knows" the answer itself or the algorithm that holds the answer. This would have been unhelpful in the interpretation of students' conceptual understanding. The construction of the test was guided mostly by four of Bloom's (1956) six levels of cognitive skills of knowledge namely; application, analysis, synthesis and evaluation (see Table 7). Each test item was therefore constructed to elicit a particular type of cognitive skill.

Table 7: Bloom's classification of cognitive skills (Adapted from Bloom, 1956).

Cognitive skill	Definition	Examples of related behaviour
Application	Using a general concept to solve problems in a particular situation; using learned material in new and concrete situations.	Apply, adopt, collect, construct, demonstrate, discover, illustrate, interview, make use of, manipulate, relate, show, solve, use.
Analysis	Breaking something down into parts; may focus on identification of parts or analysis of relationships between parts, or recognition of organisational principles.	Analyse, compare, contrast, diagram, differentiate, dissect, distinguish, identify, illustrate, infer, outline, point out, select, separate, sort, and subdivide.
Synthesis	Creating something new by putting parts of different ideas together to make a whole.	Blend, build, change, combine, compile, compose, conceive, create, design, formulate, generate, hypothesise, plan, predict, produce, reorder, revise, tell, and write.

Evaluation	Judging the value of material or methods as they might be applied in a particular situation; judging with the use of definite criteria.	Accept, appraise, assess, arbitrate, award, choose, conclude, criticise, defend, evaluate, grade, judge, prioritise, recommend, referee, reject, select, support.

The test items were constructed to elicit the students' conceptual understanding (declarative knowledge), its use (procedural) and reflection (conditional knowledge) in a practical situation; hence the focus on the four categories of Bloom's classification of cognitive skills.

(ii) Observation

Observation was used for data collection because of its ability to uncover complex interactions in a natural setting (Marshall & Rossman, 1995). It however has the limitation that the observer may affect the situation being observed. For example, (Patton, 2002) “the observer may affect the situation being observed in unknown ways” (p.306).

The setting in this study was a chemistry laboratory in which students interacted with each other, objects and their lecturer during practical work activities. Students' interaction was however confined to dyads. That is, students were paired together to promote a direct discussion of the task at hand. This enabled the researcher to observe the students as they shared their views on the task. As observations are (Wallace, 2005) "often supplemented and complemented by conversations with social actors" (p.73), the researcher used observation to ask students to explain meanings and procedures in order to confirm experiences which have been observed but not fully understood.

As the purpose was to understand how students used their prior knowledge in practical activities; the *deliberate*, *systematic* and *question-specific* method of observation was used (Figure 11). This is a highly formal type of observation to answer research questions (Evertson & Green, 1986).

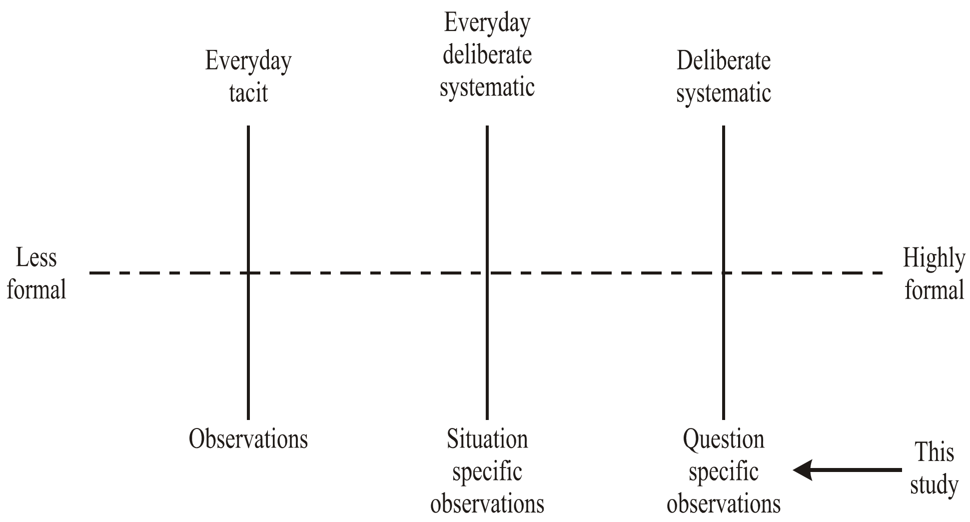

Figure 11: Continuum of observation types (Adapted from Evertson & Green, 1986).

The foci of observation were students' action and behaviour (manipulation of practical work apparatus) in relation to their understanding of the concepts, processes and their application in a practical situation. The objective was to understand how students interpreted and applied their knowledge of selected chemistry concepts and practical work processes to construct understanding and generate meaning.

A structure containing preliminary trials; planning; performance; communication; interpretation and feedback decisions was developed and used to understand the students' activities. This structure is based on the PACKS model (Millar, Lubben, Gott & Duggan, 1994), which emphasises the selection of relevant ideas from memory for interpreting data on students' performance of the investigation tasks (Figure 12).

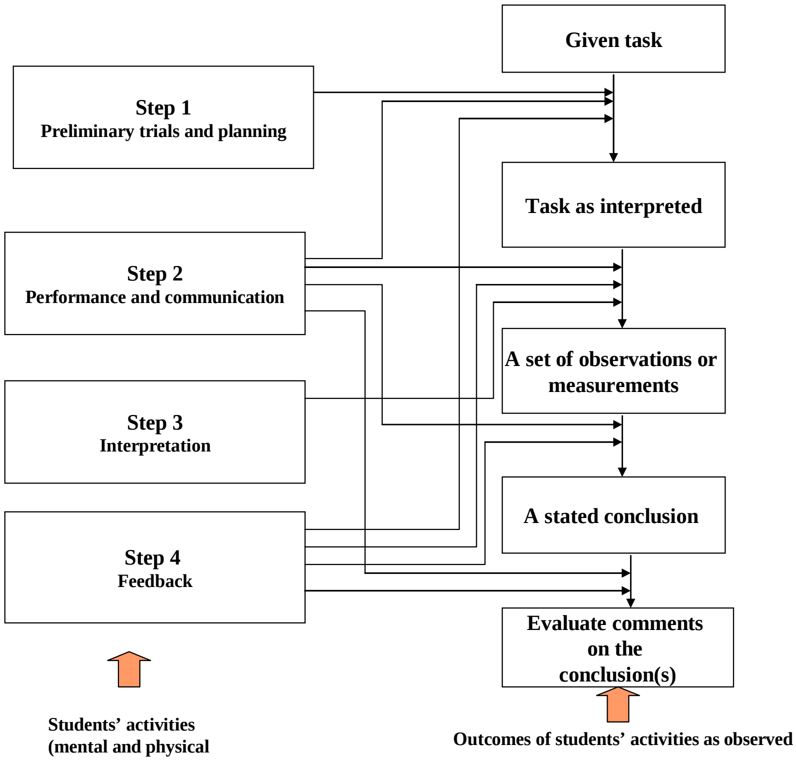

Figure 12: Data collection process (Adapted from Millar, Lubben, Gott & Duggan, 1994)

Observation procedure

Step 1: Preliminary trials and planning

At this stage dyads were asked to develop a plan they intended using to perform a given task. Since it was important that each dyad understood the nature and *purpose* of the task, students had to submit their plans for assessment before they could proceed with the task. 'Purpose' here refers to what Hart, *et al.,* (2000) describe as the lecturer's *pedagogical intentions*. That is, the lecturer's reasons for using a particular practical work activity and the way the activity is organized, how the activity "fits in" to the unit of work at that time, and how the activity is intended to result in planned student learning (p.656).

Students were interviewed while drawing up the plan on their interpretation of the design regarding the task. Their inputs and understanding were recorded as representing their knowledge and understanding. The plan for each student dyad was approved only after the researcher assessed its viability.

Step 2: Performance and communication

Performance in this step entailed students appropriate use of apparatus and their interpretation (correctly or incorrectly) of chemical changes (e.g. colour changes) as a result of their understanding of relevant concepts and processes during the practical work. Observation at this stage of the study was most *critical* because it required a high level of concentration on each dyad in their ongoing discussions. Their actions and discussions were a source of information on how they understood concepts and their relational use. The assumption was that the students' *performing* aspect linked *conceptual* understanding with *procedural* knowledge. Each step had to be monitored, and students were probed on their decisions in order to elicit and confirm their understanding.

In engaging in the practical work activities, students were allowed to discuss their activities, and had the option of referring their uncertainties or disagreements to the researcher for confirmation. These uncertainties were used to further probe students' understanding in order to gather more information on their construction of understanding and generation of meaning.

Steps 3 and 4: Interpretation and feedback discussions

Completion of the task that includes the physical manipulation of apparatus would not have been sufficient if the practical work outcomes (students' results) were not interpreted and feedback discussions did not take place. These activities are only possible if there is an understanding of empirical evidence, its nature and criteria for evaluating it (Millar, 1998). At this stage of the practical work activity, students had collected the results of the practical work activities. Students had to show their understanding of the empirical evidence.

Students were removed from their dyads and allowed to produce their individual final reports on the task. In their reports, students were expected to make decisions based on the application of their conceptual, procedural and conditional understanding of the practical work activities. At the end of the practical work activities, they were given time (in the laboratory) to write a report on their activities and the outcomes of their practical work activities. Each student was later (after a period of a week) interviewed on the contents of his or her report.

(*iii)* Interview

The aim of the interview, according to Taylor (2005), is to capture students' thoughts, perceptions, feelings and experiences in their own words. In the case of this study, this data were expected to reveal students' experience and knowledge of science concepts (acids and bases) and their understanding of practical work processes in acids and bases. Therefore, in-depth interviews were conducted. This type of interview, which is also known as an unstructured interview (Berry, 1999), is used to elicit information in order to achieve a *holistic* understanding of the interviewee's point of view of a situation.

For this study, the general interview guide approach was used (Patton, 1987). With this approach a checklist (not questions) is prepared before the interview is conducted. This helps to ensure that all relevant topics are covered. The interviewer is also free to explore, probe and ask questions deemed interesting to his or her study (Berry, 1999). The contents of the prior knowledge test and/or students' responses to the test and the practical work task requirements and/or procedures were used to *focus* the questions of the interview.

An in-depth interview was conducted in three sessions: an interview during step 2 with the dyads; a follow-up interview session with each member of the dyad about the contents of their individual reports; and an interview with both members of the dyad about the contents of individual reports, especially about the differences in content and in conceptual understanding of their test responses.

(iv) Document review (Practical work report)

At this stage two documents had been produced, namely; (1) the students' answer scripts (from their PKST) and (2) the practical work report. In addition to the responses reported during observation and interview sessions, further information was collected from the test scripts and the practical work report. These documents were important in establishing the relational use of concepts during practical work activities.

3.4.3 Data analysis process

The challenge of data analysis, especially qualitative analysis (Patton, 2002), is making sense of massive amounts of data collected. This is done by reducing the volume of information through the identification of significant patterns emerging from the information, and the construction of a framework that can later be used to communicate research outcomes through analysis. The ease or difficulty with which this process of data analysis is undertaken depends on the research questions and the research approach selected.

Analysis of data collected through the prior knowledge state test, the observation and interview methods and the practical work report was based on the "search after meaning principle" (Graesser, Singer & Trabasso, 1994, p.371–372). In this approach the researcher –

- constructs a meaning representation that represents goals at *deep* levels of representations;
- constructs a meaning representation that is coherent at both local (within a concept cluster e.g. acid strength cluster) and global (across concept clusters e.g. acidity and acid strength) levels. Coherence at local level refers to structures and processes that organise elements, constituents and referents of adjacent clauses or short sequences of clauses. At global

level, coherence is established when local chunks of information are organised and interrelated into higher order chunks; and

- attempts to explain why actions, events and states are mentioned in the text.

Students' understanding of selected chemistry concepts and their subsequent use were sought. Through this analytical principle, and for better outcomes of responding to research questions, a two-phase approach was adopted. The first phase of the analysis focused on eliciting students' understanding of concepts regarding acids and bases. As indicated earlier, understanding was sought through the prior knowledge state test, observation and interview, and practical work reports. The observation and interview were simultaneously conducted during the practical work activities. Practical work involved the titrimetric determination of the ethanoic acid content of a commercial vinegar solution.

The focus of the second phase of the analysis was to establish how students constructed meaning of concepts the way they did. A link between students' understanding of concepts and how such concepts were used in practice (theoretically and practically) was established. The use and effect of students' prior understanding of concepts was established through observation, interviewing and from students' practical reports. It should also be added that "practice" (or practical situation) here does not necessarily refer only to physical application. It includes the mental application that the researcher inferred from the students' practical work activities and during the interview process.

The domain of chemistry and the topic of acids and bases are broad. It was therefore not possible to study all acid- and base-related concepts at the same time. Only a selected number of concepts was used. Only five concepts were studied. For better facilitation of the data analysis, students' responses to questions from all data collection instruments were grouped into related and meaningful chunks or clusters of information. These clusters were later organised into sources of terms or other concepts from which selected concepts could be constructed. The chunks of information were interpreted at the level of propositional statements derived from the curriculum. Clusters were interpreted as representing students' conceptual structure in order to understand students' understanding and generation of meaning of concepts. But what exactly was analysed?

3.4.4 Specification of analysis

In this study the analysis aimed at responding to specific elements of the text in the form of concepts, meanings, thoughts, language and interpretations as presented by individual students. The framework in which these specific elements were analysed entailed students' prior knowledge (declarative, procedural and conditional knowledge) of the domain of interest (chemistry), the nature of the domain knowledge (macro level, micro level and symbolic representation), and the prerequisite quality (whether it was correct or incorrect, complete or incomplete, available or unavailable, accessible or inaccessible and organised or haphazard) and whether there were any 'misconceptions'.

As the outcome of every analysis depends to a large extend on the analyst's frame of reference, it was important to establish a theoretical frame within which the analysis would be conducted. This was done to guide interpretation and analysis. The entity to be analysed had to be indicated. In this analysis, prior knowledge, its use and its subsequent effects on understanding were the entities of analysis. As there are many types of prior knowledge, the focus of this analysis was specifically on declarative, procedural and conditional knowledge, and the interaction among them.

The three types of knowledge were analysed, focusing on concepts and principles relating to acid-base titration, since concepts (Reif, 1985) are "logically the building blocks of knowledge used to deduce important consequences, make predictions, and solve problems" (p.133). For better analysis, concepts (as appropriate knowledge and functionally useful conceptual building blocks of knowledge) were specified and described as "specification knowledge". "Specification knowledge", according to Reif (1985), is the most basic knowledge required to interpret a scientific concept fully and unambiguously without committing errors of interpretation. This knowledge entails "specification of a concept" (which in the case of this study describes declarative knowledge), its "instantiation" (which describes procedural knowledge) and "error prevention" (which describes conditional knowledge).

(i) Specification of a concept

Concepts, according to Reif (1985), must be specified according to explicit rules to ensure that they are unambiguously identified, leading to clearly interpretable scientific knowledge. Reif proposes a few ways in which a concept can be specified to achieve this:

- *Summary description:* Summary descriptions are compact and easily remembered. They are useful because they provide a brief and precise statement of the meaning of a concept. They are used as a starting point for more complete elaborations. An example of a summary description in the case of this study is the formal statement c = n/v, which defines the concept "concentration" in terms of the number of moles (n) of the substance or compound, and the volume (v) of the solution.
- *Informal description:* An informal description of a concept specifies the essential meaning of a concept without undue precision or excessive details. With this description, attention is selectively focused on a few salient features of a concept. It is useful in relating a concept to more familiar knowledge and in retrieving the concept in complex situations. For example, *endpoint* in a titration process is normally viewed as a point when the colour of the solution changes. This is not a *true* reflection of an endpoint. The colour only changes after the endpoint. It is an indication that the endpoint has been exceeded.
- *Procedural specification:* Procedural specification, unlike the two specifications discussed above, focuses on procedural knowledge. It is a step-by-step way of describing a concept. It specifies how to identify or exhibit a concept. Procedural specification provides the most *explicit* and *detailed* specification of a concept. In addition, it serves as an operational definition of a concept in that it specifies what must be done when deciding whether a concept is properly identified. For example, in describing an

acidic solution one must indicate the concept(s) used to identify the acidity of the solution. *All elements* of knowledge related to the definition or description of the solution should be part of the description to eliminate any ambiguity.

As this study dealt with the use of prior knowledge, and more specifically the use of elements of this knowledge to construct understanding and generate meaning, procedural specification was used as a reference to assess students' description of concepts.

(ii) Instantiation

Describing a concept in the learning process is not enough to demonstrate that one has an understanding or knowledge of that concept. According to Reif (1985), describing a concept does not make it usable in practice. It is important to know how the concept is applied reliably in various kinds of specific instances. The knowledge necessary to instantiate a concept involves the ability to identify and/or use the concept and to do this in various possible symbolic representations, for example, in words, pictures or formal mathematical symbolism (p.142). Adequate instantiation knowledge requires the *ability to apply* the concept in a variety of instances.

(iii) Error prevention

Error prevention indicates a person's ability to reflect on his or her prior knowledge and/or use their conditional knowledge. In addition, reliable interpretation of a concept requires individuals to possess adequate knowledge to prevent or avoid likely errors. The individual must have the knowledge to detect errors when they have been committed and to correct them appropriately (Reif, 1985, p.142–143).

3.5 Addressing issues of trustworthiness

As indicated earlier in this study (Chapter 1, subsection 1.8.2), the credibility of any research project is important if its findings are to be valid and reliable. A research study can only be valid and reliable if the researcher (Merriam, 1998) pays "careful attention to a study's conceptualisation and the way in which the data were collected, analysed and interpreted, and the way in which the findings are presented" (p.200). In qualitative research this is not an easy task, as the approach is value-laden. The researcher is, according to Patton (1990) "a research instrument, and the credibility of the research findings depends on the ability and effort of this instrument" (p.14).

In order to accurately understand how students constructed understanding and generated meaning during learning, trustworthiness was imperative. Trustworthiness was therefore enhanced through *credibility* (internal validity) and *confirmability*. According to Hoepfl (1997), credibility is the extent to which findings accurately describe reality while confirmability (Lincoln & Guba, 1985) is "an illustration of the neutrality of the interpretations" (p.320).

Credibility was enhanced by a *pilot study* at the beginning of the study. It was later enhanced by using "triangulation" and "member checks". Neutrality of interpretations (confirmability), on the other hand, was enhanced by a peer review process.

3.5.1 Pilot study

A pilot study is an important part of any research project as it gives an indication beforehand of what to expect when conducting an empirical study. In this study the *pilot study* was conducted to enhance the quality of the design; thereby improving its validity. After the pilot study, many changes had to be made to improve the credibility of the study. It was found in the pilot study that students participating in the study were not *ready* to engage in an exercise that demanded higher order cognitive skills, owing to the level of their intellectual development at the time when the pilot study was conducted.

This resulted in the adaptation of the design (from a purely open-ended inquiry to a convergent laboratory activity) to accommodate students at all levels of intellectual development.

3.5.2 Triangulation

Triangulation (Merriam, 1998) refers to the use of multiple investigators, sources of data and methods to confirm the emerging findings. In this study, only multiple methods and sources of data were used.

3.5.3 Member checks

Member checks (Merriam, 1998) refers to taking data and its tentative interpretations back to the people from whom they were derived and asking them about their plausibility. In this study amongst other methods, students had to write a post-test of prior knowledge to confirm or compare their initial responses with new responses. Although pre-test and post-test 'achievements' were not the same, their responses were consistent. That is the manner in which understanding and meaning of similar knowledge were constructed, were similar. The following illustration confirms the similarities:

<u>Case A</u>

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

Pre-test response: It means the solution has a high concentration of H^+ ions.

Post-test response: It means that the solution has a high concentration of H^+ ions.

<u>Case B</u>

Question: Differentiate between a dilute solution of a weak acid and a concentrated solution of a weak acid? Illustrate your answer with a relevant example.

Pre-test response: A dilute solution of a weak acid is an acid, which has lots of water in the solution, whereas a concentrated solution of a weak acid is an acid, which has a small amount of water in the solution.

Post-test response: A dilute solution of a weak acid is a solution that contains lots of water; a concentrated solution of a weak acid is a solution that contains little water.

For further confirmation of these responses, students were also interviewed as a follow-up on the responses they gave in the test, interview, and the contents of their written reports.

3.5.4 Peer reviews

Comments were sought from colleagues (Dr N Panichev[2]; Dr MP Motalane[3], and Prof A Johnstone[4]) on the construction and accuracy of the prior knowledge test and the importance of the cognitive load that should be considered when constructing a prior knowledge state test. The process of enhancing trustworthiness was an ongoing process throughout the study. That is, analysis and the evaluation of methods and procedures were done throughout the empirical study process.

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[2] PhD, St Petersburg State University, Russia, NRF (SA) C-rated researcher
[3] PhD, University of Pretoria, Centre for Scientific and Industrial Research South Africa, former lecturer at the University of South Africa.
[4] Retired science education professor and researcher at Glasgow University

3.6 Summary

The purpose of this chapter was to describe the processes involved in gathering information to be used by the researcher to answer research questions. In any research study it is important to use appropriate designs and methodologies to achieve credible and reliable research outcomes. On the basis of the questions posed for the study, it was deemed appropriate to use an interpretive-constructivist design. Qualitative methods were found to be the most relevant to determine first-year chemistry students' use of prior knowledge of selected concepts (of acids and bases). First a prior knowledge state test was conducted among students to supplement qualitative methods. This was followed by a practical work activity in which students were observed and interviewed as they engaged with their tasks. The results of prior knowledge, observation and interviews were used to construct students' meanings during learning. Data interpretations and/or analyses are discussed in Chapter 4.

CHAPTER FOUR

Data processing and management

… (T) o know is, in some sense, to transform the object of knowledge.

(Bettencourt, 1993, p.39)

4.1 Introduction

In this chapter, data collected are presented and analysed. As explained in Chapter 3, the purpose of the first phase of the analysis was to elicit students' understanding of concepts in the topic of acids and bases in relation to specific practical work activities. The second phase of the analysis was to establish how students arrived at the meaning of concepts by the way they explained it (i.e. how students used their prior knowledge to construct meaning of concepts). In the third phase, a link between students' understanding of concepts and how such concepts were used in practice (mentally and practically) was established. In addition, the effect of students' prior understanding of concepts or their use would be established through analysis of data collected by observation, interviews and from students' practical reports.

To better facilitate data analysis of students' responses to questions related to these concepts, all data collected from various instruments were grouped into clusters of related and meaningful chunks of information (see exhibits). The content and quality criterion for forming clusters or chunks of information was based on propositional content knowledge statements (Appendix D) generated from the curriculum. 'Specification knowledge' was used as assessment criteria for the three types of knowledge individually and in their interaction during conceptualisation.

4.2 Data presentation

In this part of the report, collected data is presented and analysed within the context of students' learning environments. For better understanding of the data and the process of analysis it was important to first explain the contexts (students' previous learning environments and academic achievements) under which data was collected and analysed.

Table 8: Summary on students' profiles

ENTITY	**Case A**	**Case B**	**Case C**
Province	**Limpopo**	**Limpopo**	**Mpumalanga**
School	**SCL A** Secondary School	**SCL B** Secondary School	**SCL C** College
Year matriculated	2005	2005	2005
Matriculation results	English: **64 (HG)** Mathematics: **42 (HG)** Physical Science: **50 (HG)**	English: **38 (HG)** Mathematics: **59 (HG)** Physical Science: **47 (HG)**	English: **47 (HG)** Mathematics: **55 (SG)** Physical Science: **48 (HG)**
Research study results	**PKST** Pre-test: **49** Post-test: **43**	**PKST** Pre-test: **66** Post-test: **41**	**PKST** Pre-test: **57** Post-test: **57**
University achievement (first semester)	Chemistry: **48** Mathematics: **58** Physics: **62**	Chemistry: **56** Mathematics: **76** Physics: **72**	Chemistry: **62** Mathematics: **54** Physics: **56**
School/practical work experience/exposure (Finding applicable to all three students)	According to Kirschner and Meester (1988), "laboratory work is intrinsic to science in general and to the scientist in particular" (p. 83). Therefore, laboratory work is considered fundamental in the teaching of science. However, it also depends how one uses laboratory work in teaching. That is, the purpose of practical work should be clearly defined to achieve its goal in teaching (Hart *et al*, 2000). In their response to the level of exposure of laboratory work at school, the three students indicated that their only encounter with practical work was through teacher demonstration. This limited the students to mere observers of the reactions during chemistry experiments. For effective use of practical work, the student should be presented with problems in experimentation to challenge his or her understanding and creativity "without being so complex as to be irresolvable" (Kirschner & Meester, 1988, p. 90). It can be concluded that students' exposure to practical work was limited and could not have helped students to solve problems or to concretise theory and acquire conceptual knowledge.		

HG: Higher Grade

SG: Standard Grade

SCL: School

4.2.1 Context for data analysis

In this study, "context" refers to students' background, i.e. their academic achievements at school level and early achievements at university (see Table 8). The rationale of the context, which includes achievements in mathematics, science and language (English), refers to prior knowledge assumed to be in place when students engage in learning activities.

4.3 Data analysis

Data analysis, as indicated earlier, would have had no meaning if the context in which it was conducted was not described. The nature of this study therefore required that students' profiles include their academic backgrounds and the profiles of the schools from which they graduated. The context of how their prior knowledge was acquired and its analysis could then be better understood. In this analysis, students' profiles (as summarised in Table 8) were used as a referent in the interpretation and explanation of the data.

In the process of data analysis, information from different sources was chunked together into categories that contained the most basic knowledge required to interpret scientific concepts fully without ambiguity or without committing errors of interpretation. This information was, for the purpose of this study, labelled "presented data ". This data (see exhibits) differed from one participating student to another. This could be expected, since students have different academic backgrounds and teaching and learning experiences, hence would bring different prior knowledge into the learning situation. The analysis was conducted on the same concepts for all three students/cases. Data in exhibit boxes were sourced from all instruments (Prior knowledge state test (PKST); Observation and Interview (O&I); Practical Work Report (PWR)) used for collecting data. However, this does not mean that all sources contributed to all exhibit boxes equally for a particular student or concept.

4.3.1 Analysis: Case A (Exhibits 4.1 to 4.4)

Exhibit 4.1

Presented data

Questions, student's responses and data sources

Q.4.1.1: Differentiate between an Arrhenius and a Bronsted-Lowry acid. (PKST: Q.6)

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

Q.4.1.2: You are told that an aqueous solution is acidic. What does this mean? (PKST: Q1)

S: It means the solution has a *high concentration of* H^+ *ions.*

Q.4.1.3: As the hydrogen-ion concentration of an *aqueous solution* increases, the hydroxide-ion concentration of this solution will – (1) increase; (2) decrease; or (3) remain the same? (PKST: Q.3)

S: Decrease. (the student did not elaborate)

Q.4.1.4: When HCl (aq) is *exactly neutralised* by NaOH (aq), the hydrogen-ion concentration in the resulting solution is …

(1) Always less than the concentration of the hydroxide ions;

(2) Always greater than the concentration of the hydroxide ions;

(3) Always equal to the concentration of the hydroxide ions; or

(4) Sometimes greater and sometimes less than the concentration of the hydroxide ions. (PKST: Q.11)

S: Always equal to the concentration of the OH^- ions.

(i) Description of specification knowledge (memorandum)

As discussed earlier, the purpose of 'specification knowledge' is to reduce ambiguity in the description of concepts. Therefore, what is required should be described before any analysis can take place. In this category, the concept of interest is an "aqueous acidic" solution. Acidity is a complex concept, as it is generated from other concepts. Therefore, other concepts or terms that are related or used in one way or the other to construct the concept of acidity must be understood first to describe it.

In describing an aqueous acidic solution, the three ways in which a concept is described (specification, instantiation and error prevention) would have to be applied. That is, a student should be able to access relevant information in his or her prior knowledge base in order to construct the concept of an aqueous acidic solution. The required prior knowledge is what Reif (1985) describes as the most important knowledge to make a concept effectively usable. That is, the knowledge required to interpret the concept appropriately. That knowledge should *specify* the concept, *apply* the specification in various particular instances, and do so *without committing errors* of interpretation. With regard to the concept of acidity, the basic knowledge required to describe an aqueous acidic solution would include, but not limited to, the following:

- The specification of the relevant acid-base concept(s) to be used for the description or construction of meaning should be given (for example, an acid according to the Arrhenius concept is a substance that, when dissolved in water, increases the H^+ ion concentration in the solution).
- Different types of solutions should be understood. For this study, the student needed to understand "aqueous solution" as a solution in which water is a solvent and that an acid increases the H^+ ion concentration and a base is a substance that increases the OH^- ions when dissolved in an aqueous solution.
- It should be understood that water (H_2O) exists in equilibrium with H^+ and OH^- ions ($H_2O \rightleftharpoons H^+_{(aq)} + OH^-_{(aq)}$).
- The relationship between the concentrations of H^+ and OH^- ions in the solution should be understood.
- Understanding that acidic solution is dependent on the concentration of H^+ ions in relation to other ions in the solution is needed. An increase of ions (H^+ or OH^-) when an acid or a base are respectively dissolved in it will determine the solutions' acidity or basicity. A solution with an H^+ ion concentration higher than OH^- ion concentration would then be deemed acidic and a solution with OH^- ions higher than H^+ would be basic. If the concentration of the two ions is stoichiometrically equivalent, the solution would be deemed neutral.
- The symbolic representation of an aqueous solution should be understood. The dissociation of water, where water at equilibrium is represented by

$K_w = [H^+] \times [OH^-]$ (equilibrium constant) = 10^{14} and $[H^+] = [OH^-]$: $H_2O \rightleftharpoons OH^-$ (aq) + H^+ (aq).

- It should be understood that any change in any of the components of the equilibrium will affect other components in one way or the other (Le Chatelier's principle).

In the formation of concept clusters such as this one (Exhibit 4.1), the purpose was to establish the knowledge of students about the concept. What could not be established directly, though, was the form or relations in which the knowledge was held. However, this could be established through the interpretation of the responses to related responses within and/or across clusters.

(ii) Student's understanding and use of concepts and the researcher's explanation and interpretations

The three types of knowledge (declarative, procedural and conditional) were analysed in the three ways proposed earlier by Reif (1985) to specify concepts unambiguously.

- Specification of a concept

Specification of a concept is a demonstration of an individual's declarative knowledge. This knowledge was mostly demonstrated by responses to the first research sub-question.

Research sub-question 1: What is students' understanding of selected chemistry concepts and processes before engaging in a first-year practical work activity?

The individual responses (as they appear in Exhibit 4.1) are assumed to demonstrate the student's representation of his or her knowledge of the concepts in question. In other words, the answers to the questions in the cluster are a direct declaration of facts, meanings and principles, as the student understands them. For example, in case **A** an acidic solution (Q.4.1.2) is "a solution that has a high concentration of H^+ ions". This response is not viable, but it is what the student understands an acidic solution to mean. The view here is that this is the understanding the student would use when asked to apply her knowledge of an aqueous acidic solution at that particular time. This response was a direct translation from the definition of an Arrhenius acid in Q.4.1.1. The student's response illustrates declarative knowledge.

- Instantiation

The responses in Exhibit 4.1 are used to demonstrate student's (in case **A**) understanding of concepts. These responses are used in this analysis as a referent of how the student used her understanding and/or meaning of an aqueous acidic solution (Q.4.1.2). This section of the analysis focused on the student's instantiation. This knowledge is demonstrated when an individual constructs understanding and/or meaning of a concept. The analysis of instantiation was a response to the second research sub-question:

Research sub-question 2: How do students use their prior knowledge of selected chemistry concepts and processes to construct understanding and generate meaning during learning?

The information that the researcher could infer from student **A**'s knowledge base (Exhibit 4.1) is that it lacked the necessary knowledge elements to enable instantiation. Most of the knowledge was either non-existent or incomplete. To successfully construct understanding one needs information with sufficient and necessary elements of that knowledge. In this cluster of responses, the student only succeeded in demonstrating declarative knowledge; and in some instances this knowledge was incomplete (Q.4.1.2). Complete declarative knowledge is important in knowledge construction – in order to describe an aqueous acidic solution the student first had to establish relations between or among related concepts. The student attempted this when responding to Q.4.1.2. The student attempted to relate the response to the response in Q.4.1.1 where "increase" was associated with "high" (see illustration 4.1 below).

Illustration 4.1

Differentiate between an Arrhenius and a Boasted-Lowry acid.

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

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.*

However, it was not possible because the student opted to use her declarative knowledge of an Arrhenius acid without first restructuring it to make sense of the requirements of the question. The other contributing factor to this inability was the incompleteness (in Q.4.1.2) of the student's relevant prior knowledge.

The student could not demonstrate an understanding of the relationship of the H^+ ions and OH^- ions in the solution. The absence or unavailability of this understanding may have contributed to her inability to explain her reasons for her responses in Q.4.1.3 and Q.4.1.4. According to Gunstone and White (1992), one must have some information about the concept in memory to understand it, because a valid measure of understanding involves eliciting the "full set of elements the person has in memory about it" (p. 6). In the case of this study, the full sets of elements are elements found in the specification knowledge. Barsalou (1993) describes these elements as feature lists that must be complete and well organised to help provide a satisfactory account of conceptual content.

On the basis of the information the student provided, and the inferred information (Exhibit 4.1) it could be concluded that the student possessed elements of information relevant to constructing meaning of the concept of interest. But they were not necessarily a full set of elements to construct meaning. According to Smith (1991), understanding occurs when two criteria, "connectedness" and "usefulness in social context", are satisfied. In the case of this student, only one criterion, namely connectedness, was satisfied (in terms of her responses to Q.4.1.1 and Q.4.1.2) within this cluster of responses. The student appropriately represented the idea of an "increase in H^+ ions" from Arrhenius' definition of an acid with a "high concentration of H^+

ions" in an acidic solution. But, based on the interpretation of Q.4.1.1 and Q.4.2.2 it can be concluded that, in terms of her prior knowledge, she had insufficient and isolated bits of prior knowledge about acids, and it was limited to operational definitions. The student's information was incomplete and poorly structured, and she was unable to construct meaning of an aqueous acidic solution.

The structure or organisations of information and the second criterion, "usefulness in social context", are somehow related: to be able to use information or knowledge it must be well structured or well organised. Prawat (1989) defines the ability to use knowledge relevantly as "transfer". Transfer would therefore be possible if the information an individual possesses is well structured or well organised. In the case of this student, transfer failed because of a lack of well-organised structure in her knowledge base.

- Error prevention

It is possible to prevent errors if a student can apply his/her "conditional knowledge", or if the student demonstrates a high level of reflective awareness. Conditional knowledge, according to Dochy and Alexander (1995), is "knowing when and where" to do or act in a situation (i.e. when and where a particular action should be taken). According to Prawat (1989), being able to apply this knowledge is dependent on two interrelated factors, namely the ability to "organise" and the "reflective awareness" of the individual.

When responding to the two questions (Q.4.1.1 and Q.4.1.2), the student apparently had relevant information in her knowledge base that could be used to construct a viable response to what an aqueous acidic solution meant. The information was relevant because the student could define an acid in both the Arrhenius and the Bronsted-Lowry theories. What was however not apparent, was how this knowledge was represented, especially in terms of the triangular nature of matter, i.e. at macro, micro (particulate) and symbolic levels. The conclusion that could be made from the responses is that the student could not use her understanding or the information implied in Q.4.1.3 (of the existence of H^+ and OH^- ions in an aqueous solution). This knowledge was inferred in her response to Q.4.1.3. The student lacked reflective awareness in her responses. Therefore, the student had reached a stage of "access failure" (Prawat, 1989). She could not respond with viable answers. The student could not use her reflective awareness to reorganise the knowledge that she had in her knowledge base or which was implied in the question (Q.4.1.3) to respond correctly or prevent an error in describing an aqueous acidic solution.

(iii) Synthesis

The aim of the study was to understand the quality of prior knowledge students possessed and its effect on the learning of certain concepts in chemistry and the construction of understanding and generation of meaning of those concepts. It is apparent that the quality of this student's prior knowledge affected her ability to respond viably to questions posed. What is also significant about this student's prior knowledge is that it was more declarative than procedural or conditional. The student's instantiation and error prevention were limited with regards to responding to questions. The student's prior knowledge at the time the empirical study was conducted is aptly summarised by Bransford, Sherwood, Vye, and Rieser, (1986) when they say:

> … the fact that people have acquired knowledge that is relevant to a particular situation provides no guarantee that *access* will occur (p.1080).

The reason why there was access failure on the part of this student needs to be further explained. Access failure for this student could be attributed mainly to the student's *mental models* of the nature of matter in chemistry. Had the student accurately represented (through mental models) the three levels at which matter existed, the recognition of the existence of all the ions and molecules (including H^+ and OH^- from H_2O) would have been reflected on and their concentrations considered in responding to the question on what an aqueous acidic solution meant. Access depends on organisation, and *good organisation*, according to Polya (1973), is more important than the extent of one's knowledge. Good organisation is made possible by the correct and accurate construction of mental models.

The following example serves to demonstrate that the student's knowledge was not well organised: The student used the Arrhenius definition to indicate that acidity is associated with the concentration of H^+ ions, but failed to do the same for linking OH^- and H^+ to an aqueous solution that was apparent in her understanding (Q.4.1.3 and Q.4.1.4). When an acid dissociates in water it releases and increases H^+ ions, but this does not necessarily make them higher than other ions (e.g. OH^-) in the aqueous solution. The contribution or effect of the OH^- ions in this solution was disregarded; hence the word "high" was used instead of "higher". In describing acidity, the student assumed (inference) the H^+ ions to be the only ions in the solution.

In conclusion, the student could not satisfy the criteria of usefulness – it could not function to describe an aqueous acidic solution. Both the student's procedural and conditional knowledge had limitations or were absent. Both the instantiation and error correction or prevention aspects (of the specification knowledge) were not satisfied.

Exhibit 4.2

Presented data

Questions, student's responses and data sources

Q.4.2.1: Why is ethanoic acid considered a weak acid? (O&I)

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

Q.4.2.2: What is the difference between a strong and a weak acid? (O&I)

S: Acid that dissociates or ionises completely is an aqueous solution.

Q.4.2.3: Differentiate between an Arrhenius and a Bronsted-Lowry acid. (PKST: Q.6)

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

(i) Description of specification knowledge (memorandum)

The concept of focus of this cluster was "acid strength". An understanding of the concept of acid strength by the student with specific reference to a weak or strong acid was sought in this category. There are three possible concepts of acids and bases the student could have used to respond to the questions on acid strength: the "Arrhenius concept", the "Bronsted-Lowry concept" or the "Lewis concept". As indicated earlier, the extent of understanding depends on the quality of the individual's prior knowledge. Therefore, the knowledge to describe a concept is specified to assess prior knowledge *fairly* and *unambiguously*. In the case of this study, the quality of knowledge was determined by specifying the knowledge the students should have demonstrated in order to be considered to possess adequate knowledge in describing a concept. With regard to describing acid strength in this cluster, the requirements included demonstrating the following:

- That the Arrhenius concept is based on the fact that acid-base reactions involve transfer of H^+ ions from one substance to another and is restricted to aqueous solutions.
- That the Bronsted-Lowry concept emphasises proton transfer but, unlike the Arrhenius concept, is not restricted to aqueous solutions.
- That the Lewis concept is based on the fact that a pair of electrons is transferred from one molecule to another. (An acid is an electron pair acceptor and a base is an electron pair donor.)
- That the use of the Arrhenius and the Bronsted-Lowry concepts will distinguish between a weak and a strong acid.
- That strong acids or bases are electrolytes that completely ionise in a solution, while weak acids or bases are electrolytes that partly ionise in solution (Brown *et al*., 2003).
- That a substance is completely ionised when all its *constituent ions* are dissociated in the solution and none of its original molecules remain un-dissociated. For example, hydrochloric acid (HCl) is a strong acid or strong electrolyte and dissociates into H^+ ions and Cl^- ions. Acetic acid (CH_3COOH), on the other hand, is a weak acid or weak electrolyte that partially dissociates into its constituent ions (CH_3COO^- and H^+).
- That partial dissociation occurs when only a fraction of original molecules dissociate into ions, and relative strengths of acids and bases are therefore determined by the extent to which they dissociate in a solution.
- That strong acids completely transfer their protons to water, leaving no un-dissociated molecules in the solution, while strong acids are more reactive than weak acids when the reactivity depends only on the

concentration of the H^+ (aq) ions (Brown *et. al*., 2003). For example, hydrofluoric acid (HF) is a weak acid but it is very reactive and vigorously attacks many substances including glass. This reactivity is due to the combined action of H^+ (aq) and F^- (aq).

(ii) The student's understanding and use of concepts and the researcher's explanation and interpretations

Responses to the questions in this concept cluster (Exhibit 4.2) aimed to elicit the student's understanding and use or construction of the concept of acid strength. The objective was to understand how the elements of the student's knowledge base on the topic of acids and bases were integrated to construct understanding or generate meaning during learning and /or in responding to questions.

- Specification of a concept

Specification of a concept had to be illustrated with responses to the first research sub-question. In this concept cluster, case **A** appears to have understood what a weak acid was (Q.4.2.1). In her response she indicated a weak acid to be a substance that is not completely ionised. This is a viable response. But did the student understand what complete ionisation meant? For this student, complete ionisation meant the complete decomposition of a molecule of acid or ionisation of all H atoms into H^+ ions from the molecule. This inference is supported by her response: "… there are still H^+ ions in the CH_3COO^-". The important question in this analysis (in terms of the quality of the responses) was whether the student would be able to instantiate this understanding or knowledge.

- Instantiation

Instantiation, like specification of a concept, demonstrates one's conceptual knowledge. In Q.4.2.2 it was expected that the student would apply her understanding of a weak acid to differentiate it from a strong acid. Since it is apparent that the student only stated what a weak acid is without understanding what it meant, it would have been difficult for her to apply this knowledge. What the student did instead was to define a strong acid. The student could not indicate the difference between a weak acid and a strong acid. In her response (Q.4.2.1) to whether ethanoic acid (CH_3COOH) was a weak acid or not, her response (in terms of declarative knowledge) was viable, because according to the Arrhenius concept of acids and bases weak acids ionise partly in an aqueous solution. However, based on the reason the student gave of what partial ionisation meant it is apparent that the student did not understand the term "ionisation".

If she understood the term ionisation, there is a high probability that she could have been able to establish the difference between a weak and strong acid in terms of Arrhenius's definition of acids. Understanding of the term "ionisation" played an important role in the construction of meaning of the concept of *acid strength*. This student had a misconception about the term ionisation. Instead, its understanding was derived from the student's prior understanding (Q.4.2.3) of an acid according to the Arrhenius concept of acids and bases. This understanding led the student to have a fixation on the H^+ ion whenever an explanation of acid strength was sought. The term "ionisation" was used to refer to the release of H^+ ions, irrespective of where the H^+ was located in the molecule (see Q.4.2.1).

The student's focus was on the H^+ as the only *active* ion in the solution. The CH_3COO^- was not considered as another ion making up the CH_3COOH molecule. Therefore, it can be concluded that the response was mainly influenced by the student's understanding of an acid as a substance which, when dissolved in an aqueous solution, *increases or releases the H^+* ions (Exhibit 4.1). The answer was constructed from this understanding. In terms of the effect of prior knowledge, this can be attributed to restructuring. The student had relevant prior knowledge, but the information as it was conceived or stored was not organised so it could be restructured to enable viable construction of required response. In this cluster, information was not well organised to construct understanding or generate meaning of weak or strong acids. Information or prior knowledge in the form in which it was stored was therefore not *accessible*, since the student could not reflect on terms such as ionisation and decomposition when referring to the formation of ions (and not the formation of constituent atoms of the CH_3COOH molecule).

- Error prevention

The student's quality of knowledge in Q.4.2.1 and Q.4.2.2 was such that it would not be useful for reflection. The student did not understand what ionisation meant. Her understanding, as far as could be determined, was that it involves the "removal" of H^+ ions from a molecule. Even if the student was able to use this knowledge appropriately, it would not have helped (because of her understanding of what ionization meant in this case). It is apparent that the student's understanding of complete ionisation had *an inhibiting effect* on her ability to use knowledge appropriately. The fact that the student interpreted "complete ionisation" as meaning decomposition of the CH_3COOH molecule to release all H^+ ions indicates a lack of appropriate knowledge to reflect on the matter. In Q.4.2.2, the student did not complete the answer. Instead of differentiating between a weak and a strong acid, the student elected to define a strong acid. These responses suggest that the student could also not reflect on the difference in the absence of correct and well-organised, complete knowledge. Hence the student's reflective awareness was inhibited by *unavailable* knowledge. Failure to prevent errors is an indication of lack of or limited conditional knowledge. That is, *when and where* to use knowledge.

(ii) Synthesis

The student's response to Q.4.2.1 could be explained by looking at two aspects that affect one's knowledge and its usage: It could be attributed to the student's prior knowledge and the nature of the subject matter. As far as the prior knowledge is concerned, it could be concluded that the student's prior knowledge was incomplete (in which case it would have been difficult to organise it and make sense of). The prior knowledge was incomplete in that the focus of describing a weak acid was based on the H^+ ions at the expense of the whole CH_3COOH molecule its constituent ions and the composition of an aqueous solution. The diminished understanding of the term "ionisation" affected, to a large extent, viability of the student's knowledge to construct understanding and generate meaning of both weak and strong acids.

The student's understanding of the nature of the subject matter, on the other hand, lacked imagery in terms of the triangular representation of matter (macro, micro and symbolic levels). This suggests that there was a *gap* between the student's mental model and conceptual model (see Figure 2) in terms of how a weak and/or strong acid dissociated in an aqueous solution. It could therefore be concluded that the student lacked the ability to *restructure her prior knowledge* to construct new knowledge of acid strength. Without complete and correct knowledge, new knowledge or well-organised knowledge construction becomes difficult (if not impossible).

Exhibit 4.3

Presented data

Questions, student's responses and data sources

Q.4.3.1: Presume that you are titrating a weak acid (e.g. CH_3COOH) and a strong base (e.g. NaOH). What would the expression "equivalence point" mean in this process? (PKST: Q.12)

S: The amount of titrant is chemically equal to the amount of analyte.

Q.4.3.2: Why is there a *temporary* colour change in a solution whenever the NaOH solution drops in the centre of the solution during titration (analyte)?

(O&I)

S: Because it has *reached* the equivalence point.

Q.4.3.4: What is meant by equivalence point? (O&I)

S: Amount of **vinegar** is equivalent to **NaOH** in the solution.

Q.4.3.5: What is meant by endpoint? (O&I)

S: When we observe colour change.

Q.4.3.6: What is the purpose of an indicator in a titration? (O&I)

S: To find the colour change and *observe* the pH of the solution.

Snippets from the practical work report (PWR).

Method

- Pipette 10 ml of vinegar solution into a 100 ml volumetric flask.
- Add deionised water to the graduation mark.
- Pipette 25 ml of vinegar solution into a conical flask.
- Titrate the NaOH solution into the conical flask until (the) colour changes.

Observation

At the beginning of the titration, there is a colour change at the centre of the conical flask.

As the process continues, the colour turned dark pink (endpoint). The colour change is due the indicator added …

Calculated percentage: 461% (estimated %: 4 to 6%).

Conclusion

% content of ethanoic acid in vinegar solution is very high.

(i) Description of specific knowledge (memorandum)

The focus in this cluster was on two important and related concepts in the titration processes. Students often confuse the use of the concepts "equivalence point" and "endpoint" in titration processes. Titrations are processes used by chemists and students to determine the concentration of a particular solute in a solution. Titration involves combining a sample of the solution with a reagent of known concentration (standard solution). During the titration process, increments of a standard solution are added to the sample being analysed ("analyte") until the reaction is stoichiometrically complete. The reaction is stoichiometrically complete when the analyte and the titrant are equivalent. This is the point when the exact stoichiometric amount of titrant has been added. This point is termed the "equivalence point" of the titration. The "endpoint", on the other hand, (Petrucci, Harwood & Herring, 2002) is "the point in a titration at which the indicator changes color" (p.726).

The indicator in acid-base titrations is a substance whose colour changes according to the pH of the solution to which it is added (Petrucci, *et al*., 2002).

In this category it was expected that students would demonstrate their understanding and knowledge of what each of the concepts meant, where each of them occurred, and how each could be identified during the titration process. The chemical processes or reactions leading to colour change also needed explaining. It was also expected that students demonstrate their understanding of the difference between equivalence point and endpoint, and show when an endpoint and equivalence point respectively were reached during titrations.

(ii) The student's understanding and use of concepts: Analysis and explanation

The aim in this cluster was to understand how the student understood and used the concepts "equivalence point" and "endpoint". Students usually confuse the meaning of these two concepts. In analysing their understanding, the focus was on the perceived 'confusion' commonly found in the use of the concepts. The analysis in this cluster (like in the previous one) entailed the three aspects of specification knowledge used by Reif (1985) when analysing a concept.

- Specification of a concept

In the case of this student, one cannot regard the responses to represent an unambiguous scientific knowledge (Exhibit 4.3). That is, they could not lead to a clearly interpretable scientific knowledge. For example, in responding to Q.4.3.1, the student described equivalence point as the point at which reacting species (titrant and analyte) are "chemically equal". In this response (Q.4.3.1) the student only demonstrated *familiarity* with what equivalence point meant (in terms of the process where reacting species combine). The word "equal" is scientifically misleading in the case of chemical reactions. Instead, the student should have used "equivalence" to demonstrate that reactions take place in different ratio relationships. This response indicates a recollection of previous experience with the term "stoichiometric equivalence". The response indicates the student's declarative knowledge of equivalence point. (The equivalence point is the point at which reacting species are combined in equal molar amounts based on the reactants relationship according to a balanced equation.). The student managed to specify equivalence point, even if the specification was not completely without ambiguity. The question that arises then is: Can incomplete knowledge be applied?

- Instantiation

According to Dochy, knowledge *availability,* which is affected or affects accessibility (see Figure 8) is the ability to utilise resources. Availability and accessibility are functions of organisation and awareness (Dochy, 1992). For knowledge to be applied successfully it has to be complete and well organised. Organised knowledge is when key concepts and procedures are connected to provide the glue that holds the cognitive structure together (Dochy, 1992). The response in Q.4.3.2 suggests that the student's prior knowledge of equivalence point (Exhibit 4.3) did not provide a "glue to hold the cognitive structure together" – the form in which this student's knowledge was organised did not make her aware of what the *temporary* colour change indicated in terms of the meaning of equivalence point (or endpoint for that matter). In her practical work report (Exhibit 4.3), the student indicated her observation of this colour change and the fact that it was not the endpoint. The response clearly indicates that this knowledge was not *complete, available and/or accessible*; therefore the response could not have been viable. Inaccessible knowledge illustrates *poorly organised* knowledge. The organisation of knowledge in this instance was such that it could not be activated to be immediately usable to construct a viable response.

In Q.4.3.2 the term "temporary" was supposed to have *hinted* to the student that the titration was still in progress. It is apparent from her response (Q.4.3.2) that the student did not consider the *meaning* of the term "temporary" in the process of titration. The equivalence point could not have been reached while the colour kept reverting to the original colour during titration. The student did not, in this case, demonstrate connectedness. The student did not appropriately represent the idea of "temporary change" or connect it with her understanding of equivalence point. Therefore, it can be inferred that the student regarded *equivalence point and endpoint* to mean the same thing, and are both indicated by a colour change (considering the responses in Q.4.3.4 and Q.4.3.5). However, it should be noted that equivalence point is *effectively* the endpoint (as it is the point at which the amounts of reacting species are stoichiometrically equal). But the endpoint is not necessarily the equivalence point. Endpoint (colour change) is an indication of the fact that the equivalence point has been exceeded.

- Error prevention

As indicated earlier (Prawat, 1989), accessibility depends on one's "organisation" and "reflective awareness". In the case of this student, reflective awareness was lacking. For example, the student failed to recognise the importance of the term "temporary" in Q.4.3.2 to guide her responses. In responding to questions involving colour change, the student did not reflect on the nature of the subject matter she was dealing with. Colour change involves a chemical reaction. A symbolic representation at micro level (through her mental model) of a reaction of an indicator in different media would have facilitated a better response. The indicator exhibits different colours in different media:

$$\mathbf{HIn\ (aq) + H_2O\ (l) \rightleftharpoons H_3O^+\ (aq) + In^-\ (aq)}$$

Colour A **Colour B**

Phenolphthalein
(Colourless) **(Pink)** **pH 8, 00 - 10, 00**

In the case of this particular practical activity, (where a base reacts with an acid) phenolphthalein was the indicator. In an acid medium, phenolphthalein is colourless and in a basic medium phenolphthalein turns pink. In her responses, the student viewed colour change only at the macro level. That is, physical change of colour (see the response to Q.4.3.1; vinegar and not CH_3COOH is reacting with NaOH). This representation illustrates the influence of incompleteness in one's prior knowledge. The student's prior knowledge did not enhance understanding or relational use of knowledge in this practical work activity.

The student did not consider or reflect on all the steps she had undertaken in her calculation to reach her final answer. The student did realise that her answer was far too high, but could not remedy the situation. The student was unable to retrace her steps in the method to determine what could have been the source of the "high percentage content" in her calculations. This inability to reflect on her prior knowledge indicates a lack of reflective awareness in her manipulations during practical work. For example, the dilution factor of the original solution of vinegar was not considered in her calculations. The density of the vinegar solution was not used anywhere in her calculations. The student's knowledge was not well organised. She could not construct understanding from the information at her disposal.

(iii) Synthesis

The student's responses (on equivalence point, endpoint and colour change of the indicator) could be explained in terms of the effects of prior knowledge and the nature of subject matter. Some responses could be attributed to the effect of prior knowledge (Q.4.3.1 to Q.4.3.6). The prior knowledge was *unavailable, inaccessible and not well structured*. The fact that the student managed to explain what an equivalence point was (Q.4.3.1) and the purpose of an indicator (Q.4.3.6) did not mean she could use this knowledge appropriately. This is so because the knowledge was not accessible. It was not accessible because it was not well organised. If it was well organised, it may have been possible for the student to restructure it to construct new understanding or meaning. The level of the subject matter at which the student understood reactions affected the student's understanding of the chemical process involved. In this case, the student did not view the reaction at micro level (see Figure 4); for example, she used the term "vinegar" instead of "acetic acid" (CH_3COOH) reacting with NaOH.

Exhibit 4.4

Presented data

Questions, student's responses and data sources

Q.4.4.1: Differentiate between a *dilute* solution of a *weak* acid and a *concentrated* solution of a weak acid. Illustrate your answer with a relevant example. *(*PKST: Q.5)

S: Dilute weak acid does not produce gaseous gas while concentrated acid produces substances. $H_2CO_3 \rightarrow CO_2^- + H^+$

$H_2CO_3 \rightarrow H_2O^+ + HCO_3^-$

Q.4.4.2: What is the difference between a strong and a weak acid? (O&I)

S: Acid that dissociates or ionises completely in an aqueous solution.

Q.4.4.3: Why is ethanoic acid considered a weak acid? (O&I)

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

Q.4.4.4: Calculate the molarity of HCl with a density of 1,057 g/ml and purity of 12% by mass. (PKST: Q16)

S: D = m/v; 1,057 = (12/100)/v

v = 0,12351

c = m/mv

= 0, 03 mol/dm^3

Q.4.4.5: Illustrate how 500 ml of a 6 M solution of NaOH is diluted by a factor of *25.* (PKST: Q.20)

S: 6 x 500/25

Q.4.4.6. What do you understand by the term "concentration"? (O&I)

S: Concentration is the ratio of moles per volume (n/v).

Q.4.4.7: What do you mean by the term "dilute"? (O&I)

S: To reduce the concentration of vinegar.

Q.4.4.8: What is the concentration of ethanoic acid in vinegar after dilution? Is it high or low? (O&I)

S: It is not yet known.

Q.4.4.9: What happens if it adds the volume? (O&I)

S: It reduces the concentration.

(i) Description of specification knowledge (memorandum)

In performing practical work, students are expected to demonstrate their skills in carrying out their work. Skills are the part of the knowledge system that includes declarative, procedural and conditional knowledge. There are decisions to be taken in terms of which step to follow and how to respond in a situation where the process is not yielding results as expected. Students are therefore expected to integrate their knowledge to successfully complete their practical work tasks. The questions in this section are based on practical work activities. Some of the questions may not make sense in the absence of a context. However, the context will be explained in the interpretation of the students' responses to these questions.

The concept of interest in this category was "concentration". Concentration refers to the number of moles (n) of an acid per volume (v) measured in dm^3 or cm^3 of a given quantity of solvent. Solutions with different concentrations are referred to as either dilute or concentrated in relation to each other. For example, a dilute solution of a weak acid refers to the relatively small number of moles (n) of acid per relatively large volume (v) of solvent; whereas a concentrated solution refers to a relatively larger number of moles per relatively smaller volume of solvent, e.g. 0, 01 M ethanoic acid is dilute, as compared to a 0, 1 M solution of ethanoic acid. Concentration of a solution can be expressed in a variety of ways, for example as moles per litre of solution (molarity), moles per kilogram of solution (molality), percentage concentration (m/m per cent; m/v per cent; v/v per cent), parts per million (ppm) or mg per litre. In this activity, concentration was expressed in moles per litre and percentage mass per mass. Students were expected to demonstrate their ability to manipulate figures of masses and volumes through dilutions to determine the concentrations of solutions.

In addition, this section looked at the concept of concentration with specific focus on the relationship between a dilute and a concentrated solution. The student was expected to relate the two terms (dilute and concentrated) through the manipulation of the relationship between concentration (c), number of moles (n) and volume (v). It was therefore required that the student demonstrates declarative, procedural and conditional knowledge (since the manipulation of a relationship between factors or concepts requires that one is conversant with what they are, what they mean and when and where they are applicable). The terms "dilute solution" and "concentrated solution" are related to concentration by the equation:

$$\mathbf{C = n/v} \qquad \textbf{(1)}$$

where C = concentration, n = number of moles of solute in the solution, and v = volume of the solution. They are related to dilute and concentrated solutions in the sense that a dilute solution refers to a solution with a relatively small number of moles (n) dissolved in a relatively large volume (v) of solvent, and a concentrated solution is a solution in which a relatively larger number of moles (n) is dissolved in a relatively small volume (v) of solvent. These relationships can be demonstrated mathematically as follows:

$$\mathbf{C = n/v \text{ where } C = 1/v \text{ and } C \propto n} \qquad \textbf{(2)}$$

Questions in this category were aimed at probing the student's understanding of terms associated with concentration and strength in solution chemistry. Generally, students confuse "dilute" for "weak" and "concentrated" for "strong". This results in students being unable to apply the concepts with understanding in practice (for example, in calculations or during practical work activities).

(ii) The student's understanding and use of concepts: Analysis and explanation

Concepts for analysis in this cluster (in terms of concept specification, instantiation and error prevention) were a "dilute solution of an acid", "weak acid" and a "concentrated solution".

- Specification of a concept

The student's response (Q.4.4.1) reaffirmed the 'confusion' students demonstrate when dealing with the terms "dilute" and "weak" with regard to acids and bases. In this response, the student misconstrued a weak acid with a dilute solution of a weak acid. A "dilute solution of a weak acid" is described (by the student) in terms of the dissociation of an acid when describing a weak or a strong acid. The understanding of the two reactions, which are not necessarily a correct representation of the reaction, confirms the misconception. A weak acid or a strong acid behaviour/definition can be demonstrated symbolically with an equation that illustrates that they ionise completely or partially. A dilute and/or concentrated solution can be explained by expressing their concentrations in moles/dm^3 or any other expression of concentration and comparing them (e.g. 0, 02 M and 0, 05 M CH_3COOH represent a dilute and concentrated solutions respectively).

The student's representation of a dilute and/or concentrated acid had no relation to the solution concentration or number of moles in a given volume of solution. The two terms (dilute and concentrated) were not at all described in the relationship c = n/v or the number of moles per given volume of a solution. When asked to define "concentration" (Q.4.4.6), the student responded with a correct answer (c = n/v). This was followed with a correct response in Q.4.4.7 when asked to explain what the term "dilute" meant, although the student had a language deficiency in responding to the question. It was apparent that the student had knowledge of facts (declarative knowledge) about the terms.

- Instantiation

All meaning, according to Pines (1985), is relational and elucidation of meaning is possible through the analysis of relations. The student's responses in the case of this cluster did not generate meaning as her knowledge was not well organised for building relations. The student's knowledge was made up of isolated concepts, which made it difficult for applicable knowledge construction. As indicated earlier, the student had declarative knowledge that she could not access for procedural purposes. As isolated facts, her knowledge could not readily be used, since it was not structured in a comprehensible way that could be easily activated to make sense of the incoming information. Therefore it can be concluded that the student's knowledge was of a poor quality. It was not available and could not be accessed owing to a lack of quality structure. For example, the responses to

Q.4.4.4 and Q.4.4.5 required the restructuring of declarative knowledge of density (d = m/v) and that of concentration (c = n/v) for procedural purposes. The student was expected to restructure her declarative knowledge into procedural knowledge to respond to both these questions. In Q.4.4.4, the student demonstrated that parts of her knowledge were correct (e.g. d = m/v). But her prior knowledge was incomplete. Incomplete knowledge in this case inhibited the ability to arrive at a correct answer. The responses to Q.4.4.6, Q.4.4.7 and Q.4.4.8 confirm the conclusion that this researcher made earlier about the poor organisation of the student's knowledge. If dilution means reduction of concentration (Q.4.4.5) and if volume increases (Q.4.4.7) reduces concentration, then the concentration in Q.4.4.8 should have been low.

- Error prevention

The student's responses indicate a lack of reflection during learning and using her responses in other questions to prevent or correct mistakes committed. According to Prawat (1989), knowledge that lacks organisation tends to affect the individual's reflective awareness. In the case of this student, the lack of reflective awareness was evident in most of the related questions (Q.4.4.5 to Q.4.4.9).

(iii) Synthesis

Although it was not directly discussed, one of the factors that contributed to this student's inability to respond viably to many questions in this cluster was the nature of the subject matter. The subject here is chemistry. The student could not respond viably as she could not construct mental models because her imagery of matter was not well represented. For example, the student could not differentiate between "dilute" and "weak" because she represented concentration in terms of the strength of an acid. Instead of using moles and volume, the student used symbolic representation of a dissociating acid. This indicates confusion in the student's organisation of knowledge in her knowledge base. Poorly organised knowledge cannot be used successfully to construct understanding or generate meaning, as it is difficult to access such knowledge.

4.3.2 Analysis: Case B (Exhibits 4.5 to 4.8)

Exhibit 4.5

Presented data

Questions, student's responses and data sources

Q.4.5.1: Differentiate between an Arrhenius and a Bronsted-Lowry acid. (PKST: Q.6)

S: Arrhenius: Acid when react liberate/release hydrogen ion $H^{+.}$

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

Q.4.5.2: As the hydrogen ion concentration of an aqueous solution increases, the hydroxide ion concentration of this solution will – (1) increase; (2) decrease; or (3) remain the same? (PKST: Q.3)

S: Hydroxide ion (OH^-) will also increase because if you increase the concentration of acid in chemical reaction you also increase the concentration of base.

Q.4.5.3: You are told that an aqueous solution is acidic. What does this mean? (PKST: Q.1)

S: It means that every acid is in the form of water molecules.

Q.4.5.4: In terms of the Bronsted-Lowry definition of acids and bases, what is a strong acid and a weak acid? (PKST: Q.8)

S: Strong acid is acid that ionises completely in water.

Weak acid is acid that ionises partly in water.

(i) Description of specification knowledge (memorandum)

For a description of specification knowledge (memorandum), refer to exhibit 4.1 above.

(ii) The student's understanding and use of concepts: Analysis and explanation

Analysis in this cluster of questions and responses focused on the concept "acidity". This concept, like any other concept, is a product of construction of other concepts or terms. The four questions were clustered together to elicit information from the student's knowledge base that, on the basis of the described specification knowledge, is considered relevant and sufficient to construct the meaning of an aqueous acidic solution. The cluster was constructed such that it could enable inferences from the student's knowledge base to demonstrate the student's understanding of the three ways concepts can be understood when described (namely specification of concepts, instantiation and error prevention).

- Specification of a concept

As concepts are built from other concepts or terms, three of the four questions in this cluster (Q.4.5.1, Q.4.5.2 and Q.4.5.4) were posed to determine the student's basic understanding of the concepts and/or terms with the potential to describe an "aqueous acidic" solution (Q.4.5.3). In his response to these questions, the student demonstrated his declarative knowledge of the concepts. This does not necessarily mean the responses were all viable, but they indicate how the student 'understood' the concepts. It is apparent from the student's responses that he was able to state or define most terms or principles with information that could be used to construct understanding of an *acidic aqueous solution*. The question here is whether the student was able to use this knowledge to construct meaning of an acidic solution?

- Instantiation

Instantiation, as indicated earlier, has to do with one's ability to apply knowledge. Asking the definition of an aqueous acidic solution was aimed at allowing the student to construct the meaning of an aqueous acidic solution. The ability to describe an aqueous acidic solution also depended on the student's understanding of what an aqueous solution is. The student's response to Q.4.5.2, although incorrect, is an indication that the student understood that ions are formed when water dissociated. It was also apparent that the student interpreted an increase in hydrogen ion to come from the dissociation of the solvent rather than the introduction of the ion in the aqueous solution itself. In other words, the student described the *dissociation of the water molecule* ($H_2O \rightleftharpoons H^+ (aq) + OH^-(aq)$) instead of the introduction of an H^+ ion. This understanding resulted in the construction of the response as indicated below:

As the *hydrogen ion* concentration of an aqueous solution increases, *the hydroxide-ion* concentration of this solution will – (1) increase; (2) decrease; or (3) remain the same?

Response: Hydroxide ion (OH^-) will also *increase* because if you increase the concentration of acid in chemical reaction you also increase the concentration of base.

The emphasis of the student's responses on the aqueous solution is also apparent from his answer to Q.4.5.3. The *aqueous acidic solution* the student refers to here is the form in which the water exists rather than the excess H^+ ions (from the dissociating acid) in water solvent. The impression created from these responses is that the student's mental models were inaccurate in terms of the equilibrium of the aqueous solution. That is, they could not enhance his ability to construct a viable response of what an aqueous acidic solution was.

The student's inability to construct a viable meaning of an aqueous acidic solution suggests the form or structure of his knowledge was not organised in a way in which accurate mental models could be constructed. In addition the type of responses given could be the student's imagery of the nature of the subject matter. In this case, the student's view of matter is more at the macro level than at the two other levels of matter (micro and symbolic levels). The student managed to associate "aqueous" with water, but could not represent it at the appropriate symbolic level where ions (H^+ and OH^-), and not the water molecule, are active in the determination of an aqueous solution. The symbolic representation would have enhanced a valid response to Q.4.5.2 and to describe an acidic solution in Q.4.5.3 (as an excess of H^+ ions in the solution).

- Error prevention

In the interpretation of concepts (Reif, 1985), students need adequate knowledge to prevent errors and to correct them appropriately when they have been committed. It is apparent from this student's responses (knowledge base) that his ability to prevent errors was inadequate. For example, his response to Q.4.5.2 indicates his incorrect mental model of the chemical reaction involved in this particular reaction. An aqueous solution is the dissociation of a water molecule as a reaction: ($H_2O \rightleftharpoons H^+$ (aq) + OH^-(aq)). Introducing extra H^+ (aq) ions would *upset* the equilibrium when the extra H^+ ions react with OH^- ions (Le Chatelier's principle). The student's response indicates his failure to reconstruct his current knowledge to construct meaning based on the chemical reaction involved. According to Prawat (1989), knowledge that lacks organisation tends to affect the individual's reflective awareness.

(iii) Synthesis

In this cluster, the student demonstrated his declarative knowledge of the concepts or terms that could be used to describe or construct meaning of an *aqueous acidic* solution. But his poor organisation or structure of that knowledge is apparent. The student could not reorganise his knowledge to construct meaning with the information at his disposal. The information, as indicated earlier, was more declarative. In addition, the student had difficulty with the nature of matter. In most of the responses, the student's view of matter was mostly at a macro level. The nature of the subject matter inhibited the student’s ability to give valid responses to a large extent. The inappropriate use of the nature of the subject matter resulted in the student failing to recognise mistakes and correct them appropriately when the need to do so arose.

Exhibit 4.6

Presented data

Questions, student's responses and data sources

Q.4.6.1: In terms of the Bronsted-Lowry definition of acids and bases, what is a strong acid and a weak acid? (PKST: Q.8)

S: A strong acid is acid that ionises completely in water. Weak acid is acid that ionises partly in water.

Q.4.6.2: Is acetic acid a weak acid or a strong acid? (O&I)

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

Q.4.6.3: What does it mean to ionise incompletely? (O&I)

S: The participant cannot explain what it means to "incomplete ionise".

Q.4.6.4: Demonstrate how a weak acid ionises "incompletely". (O&I)

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

(i) Description of specification knowledge (memorandum)

For a description of specifications knowledge (memorandum), refer to Exhibit 4.2 above.

(ii) The student's understanding and use of concepts: Analysis and explanation

In this cluster, just like in the clusters analysed earlier, the objective was to understand how students use their previously acquired knowledge of concepts in chemistry and ways of thinking to generate meaning of related concepts. The aim of this study was to understand this meaning generation within the realm of three types of knowledge, namely declarative knowledge, procedural knowledge and conditional knowledge. The concept to be analysed in this cluster was "acid strength".

- Specification of a concept

According to Phye (1997), specification of a concept demonstrates one's declarative knowledge. The student's responses in exhibit 4.6 give an indication of his knowledge of the concepts relevant (according to the specification knowledge) to the construction of the concept "acid strength". However, the responses do not suggest that the student responded (Exhibit 4.6) viably, but the responses are an indication of the student's understanding of such concepts or terms. What is important is the student's understanding and use in a practical situation.

- Instantiation

In responding to Q.4.6.1 it is apparent in the researcher's view that the student was familiar with the terms "strong acid" and "weak acid" (according to the Bronsted-Lowry concept of acids and bases). The term "familiarity" was advisedly used here to avoid committing oneself to terms such as "knowledge". Knowing has a variety of meanings depending on one's view of what learning and/or knowledge is. For example, Schwartz and Reisberg (1991) refer to knowing as implying that one has experienced something or thought about it before and remembering the experience. As the purpose of this study was to establish if students understood certain concepts and their use, it would have been inappropriate to use the term "knowledge" before it was established.

In terms of declarative knowledge, the student's knowledge of the weak and strong acids was viable (Q.4.6.1). All the terms ("ionise", "complete" and "aqueous solution") were appropriately used according to the requirements of the specification knowledge. However, in his attempt to describe why acetic acid was a weak acid the student used the term "incompletely" to construct the meaning of a weak acid, instead of "partly". It is apparent in the context of the question and the student's response that the term was used as an opposite of the term "completely" (as it is associated with the term "weak", which is the opposite of "strong"). Generally, the student managed to demonstrate his declarative knowledge of strong and weak acids. The only limitation in his response was his limited vocabulary – in his use of the term "incompletely".

In Q.4.6.4, the context of the statement "ionise incompletely" is apparent. That is, the ionisation referred to here is not the formation of ions in an aqueous solution of CH_3COOH, represented by the dissociation of acetic acid in water;

$$\mathbf{CH_3COOH \rightleftharpoons CH_3COO^-_{(aq)} + H^+_{(aq)}.}$$

It is a total disintegration or decomposition of the acetic acid molecule (CH_3COOH) into its constituent atoms. The influence of this conception could be traced back to the term "complete", and the student should have used his understanding of what an acid is according to the Arrhenius concept (i.e. the formation of H^+ ions in aqueous solution). In this case, the student expected all H atoms to be ionised to H^+ ions.

The student's understanding of ionisation demonstrated in Q.4.6.4 was influenced by the term "complete" in the definition of a strong acid:

Demonstrate how a weak acid ionises "incompletely".
Response: … *Not all H^+* ions have ionised … there *are still three H^+ ions in the CH_3COO^- ion.*

On the strength of this understanding the student developed a mental model of the decomposition of the acid to form H^+ ions from all the hydrogen atoms found in the acetic acid molecule. The fact that the student just associated *strong* with *weak* and *complete* with *incomplete* is apparent in his response to Q.4.6.3. The student could not explain what it meant in the context it was used.

- Error prevention

The successful performance of any task is, according to Reif (1985), facilitated by one's awareness of likely errors and pitfalls. In a learning situation, teachers warn their students of mistakes commonly made when responding to questions. In responding to questions, students should also reflect on their responses to make sure that they make scientific sense. This reflection is only possible if the student has relevant and ‘correct’ knowledge. In other words, this knowledge must be available and/or accessible to the student. It is apparent that most of this student's knowledge was declarative.

His inability to use knowledge to reflect on his current knowledge is referred to as the problem of "inert knowledge" (Phye, 1997; Prawat, 1989). Students thus have relevant knowledge (in whatever form) but cannot recall or use it. This student's declarative knowledge could not be reconstructed to make sense of what a weak acid was compared to a strong acid or vice versa.

(iii) Synthesis

As indicated earlier, the purpose of this analysis was to elicit understanding of student's declarative, procedural and conditional knowledge. It can be concluded that the student's knowledge was affected in diverse ways. The assumption is that the outcomes of learning depend on the quality of the characteristics of prior knowledge (Dochy, 1992). These characteristics intervene in the learning process or its outcomes and causing interference in learning. With this student there was some interference as a result of these qualities. In response to Q.4.6.1, the student demonstrated his declarative knowledge of a strong and weak acid despite the fact that he used inappropriate terms. The student's declarative knowledge can be described as reasonable, complete and correct. The responses to Q.4.6.2 to Q.4.6.4 indicate that declarative knowledge does not necessarily translate into procedural and/or conditional knowledge. In other words, knowledge was available but could not be used to respond to other situations.

In his response to Q.4.6.4, "complete ionisation" was misconstrued with disintegration. That is, the knowledge of strong and weak acids was not accessible because it was not well structured. It was not in a form that could be used to represent correct information about what ionisation means in describing a weak and a strong acid. In conclusion, procedural and conditional knowledge were not such that they could be applied and/or reflect on.

Exhibit 4.7

Presented data

Questions, student's responses and data sources

Q.4.7.1: What is meant by equivalence point? (Q&I)

S: When the amount of reagent is equivalent to the amount of the analyte.

Q.4.7.2: How does equivalence point differ from endpoint? (Q&I)

S: Endpoint is when the reaction is judged to be complete.

Q.4.7.3: When do you judge the reaction to be complete? (Q&I)

S: When the colour changes.

Q.4.7.4: When does the colour change? (Q&I)

S: At (the) endpoint standard amount is higher than analyte.

Q.4.7.5: Presume that you are titrating a weak acid (e.g. CH_3COOH) and a strong base (e.g. NaOH). What would the expression "equivalence point" mean in this process? (PKST: Q.12)

S: Equivalence point means that the amount of weak acid (CH_3COOH) is equal to the amount of strong base (NaOH).

Snippets from the practical work report (PWR)

Method/procedure

) The solution of vinegar (10, 00 cm^3) was *added to a pipette* and the solution was transferred to a volumetric flask and diluted to the mark with distilled water.

i) And *25 cm^3 pipette of vinegar* solution was transferred to two conical flasks.

Calculations

A: D = m/v

m = d x v

= 1,045g/cm^3 x 15, 00 = 15,675 g % 15,675/21, 3 cm^3 x 100 = 73, 6%

Observation

The solution of vinegar changes from light colour to pink.

The pink colour shows that there is a solution of ethanoic acid.

Conclusions

This shows *that vinegar* is a strong acid when reacting with sodium hydroxide and it liberates water and ethanoic acid.

(i) Description of specification knowledge (memorandum)

For a description of specification knowledge (memorandum), refer to Exhibit 4.3 above.

(i) The student's understanding and use of concepts: Analysis and explanation

This cluster of questions and responses was compiled to indicate how the student would specify or understand and apply the concepts in a practical situation. This clustering was based on Pines' (1985) assertion that the meaning individuals attach to a word and their conceptual framework make them knowledgeable in a particular area depending on the relations they form. The cluster was aimed at demonstrating the relations used by the student to construct meaning from his responses. From these relations conclusions could be made to understand how the student understood and used a specific concept. In the case of this cluster, the concepts of interest were "equivalence point" and "endpoint".

- Specification of a concept

In his response to what "equivalence point" meant (Q.4.7.1), it is apparent that *equivalence* for this student meant *equal*. Equivalence can only mean *equal* in a 1:1 ratio reaction. If the student was aware of the differences and similarities between equivalence and equal, the point of the reaction ratio could have been indicated. The failure or inability to indicate this shows his incomplete understanding of the concept. In responding to Q.4.7.2 the student did not differentiate between the two concepts, but elected to explain what endpoint is. But from his response to Q.4.7.4 and Q.4.7.5 it appears that the student could differentiate between the two concepts. The conclusion is that the student demonstrated his declarative knowledge of the two concepts. But would it be possible for him to use this understanding in practice?

- Instantiation

Many students (Reif, 1985) are unable to apply concepts in particular situations, even if they have managed to define them. In the case of this student, the description of “equivalence point” made it difficult to apply it to all practical situations. Describing it as "equal" could only be applied if the reactants were reacting in a 1:1 ratio (such as in the case of the reaction between acetic acid (CH_3COOH) and sodium hydroxide (NaOH)). This description of equivalence in reactions with different reaction ratios would not be applicable. It is evident from his responses that the student regarded equivalence as equal – regardless of the ratio in which the reactants reacted. This response indicates the level at which the student constructed his mental models as far as the nature and reaction of matter was concerned. The student viewed the reaction at a macro level of matter. The student's description of *endpoint* seems to be the same as that of the *equivalence* point. The explanation of endpoint is superficial (in the sense that it is viewed only as colour change and not as a different type of reaction between different chemical species). The student also did not view the reaction as ethanoic acid (CH_3COOH) reacting with sodium hydroxide (NaOH), but a reaction of *vinegar* – there was no reaction equation in all his calculations in the practical work report.

The superficial nature of the student's response is confirmed in Q.4.7.4, where the amount of reactants rather than the reaction taking place is preferred to explain the colour changes. The colour change is "seen" in terms of the amounts of reacting species. This response reinforces the idea that the student's mental models were constructed at a macro level. The important chemical reaction between the indicator and the two different media (acid and base) were not part of the student's constructed mental model:

$$\mathbf{HIn\ (aq) + H_2O\ (l) \rightleftharpoons H_3O^{+}\ (aq) + In^{-}\ (aq)}$$

Colour A **Colour B**

Phenolphthalein

(Colourless) **(Pink)** **pH 8, 00–10, 00**

The quality of the student's responses to this cluster of concepts could have been affected significantly by the three prior knowledge factors (namely incompleteness, organisation and structure). For example, in describing equivalence point it is apparent the student's understanding was limited. Equivalence was synonymously described as equal without specifying the reaction ratio. This description would have a negative effect on its use in cases where the reaction was not 1:1. The student's inability to recognise the limitation of his description of equivalence indicates that his knowledge was incomplete and poorly organised.

Finally, what is significant about the student's understanding of the two concepts in relation to each other and their use is the use of "amount of reactants" instead of the reaction behind the changes (e.g. colour change). This shows that the student constructed his mental models of what transpired at the macro level. The question is whether the student was in any position to reflect on the viability of his responses to the questions (Exhibit 4.7)?

- Error prevention

One is able to prevent an error or correct it if you have relevant prior knowledge to do so. In other words, an error can be prevented if the individual has available or accessible information or knowledge that can help him or her reflect on the errors committed. This student's knowledge was in such a form that it could not be accessed. It is apparent that the student had declarative knowledge that was memorised. In this form, knowledge is difficult to restructure as it was conceived without understanding. Therefore, the student could not use this knowledge in a practical situation when it was demanded of him (Exhibit 4.7). For example, in Q.4.7.5 equivalence point is not necessarily a point when the amount (depending on what amount means) of weak acid is equal (equal needs explanation) to the amount of strong base. The term "equal" can only be used provided the reaction is a 1:1 reaction (in molar terms). The student did not reflect on the stoichiometric relationship. Error prevention is about decision-making. Decision-making requires the application of knowledge. Without information to construct such knowledge, errors cannot be prevented or corrected.

(ii) Synthesis

Generally, the student demonstrated incomplete knowledge of what the terms "equivalence point" and "endpoint" meant. Most of his understanding was superficial. It was superficial in the sense that the understanding was not based on the reactions that took place in a solution. The explanations were based on the *amount* of solution and the changing of physical appearances rather than on the chemical reactions behind the changes. This could be a demonstration of the level at which the student was taught about the subject matter. That is, the student may not have been aware of any other level at which matter could be described. It could also be that the levels were not explained to him during teaching to enable him to construct mental models on the basis of the different levels at which matter exists. Without relevant mental models it becomes difficult, or even impossible, to construct viable knowledge or understanding. It is also difficult or impossible to reflect without relevant mental models.

Exhibit 4.8

Presented data

Questions, student's responses and data sources

Q.4.8.1: Differentiate between a *dilute* solution of a weak acid and a *concentrated* solution of a weak acid. (PKST: Q.5)

S: Dilute solution of a weak acid is an acid, which has *lots of water* in the solution whereas concentrated solution of a weak acid is an acid which have (a) *small amount of water* in the solution.

Q.4.8.2: What do you mean by *concentration*? (O&I)

S: Number of *moles* per given *volume.*

Q.4.8.3: Why do you dry glassware before using it? (Student dries conical flask before adding sample) (O&I)

S: We need the amount of vinegar only … not of vinegar and deionised water.

Q.4.8.4:.Why do you need the amount of vinegar only? (O&I)

S: It is a method … I do not know, Sir.

Q. 4.8.5: Why did you not dry the volumetric flask in which a sample was diluted? (The student did not dry the volumetric flask in which a dilute solution was prepared as was the case with other apparatus) (O&I)

S: Because we use deionised water to *dilute* the vinegar sample.

(The student becomes suspicious and retorts: This action will change the concentration of the solution, Sir.)

Q.4.8.6: How will it change the concentration of the solution? (O&I)

S: I do not know, but it will change the concentration of the solution … more deionised water will be added.

Q.4.8.7: Will it change the number of moles of acid to be titrated? (O&I)

S: The size of the container determines the concentration.

Q.4.8.8: What do you mean by concentration? (O&I)

S: Number of moles per given volume.

Snippets from the practical work report

Method/procedure

(ii) The solution of vinegar (10, 00 cm^3) was *added to a pipette* and the solution was transferred to a volumetric flask and diluted to the mark with distilled water.

(iii) And *25 cm^3 pipette of vinegar solution* was transferred to two conical flasks.

Calculations

A: d = m/v

m = d x v

= 1,045g/cm^3 x 15, 00 = 15,675 g % 15,675/21, 3 cm^3 x 100 = 73, 6%.

(i) Description of specification knowledge (memorandum)

For a description of specification knowledge (memorandum), refer to Exhibit 4.4 above.

(ii) The student's understanding and use of concepts: Analysis and explanation

The concepts of "dilution" and "concentration" are concepts many students find difficult to use in practice, especially during calculations. It becomes even more difficult if students are confronted with the new learning environment of practical work. Most students entering higher education in South Africa come from a background where resources for science learning were limited (in some instances non-existent). It is not surprising to find students in a first-year chemistry class failing to use concepts such as dilution or concentration in practical work situations. This failure is prevalent when students have to do calculations where dilution factors have to be taken into consideration. In this cluster, the understanding of concentration and dilution (specification of a concept, its instantiation and error prevention) was probed.

- Specification of a concept

Exhibit 4.8 above contains the questions and responses from the student that in the view of the researcher could assist in highlighting the student's understanding of “concentration” and “dilution”. To understand a concept, one must first be able to specify it. In his response to the first question (Q.4.8.1), the student established important relationships in terms of what dilute and concentrated solutions were. In describing a dilute and concentrated solution, it appears that the student was familiar with the relationship (in amount) between the solvent (water) and the solute (acid). The solvent was viewed as being more in amount in a dilute solution as compared to the solute. In a concentrated solution, the solvent (water) is less than the solute (acid). The student's response indicates an understanding of dilute and concentrated solutions. Could this understanding, in the form it was specified, be applied in practice?

- Instantiation

In his response to what concentration means (Q.4.8.2), the student managed to indicate concentration as a function of moles and volume; but he could not do the same in Q.4.8.1. In his response to Q.4.8.1, "dilute" and "concentrated" were described in terms of the solvent (water). The student viewed the solute as a constant. From this response it is clear that the description of concentration was algorithmic. The student could not use this knowledge to develop a mental model of a relationship (c = n/v). It can be concluded therefore that the understanding of solvent and acid were at a macro level, since they were not considered in relation to c = n/v. If this had been the case, the student would have used this relationship to differentiate between a dilute and concentrated solution of acetic acid (as described in the specification knowledge above). It can be concluded that the structure of the student's knowledge resulted in relevant knowledge being unavailable and therefore not being accessible.

In Q.4.8.3 the student's knowledge of the relationship c = n/v was probed. The researcher’s aim was to test what dilution factor the solvent introduced in the solution of a particular concentration. In responding to this question, the student was supposed to have used his understanding or develop a mental model around the c = n/v relationship. On further questioning (Q.4.8.6), the student recalled that the addition of the solvent would change the concentration, but could not indicate how the concentration would change (whether it would decrease or increase). This shows that the student's knowledge was isolated and not accessible. Knowledge in this form cannot be restructured to construct new understanding or meaning. Inability to reconstruct knowledge is also evident in the student's failure to refer/consider the dilution of the original sample after 10 cm^3 of the solution was transferred into the volumetric flask during the practical work task. Nowhere in the calculation was the acid content considered (Exhibit 4.8).

- Error prevention

The ability to interpret information or a concept depends on one's relevant and adequate prior knowledge. This student only demonstrated declarative knowledge. With this limited knowledge, the reflective awareness to prevent errors (by application of conditional knowledge) appeared impossible. Conditional knowledge was lacking because the student could not make connections (connectedness) between components (c = n/v) of his declarative knowledge. This resulted in a failure to decide what the effect of adding a solvent would be on the concentration. The student was also unable to realise that any addition of the solvent to the sample affected the relationship between all terms in c = n/v. This reflection was missing in the students' manipulation of apparatus and the sample during the experimental work.

(iii) Synthesis

In this cluster of questions and responses, the student had to demonstrate declarative knowledge of the concepts "dilute" and "concentration". However, the student could not successfully use this knowledge in a practical situation. This became evident when the student was asked to explain his actions during practical work. In the case of this student, it can be attributed to *incompleteness* of knowledge (when parts of prior knowledge are correct but incomplete). The 'correct' parts of this student's responses were his reference to dilution and concentration in terms of the amount of the solvent and the amount of the solute (only referred to as acid) and the description of concentration in terms of moles per given volume. The incomplete part was his inability to use the description of concentration to differentiate a dilute acid from a concentrated acid through the manipulation of the relationship c = n/v. This is understandable because the student (in defining a dilute/concentrated solution) only managed to use the amount of solvent (H_2O) without using the number of moles of the solute.

Another factor that inhibited learning in this case was the factor of *availability* of knowledge. From the student's response to Q.4.8.2 it is clear that he had the knowledge but could not use it when it was required. This can be attributed to a failure to make *connections* between available knowledge (c = n/v with dilute and concentration) and its "usefulness". The knowledge of c = n/v was not activated. A third factor inhibiting this student's learning was the factor of *accessibility*. Prior knowledge was not immediately available, as it was not organised in the correct structure for use. Available knowledge is easily activated when it is accessible. Prior knowledge is more accessible if it is well organised. As far as this student is concerned, his knowledge was not well organised, since it could not be accessed when required.

In conclusion, this student's responses revealed the availability of knowledge as declarative knowledge, but limited only to knowledge specification. The student was unable to apply his knowledge and prevent errors in the responses given. The student's three types of knowledge (declarative, procedural and conditional) were not sufficiently integrated to help in responding appropriately to questions.

4.3.3 Analysis: Case C (Exhibits 4.9 to 4.12)

Exhibit 4.9

Presented data

Questions, student's responses and data source

Q.4.9.1: Differentiate between an Arrhenius and a Bronsted-Lowry acid. (PKST: Q.6)
S: Arrhenius acid is a substance that increases H^+ ions in aqueous solution whereas with Bronsted-Lowry acid it is a proton donor.
Q.4.9.2: You are told that an aqueous solution is acidic. What does this mean? (PKST: Q.1)
S: It means that it contains hydrogen ions.
Q.4.9.3: Was the solution in the conical flask before titration acidic or basic? (O&I)
S: Acidic because the pH was less than seven.
Q.4.9.4: What was the pH after the colour change? (O&I).
S: Neutral.
Q .4.9.5: In which solution is the phenolphthalein pink? (O&I).
S: It is pink in a base.
Q.4.9.6: If it is pink in a base, what would its pH be after endpoint? (O&I).
S: More than seven … it is neutral?
Q.4.9.7: When is a solution neutral? (O&I).
S: When its pH is equal to seven.
Q.4.9.8: When pH = 7, what is the concentration of OH^- in relation to the concentration of H^+ ions? (O&I).
S: $[OH^-] = [H^+]$

(i) Specification knowledge

For a description of specification knowledge (memorandum), refer to Exhibit 4.1 above.

(ii) The student's understanding and use of concepts: Analysis and explanation

The responses to the eight questions in this cluster were chunked together to reflect on the student's domain-specific prior knowledge (declarative, procedural and conditional knowledge) of the concept "acidity". The eight questions were aimed to draw as much of the student's knowledge as possible and her ability to use it in constructing understanding of an "aqueous acidic" solution. In the formation of concept clusters such as this one, the purpose is to establish the relevant knowledge the student has about or related to the concept. It could not be established initially in which form this knowledge was held. But eventually it could be established by interpreting the responses to different related questions using Reif's (1985) three ways of describing a concept.

- Specification of a concept

In her response to Q.4.9.2, the student described the meaning of an aqueous acidic solution as a substance containing hydrogen ions. This description was apparently derived from an interpretation of the Arrhenius and Bronsted-Lowry concepts of acids and bases. The acidity of the solution was described in terms of the pH of the solution. This shows that the student made a connection between acidity and pH. This relationship was further confirmed by the student's response to Q.4.9.7 and Q.4.9.8. In Q.4.9.8, the student showed her understanding of the dependence of acidity on the concentration of H^+ ions in the solution. The question however, is whether this understanding could be applied appropriately in practice?

- Instantiation

In her response to Q.4.9.1, the student described an acid according to both the Arrhenius and Bronsted-Lowry concepts. As the question was not restrictive in how to differentiate, any differentiation that met the minimum requirements of the specification knowledge was acceptable. This student showed the difference between one acid dissolved in water increasing H^+ ions in solution (Arrhenius) while the other (Bronsted-Lowry) donates a proton.

This response was viable at a declarative level. In responding to Q.4.9.2, the student made a connection between the H^+ ions and acidity. However, this was not adequate to construct meaning of an "aqueous acidic" solution. The student could not access relevant information or knowledge enabling her to construct meaning of an aqueous acidic solution. The question one can ask is whether the student had this information or knowledge. The responses to Q.4.9.8 and Q.4.9.3 show that the student 'understood' the meaning of the relationship between H^+ and OH^- ions (in terms of what an acidic, a basic and a neutral solution are):

Was the solution in the conical flask before titration *acidic or basic?*
Response: Acidic because the *pH was less than seven*.
When pH = 7, what is the concentration of OH^- in relation to the concentration of H^+ ions?
Response: $[OH^-] = [H^+]$

The connection made by the student between related information and the information at her disposal did however not translate into usefulness in the social context (Glynn & Smith, 1991). The solution containing hydrogen ions did not necessarily make it acidic. An aqueous acidic solution contains both hydrogen and hydroxide ions, but with more hydrogen ions than hydroxide ions. In describing an acidic solution, it could be concluded that the student had adequate and relevant knowledge, but it was *inaccessible* because it was not *well structured*. The student's knowledge could thus not be used to construct a viable meaning of what an aqueous acidic solution was. Was the student aware of the information she had?

- Error prevention

In Q.4.9.3 to Q.4.9.8, the student's understanding was further probed to establish her reflection of the relation between acidity and pH (OH^- and H^+). In her response to whether the vinegar solution in the conical flask was acidic or basic, the student responded by using the pH scale. Her response that the pH was less than seven was *correct*; but (in this practical work) there was no way of determining this except by way of the student's previously learned declarative knowledge about the pH scale and acidity (i.e. that the pH of an acid is below seven and that of a base is above seven and the colour of the phenolphthalein in the solution is colourless in an acid and pink in a base).

The response to Q.4.9.4 illustrates that the student did not follow the reaction process in terms of the reacting species (OH^- and H^+ ions). That is the acid and base reaction that took place. The student did not engage with the reaction at the appropriate level, for example, at the molecular and symbolic levels. Her response to Q.4.9.4 was focused on the outcome of a reaction between equal amounts of an acid and a base where the resulting solution became neutral. The fact that the student responded that the *pH was neutral* instead of giving a value of the pH indicated the student's selective attention approach in her response. The answer of "neutral" was based on the acid-base reaction (the reaction of an acid and a base resulting in a neutral solution provided the amounts at the end of the reaction are equivalent). This also indicates that the student's knowledge was *incomplete* since not every acid-base reaction results in a neutral solution; this only happens when the number of moles of the reacting species is stoichiometrically equivalent.

(iii) Synthesis

The questions in this cluster were aimed at establishing the student's knowledge (declarative, procedural and conditional) and her ability to integrate this knowledge and use it appropriately in practical situations. Questions 4.9.5 to 4.9.8 were aimed at helping the student reconstruct the information she had about acid-base titration with phenolphthalein as an indicator. From the responses given it is clear that the student had relevant prior knowledge, although it was more pronounced as declarative knowledge. What was "missing" though was the ability to reorganise this information or knowledge to make connections and eventually make it useful in practical situations.

In responding to these questions, the student had sufficient knowledge available to construct viable responses to the questions. Dochy (1992) believes that individuals with a great deal of prior knowledge process new information by means of a different cognitive structure than those with little domain-specific prior knowledge. Individuals with more prior knowledge have alternative routes with which they can process and elaborate on information. In responding to Q.4.9.5 to Q.4.9.8 the student demonstrated that she had relevant prior knowledge. However, this knowledge appears to have been poorly organised for successful constructing understanding or generating meaning of an aqueous acidic solution.

Exhibit 4.10

Presented data

Questions, participant's responses and data source

Q.4.10.1: Differentiate between an Arrhenius and a Bronsted-Lowry acid. (PKST: Q.6)

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

Q.4.10.2: In terms of the Bronsted-Lowry definition of acids and bases, what is a strong and a weak acid? (PKST: Q.8)

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.

Q.4.10.3: As the hydrogen ion concentration of an aqueous solution increases, the hydroxide ion concentration of this solution will – (1) increase; (2) decrease; or (3) remain the same? (PKST: Q.3)

S: Decrease because if the acid is strong then the base is weak.

(i) Description of specification knowledge (memorandum)

For a description of specification knowledge (memorandum), refer to Exhibit 4.2 above.

(ii) The student's understanding and use of concepts: Analysis and explanation

The aim with this concept cluster was to demonstrate the student's understanding of "acid strength", and the application of the principle of acid strength. As there are three ways in which acids and bases can be described at this level of learning (first-year university chemistry), the focus in this cluster was on the Arrhenius and Bronsted-Lowry concepts. The student's understanding was probed using Reif's (1985) three-step approach of describing a concept.

- Specification of a concept

In her response to Q.4.10.1, the student demonstrated her ability to define or explain (declarative knowledge) the two concepts (Arrhenius and Bronsted-Lowry). In addition (Q.4.10.2), the student managed to describe what a "weak" and a "strong" acid were. Possession of declarative knowledge was earlier described as no guarantee for translating it into usable knowledge. In fact, Reif (1985) believes that the mere definition of concepts or statements of principle are insufficient building blocks in enabling one to perform complex intellectual tasks.

- Instantiation

This student's response to Q.4.10.3 confirms the notion that the mere definition or description of a concept is not sufficient for one to perform a complex intellectual task. In her response to Q.4.10.3 the student could not explain why there should be a decrease in OH^- ion concentration when the H^+ ion concentration is increased. This illustrates the student's misconception of what is meant by a "strong" or "weak" acid. The view in this study is that the student misconstrued concentration with acid strength. The student's response (that the increase in H^+ ions decreases the OH^- ion) was viable. The response to any question is a product of one's mental model. It is apparent from the student's responses that they were based on her understanding of what an acid was according to the Arrhenius and Bronsted-Lowry concepts. It is also apparent that the student had an understanding of what a strong and weak acid were based on the two concepts (Arrhenius and Bronsted-Lowry).

The student used her understanding of a strong and a weak acid (Q.4.10.2) to explain her choice of the term "decrease" in her response to Q.4.10.3. Her reasoning was due to her understanding of a strong acid in terms of the Arrhenius concept. The base or hydroxide ions in this case were interpreted as a "weak acid" that partly ionises in an aqueous solution with a low number of ions; hence the response: "decrease". The response appears not to have been derived from the reaction of the hydrogen ions and hydroxide ions where the concentration of the hydroxide is reduced or decreased because of the reaction with the hydrogen ions to form the water molecule in the reaction: $H^+(aq) + OH^-(aq) \rightleftharpoons H_2O$).

- Error prevention

Viability of responses in any learning situation depends on the quality of one's prior knowledge. Knowledge that is complete and correct helps reflective awareness. Without reflective awareness errors in one's knowledge (responses) become difficult to detect and correct. This student's prior knowledge was inadequate to construct mental models for differentiating between a weak and strong acid and the concentration of H^+ and OH^- ions in the solution.

(iii) Synthesis

What can the student's responses be attributed to? It is apparent that the student could construct a viable response based on the knowledge demonstrated. However, there was a problem with how the information or knowledge was conceived and stored in her long-term memory. Most of this student's knowledge was declarative and could have been conceived through memorisation. For example, the student misconstrued acid strength with concentration because she indicated that a strong acid decreased the weak base (in her response to Q.4.10.3). With regard to the quality of her prior knowledge, the response and the reason for the response could be attributed to the form in which her knowledge was structured at the time of responding to the question (Q.4.10.3). The structure and organisation of knowledge affected the construction of viable knowledge. The knowledge was inaccessible. It was poorly structured or organised and could not be used viably in practical situations. This student's knowledge was correct (declarative knowledge), but could not be applied as procedural and/or conditional knowledge to build any relational meanings.

Exhibit 4.11

Presented data

Questions, student's responses and data source

Q.4.11.1: Presume that you are titrating a weak acid (e.g. CH_3COOH) and a strong base (e.g. NaOH). What would the expression "equivalence point" mean in this process? (PKST: Q.12)

S: It will mean that the amount of added strong acid is equivalent to the base.

Q.4.11.2: What do you understand by the term endpoint in a titration process?
(O&I)

S: It indicates physical change.

Q.4.11.3: Differentiate between equivalence point and endpoint? (O&I)

S: Equivalence point indicates that amount of added standard reagent is equal to analyte.

Q.4.11.4: Which one between equivalence point and endpoint occurs first in a titration? (O&I)

S: Endpoint.

Q.4.11.5: Why do you think endpoint comes before equivalence point? (O&I)

S: Endpoint means after everything has happened ... No, Sir … this one is confusing. I am sticking to my first answer. Maybe I understand the meaning … I do not know what happens. (After a while): I think it is equivalence point … before we see any changes (in colour).

Snippets from the practical work report

Method

- 10 cm^3 of vinegar was transferred into a 100 cm^3 volumetric flask with a pipette with distilled water up to the mark.
- 25 cm^3 of vinegar was transferred into 2 conical flasks using a pipette.
- Three drops of phenolphthalein were added …
- NaOH was then titrated … until the endpoint was reached.

Calculations

See Exhibit 4.12

Observation

The colour of the vinegar changed from colourless to pink after titration with NaOH.

(i) Description of specific knowledge (memorandum)

For a description of specification knowledge (memorandum), refer to Exhibit 4.3 above.

(ii) The student's understanding and use of concepts: Analysis and explanation

Titration processes play an important role in the teaching of chemistry at first-year level. On this basis, if a good foundation of chemistry is to be built students should as part of learning chemistry, understand titrations and the chemical processes involved. In this cluster of questions and responses, two related and often confused concepts were the focus. These two concepts are "endpoint" and "equivalence point". The understanding of these concepts is generally superficial, with little emphasis on the reaction behind it. In this analysis, just like in previous analyses so far, the understanding of how students understand the two concepts was confined to specification of a concept, its instantiation and error prevention in the use of concepts.

- Specification of a concept

Specification of a concept (Reif, 1985) indicates the meaning of the concept according to specified rules that ensure that the concept is unambiguously identified and is understood as clearly interpretable scientific knowledge. In the case of this analysis it meant ensuring the accurate interpretation of what the student understood the concept to mean and its use in practical situations. Students were subjected to a prior knowledge state test, where they were required to elaborate on their responses so that the researcher could establish the extent of their understanding of the concepts. Some of the responses were drawn from the interview with the researcher (Exhibit 4.11).

- Instantiation

In her responses to questions Q.4.11.1 and Q.4.11.2, the student's understanding of "equivalence point" and "endpoint" respectively was probed. Her response to Q.4.11.1 shows uncertainty as to the meaning of equivalence point. However, it was clarified by the response to Q.4.11.3. In her response to what "equivalence" means, the student equated it to "equal". Endpoint, on the other hand (Q.4.11.2), was viewed as describing only a physical change of the solution (i.e. colour change).

"Equal" in stoichiometric terms needs further explanation, as it does not necessarily indicate equivalence. Equivalence point takes into consideration the fact that a balanced chemical reaction needs to be considered if a decision on *equality* of reactants is to be pronounced. The student's knowledge in her use of the term “equal” was indicative of incomplete knowledge. Equal (in terms of the reacting species) does not necessarily make them equivalent unless what is being measured and the units used are specified. A balanced equation determines whether equal can describe equivalent. In a 1:1 ratio reaction, "equal" means "equivalent". In the context of the practical work activity for this task, the student's response was viable since the reaction was a 1:1 ratio between acetic acid (CH_3COOH) and sodium hydroxide ($NaOH$).

Her response to Q.4.11.2 reflects her view of the reaction in the titration mixture. The student's developed mental model of what takes place in the reaction vessel did not indicate knowledge of the micro or symbolic levels of the changing of matter in the reaction. To describe endpoint simply as a physical change (colour change) gives no indication that the student viewed the change as a chemical reaction of the indicator or the type of medium (basic or acidic). This inference is confirmed by the student's "incorrect" response to Q.4.11.4. On further probing, the student changed her mind (Q.4.11.5).

This illustrates the process of reorganising prior knowledge in the student's response to the question:

> Why do you think endpoint comes before equivalence point?
> Response: Endpoint means after everything has happened...
> No, Sir … this one is confusing.
> I am sticking to my first answer.
> Maybe I understand the meaning …
> I do not know what happens …
> (After a while): I think it is equivalence point …
> before we see any changes (in colour).

It can be concluded that the student had knowledge about equivalence point and endpoint, but it was not immediately available, as it was not well structured to immediately meet the requirements of the incoming information. Regarding the change of colour of the indicator, it is apparent that the student had no prior knowledge of how (chemical reactions) and when the colour of the indicator changes. In conclusion, the student's knowledge of equivalence point, endpoint and indicator reaction was incomplete.

- Error prevention

The extent to which a person understands his or her domain's knowledge determines the extent to which he or she can use this knowledge to reflect, detect and correct errors. Initially, the student made errors regarding the terms used. For example, she used the term equal synonymously with equivalent, indicating that she did not have adequate knowledge to develop a mental model of what each of these terms meant in practice. However, in her processing of the difference between “endpoint” and “equivalence” point the student managed to use her understanding of what physical change meant to arrive at a viable response of which one of the two terms came first in a titration process.

Another example of failure to reflect on one's prior knowledge is the inability to use information relevantly. In her calculations, the student used the formula d = m/v and the volume from the titration to determine the mass of the acetic acid in the vinegar solution, instead of the volume of the sample. This resulted in the percentage content calculated at 94, 88%. This result should have prompted the student to reconsider her calculations (since it was far higher than the estimated 4% to 6% indicated in the method).

In conclusion, the student generally did not reflect on the knowledge she possessed or constructed during learning.

(iii) Synthesis

The student managed to describe the two concepts without necessarily understanding what they meant in practical terms. The student was able to indicate what they signified without being able to demonstrate with relevant chemical reactions what the significance of, for example, equivalence meant when an acid or base reacted with an indicator. The conclusion one can make from this is that the student's knowledge was incomplete and therefore difficult to instantiate in a practical situation. In addition, the effect of the student's view of the nature of matter contributed to her inability to understand and apply this knowledge in practice. The student did not use all the information at her disposal or constructed during the practical work activities. The dilution of the solution, for example, was not considered in her calculations. No reaction equation was used for a molar relationship between reacting species.

Exhibit 4.12

Presented data

Questions, participant's responses and data source

Q.4.12.1: Is it possible to weigh vinegar in solution form? (O&I)

S: Yes … but you must have a solid.

Q.4.12.2: How would you determine the mass of vinegar? (O&I)

S: By using the density.

Q. 4.12.3: Show the calculations to determine the % content of CH_3COOH. (PWR)

S: D = m/v

Mass = 1,045 g/cm^3 x 22, 7 = 23, 72

% CH_3COOH = 23, 72/25 x 100 = 94, 88%

Q.4.12.4: Calculate the molarity of HCl with a density of 1,057 g/cm^3 and purity 12% by mass. (PKST: Q.16)

S: C = n/v

= 1,057/10^3) x 1 mol HCl/36, 45 g

= 28, 99 mol x 12 g

= 3, 479 mol/l

Q.4.12.5: Differentiate between a *dilute* solution of a *weak* acid and a *concentrated* solution of a weak acid. Illustrate your answer with a relevant example. (PKST: Q.5)

S: Dilute solution of a weak acid: A solution which dissolve(s) completely is a weak acid: $CH_3COOH \rightleftharpoons CH_3COO^- + H^+$. Concentrated = that ionised partly: $NH_4 \rightarrow NH_3^+ + H_3O^+$.

Q.4.12.6: What would have been the effect if a 5-molar solution of NaOH was used in the place of a 0, 1-molar solution in this titration? (O&I)

S: Using a high concentration solution will increase the % of ethanoic acid in the vinegar solution. If you use 5 M NaOH endpoint is quickly reached.

Q. 4.12.7: What makes endpoint to be reached quickly? (O&I)

The student cannot account for this phenomenon.

Q.4.12.8: As the hydrogen ion concentration of an *aqueous solution* increases, the hydroxide ion concentration of this solution will – (1) increase; (2) decrease; or (3) remain the same? (PKST: Q.3)

S: Decrease because if the acid is strong then the base is weak.

Q.4.12.9: When HCl (aq) is exactly neutralised by NaOH (aq), the hydrogen ion concentration in the resulting solution is …

(1) Always less than the concentration of the hydroxide ions;

(2) Always greater than the concentration of the hydroxide ions;

(3) Always equal to the concentration of the hydroxide ions;

(4) Sometimes greater and sometimes less than the concentration of the hydroxide ions.

(PKST: Q.11)

S: Always equal to the concentration of the OH^-.

(i) Description of specification knowledge (memorandum)

For a description of specification knowledge (memorandum), refer to Exhibit 4.4 above.

(ii) The student's understanding and use of concepts: Analysis and explanation

The focus in this cluster of questions and responses was to analyse the student's understanding of concentration and related terms. The questions were mostly based on the student's practical activities. In the practical work task, the student was initially asked to develop her own method for analysing acetic acid (CH_3COOH) in vinegar. At this stage, observations and an interview were conducted. The analysis was also based on the student's practical work report, in which she reported all her activities (including calculations for the analysis). The analysis followed the same pattern as the previous analyses where three areas (specification of concept, its instantiation and error prevention) were used as focus.

- Specification of a concept

The method developed by this student required that the vinegar solution be weighed. The student was subsequently asked (Q.4.12.1) whether it was possible to weigh the vinegar solution in its liquid form. According to this student, weighing was only possible if a substance was weighed in its solid form. The intention with this question (Q.4.12.1) was to determine if the student could relate this action (weighing of a liquid) to the relationship between "density", "volume" and "mass" (d = m/v). The student was aware (Q.4.12.2) that one needed the density in determining the mass of a solution, but could not explain its relationship to the weighing of the solution. Was this illustrative of poor organisation of her knowledge structure?

- Instantiation

In the calculation (from the report), the student could not use the density to determine the mass, and eventually the percentage, of acetic acid content of vinegar. Did the knowledge structure contribute to the student's inability to calculate the percentage content of the acid in vinegar? Her responses to Q.4.12.1 and Q.4.12.2 illustrate that the student had knowledge on density and its relationship to volume and mass. But it seems that the knowledge could not be accessed immediately owing to the way it was organised. The knowledge was stored in such a way that it made it difficult to access or use for making connections in calculations. The student could not make connections between relevant elements of her knowledge to make it useful in practical situations. However, the student did manage (Q.4.12.4) to apply the d = m/v equation in an attempt to determine the percentage concentration of the acid. This indicates an algorithmic approach to solving problems. The incorrect answer obtained could be attributed to her failure to make sense of the relationship between density, mass and volume, and eventually what percentage purity meant (as this could not be demonstrated in Q.4.12.2, Q.4.12.3 and Q.4.12.4). The student showed that she had knowledge that was not well structured and could therefore not be used in a practical situation. Connections were made but could not be used coherently to respond to new incoming information.

In Q.4.12.5, the student misconstrued the term "dilute" with "weak", and a definition of a strong acid was confused with that of a weak acid. A dilute solution, as indicated earlier, has to do with the number of moles in a given volume. A weak acid, on the other hand, is concerned with the extent of the dissociation of an acid in an aqueous solution (according to the Arrhenius concept of acids and bases). The confusion between these terms (as described above) could be attributed to the student's knowledge organisation or structure. According to Dochy (1992), the way information is stored in memory influences the manner in which it is coded. When it is activated it will affect the meaning attached to an event by an individual. In the case of this student, dilute and weak meant the same thing.

The student's response to Q.4.12.6 creates the impression that increasing the concentration of the standard solution would increase the concentration (% content of acetic acid) of the analyte (sample). The student further indicated that increasing the concentration of the standard solution would hasten the attainment of the endpoint. This statement is viable provided the concentration of the analyte remains constant, but does it suggest that one needs both titrant and analyte in *high* concentrations to reach endpoint? The confusion is understandable if one considers the student's response to Q.4.12.5. The student did not use c = n/v in her reasoning. Her knowledge (in terms of the relationship c = n/v) appears to be a misconception. In her responses, the student did not make any connection between the terms "moles", "volume" and "concentration".

In responding to Q.4.12.8 the student initially gave a correct answer on the change in the concentration of OH^- ions. But when elaborating on the reason why there was a decrease of OH^- ions when the H^+ ions increased, the student clearly did not make use of the equilibrium reaction ($H^+_{(aq)} + OH^-_{(aq)} \rightleftharpoons H_2O$) to explain her response. The response was not constructed with the three levels of chemistry's nature in mind (viewing chemistry at molecular level where ions in the solution and their reaction become the guiding light of what might be happening). The response seems to be based on the notion that the stronger the substance (acid) is, the higher the number of moles is. Stoichiometry is confused with strength. No consideration is given to the fact that the number of moles involved is what counts during titrations. It is not explicitly indicated here if strength refers to moles or extent of dissociation.

The answer to Q.4.12.6 could have been influenced or derived from the same understanding of the response to Q.4.12.8. The response to Q.4.12.9 may have been influenced by the student's familiarity with the terms neutral and equal in terms of the relationship between the OH^- ions and H^+ ions. According to Dochy (1992), individuals selectively use their prior knowledge to attend to information they are familiar with. This process occurs at a deeper level. Prior knowledge is said to fulfil a directive role in the sense that relevant information receives more attention; hence the selective attention hypothesis.

- Error prevention

Error prevention is important in the quality of knowledge being constructed. Without adequate and relevant knowledge, error prevention becomes almost impossible. It is apparent from the quality of this student's prior knowledge (as demonstrated in her responses) that error prevention was not possible. It was indicated earlier in the discussion that the student's knowledge was not well organised for better application. Error prevention is about reflection and organisation. Without well-organised and adequate knowledge, reflection becomes impossible. The conclusion here is that the student's conditional knowledge was not adequate to have prevented or detected errors. This is also the reason for the many mistakes in her responses in this cluster.

(iii) Synthesis

This cluster was about understanding the student's use of concentration in a practical situation. The student was expected to transform her declarative knowledge into procedural knowledge and at the same time using her conditional knowledge to prevent potential errors. It can be concluded that the student demonstrated her possession of declarative knowledge of some of the concepts in this cluster. But this knowledge was unrelated isolated bits of knowledge. This resulted in the student being unable to apply the knowledge to construct meaning; therefore, her attempt to respond to certain questions was not successful. The student could not use her knowledge relationally, as it was not organised in a way that it was accessible.

4.4 Summary

In this chapter, data obtained during the empirical study was interpreted and explanations provided for students' responses. Although the objective of the study was not to make any comparison between the three students, there were more commonalities than differences between the quality and usage of concepts by the three students. For example, most students managed to respond viably to questions that required declarative knowledge or specification of a concept (e.g. Q.4.11, Q.4.5.1 and Q.4.9.1). Responses to questions that required procedural knowledge or instantiation and conditional knowledge or error prevention were poorly responded to (e.g. Q.4.1.2, Q.4.5.3 and Q.4.9.2).

It is apparent also that the viability of responses as interpreted from specific elements of students' texts (concepts, meanings, thoughts, language and interpretations) was influenced not only by the quality of their prior knowledge (e.g. incompleteness in Q.4.1.3); but also by the nature, such as in Q.4.1.3 (particulate nature of matter was not used to develop a mental model of ions H^+ and OH^- in solution) of the subject matter). In some of the responses, for example, the students managed to define or specify concepts unambiguously according to explicit rules (e.g. Q.4.1.1, Q.4.5.1 and Q.4.9.1) but could not instantiate them (e.g. Q.4.1.2, Q.4.5.3 and Q.4.9.2). The students' knowledge is aptly summarised by the notion (Bransford *et al.*, 1986) that "the fact that people have acquired knowledge that is relevant to a particular situation provides no guarantee that access will occur" (p. 1080). The knowledge must be well organised for accessibility.

Incompleteness was one of the prevalent features of students' knowledge. Students with this quality of knowledge are unable to access or reflect on this type of knowledge. Incomplete knowledge is inaccessible because it is not well organised; hence it is unavailable. Most of the knowledge possessed by the three students existed as isolated bits of information in their knowledge bases. With this type of knowledge it would be difficult to construct understanding and/or generate meaning to respond viable to questions or engage productively in activities, and more specifically practical work activities (in the case of this study) that require accessibility to relevant prior knowledge.

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.

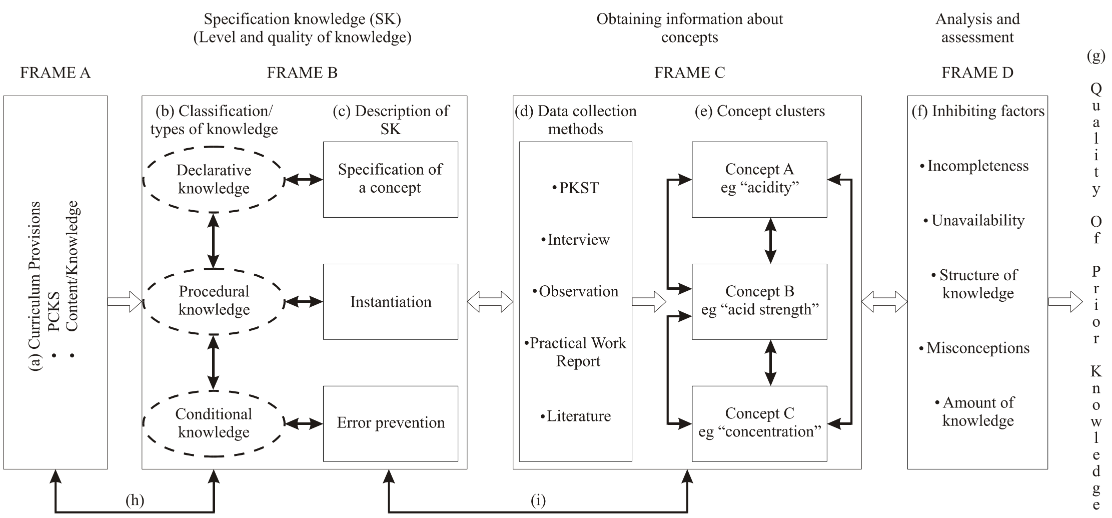

Figure 13: Framework for assessing prior knowledge and its usage.

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:

Illustration 5.1

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*** $\boldsymbol{H^+}$ *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).

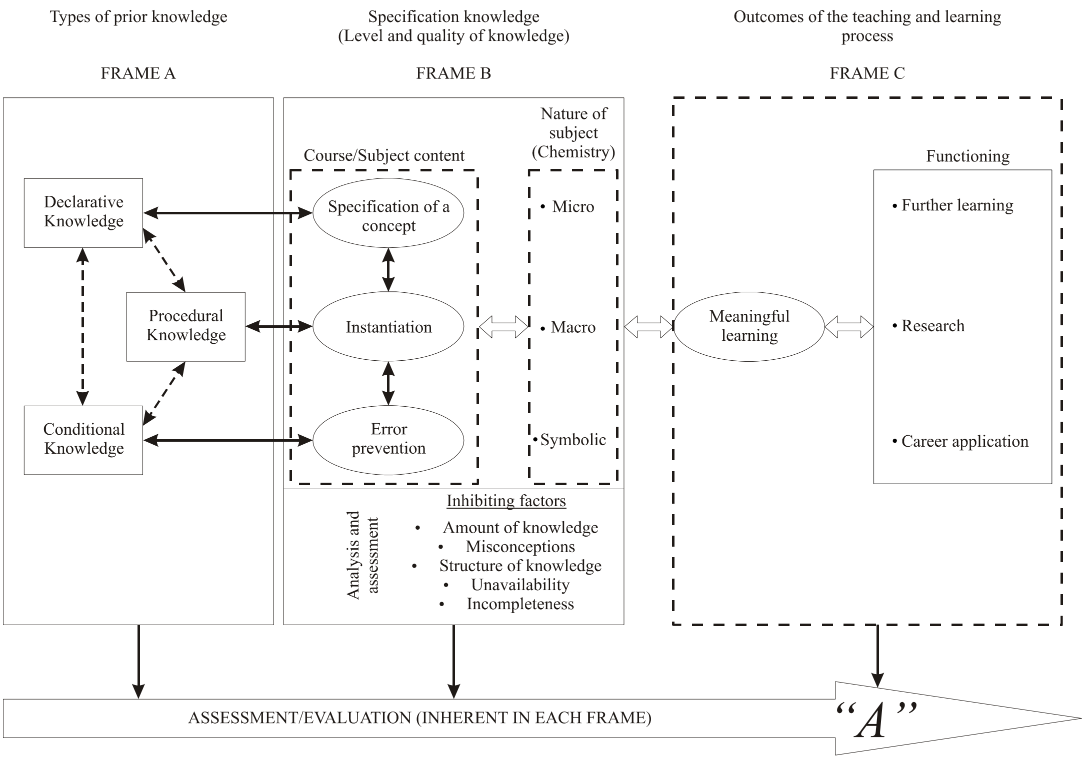

Figure 14: Prior knowledge framework for enhancing meaningful teaching and learning of chemistry concepts.

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).

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APPENDIX A

Observation and Interview Schedule

Event and/or observation	Question	Clarification (of question; expectation; intention; action; activity)	Response (by either first (S_1) or second (S_2) respondents

APPENDIX B

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Prior Knowledge State Test

Instruction: Answer all the questions and explain (or elaborate on) your answers where applicable.

1. You are told that an aqueous solution is *acidic*. What does this mean?

2 Which 0.1 M solution among HBr (aq); CO_2 (aq); LiOH (aq); CH_3OH (aq) will turn phenolphthalein pink?

3. As the hydrogen ion concentration of an aqueous solution increases, the hydroxide ion concentration of this solution will (1) increase (2) decrease (3) remain the same.

4 Calculate the pH of a solution with a hydronium ion concentration of 0.01 moles per liter.

5. Differentiate between a *dilute* solution of a weak acid and a *concentrated* solution of a *weak* acid? Illustrate your answer with a relevant example.

6. Differentiate between an Arrhenius and a Bronsted-Lowry acid.

7 Why does ammonia behave both as an Arrhenius base and as a Bronsted-Lowry base when dissolved in water?

8 In terms of Bronsted-Lowry definition of acids and bases what is a strong acid and a weak acid?

9 What is meant by *an amphoteric* substance? Use the hydrogen oxalate ion ($HC_2O_4^-$) in water for your explanation.

10 An unknown salt is NaF, NaCl, or NOCl. When 0.05 mol of salt is dissolved in water to form 0.500 dm^3 of solution, the pH of solution is 8.08. Identify the salt and explain your choice.

11 When HCl (aq) is exactly neutralized by NaOH (aq), the hydrogen ion concentration in the resulting solution is (1) always less than the concentration of the hydroxide ions (2) always greater than the concentration of the hydroxide ions (3) always equal to

the concentration of the hydroxide ions (4) sometimes greater and sometimes less than the concentration of the hydroxide ions.

12 Presume that you are titrating a weak acid and a strong base (e.g. NaOH). What would the expression "equivalence point" mean in this process?

13 A 25.0 cm^3 0.10 M CH_3COOH (aq) was titrated with 0.20 M NaOH (aq). Calculate the total volume at the equivalence point was reached?

14 Solutions which contain a weak conjugate acid-base pair can resist drastic changes in pH upon the addition of small amounts of strong acid or base. What are these solutions called and how do they resist the change in pH?

15 Calculate the molality of 49.0 mg of H_2SO_4 in 10.0ml of solution.

16 Calculate the molarity of HCl, density 1.057 g/ml, 12.0% by mass.

17 Calculate the concentration of a 150 ml of a 0.1200 M solution diluted to 200.0ml

18. A 20 ml sample of vinegar having a density of 1.055 g/ml requires 40.34 ml of 0.3024 M NaOH base for titration. Calculate the percentage of acetic acid ($HC_2H_3O_2$) in the sample.

19 Define the term *standardization.*

20. Illustrate how a 500 ml 6 M solution of an acid is diluted by a factor of 25.

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APPENDIX C

Practical work task

Practical Work Task
Aim To determine % content of ethanoic acid in a solution of commercial vinegar.
Objective ❑ To determine the % content of ethanoic acid in commercial vinegar by titrimetric methods. **Useful information** ❑ Commercial vinegar generally contains % ethanoic acid of between 4% and 6%. ❑ Density of vinegar is 1.045g/cm^3 ❑ Ethanoic acid is a weak acid. ❑ Estimate end-point at 25.00 cm^{-3} ❑ Determinations should be in duplicate. **Experimental** ❑ Work in pairs ❑ Prepare an experimental plan that outlines how you are going to : o Perform the experiment. o Analyse the data in order to extract the required information. ❑ Have your plan reviewed before you start with your practical work ❑ Analyse results (Individually) ❑ Write report (Individually). In your report include: o Title. o Aim. o The procedure or method. o Observation and/or explanation of phenomena. o Results of weighing and titrations (in tabular form and calculations). o Conclusions. **Summary of the activity** ➢ **Formulate plan.** ➢ **Discuss plan with the instructor before proceeding.** ➢ **Perform the task.** ➢ **Analyse results.** ➢ **Write report.**

APPENDIX D

Propositional statements representing knowledge of acids and bases and titration processes

PCKS 1: Early known facts about acids

1.1 Acids when dissolved in water have a sour taste (The name acid comes from the Latin word *acidus*, which means "sour").

1.2 Acids cause the dye litmus to change from a blue to a red colour. (Litmus is a naturally occurring vegetable dye obtained from linchens).

1.3 When certain metals, such as zinc and iron, are placed in acids, they dissolve with the liberation of gas.

PCKS 2: **Early known characteristics of bases**

2.1 Water solutions of bases feel slippery or soapy to the touch and have a bitter taste.

2.2 Bases cause the dye litmus to change from a red to a blue colour.

2.3 When certain greases are placed in a base solution, they dissolve.

PCKS 3: **Definitions of acids and bases**

3.1 Arrhenius definition: Acid is a substance that releases the hydrogen ions (H^+) in aqueous solution (water).

$$\textbf{e.g. } HNO_3\,(l) + H_2O \rightarrow H^+\,(aq) + NO_3^-(aq)$$

Arrhenius acids when in the pure state (not in solution) are covalent compounds, that is, they do not contain H^+ ions. These ions are formed through a chemical reaction, when the acid is mixed with water.

Base is a substance that releases hydroxide ions (OH^-) in aqueous solution (aq).

$$\textbf{e.g. } NaOH\,(s) + H_2O \rightarrow Na^+\,(aq) + OH^-(aq)$$

Arrhenius bases are usually ionic in the pure state, in direct contrast to acids. When bases dissolve in water, the ions separate to yield OH^- ions.

3.2 Bronsted- Lowry definitions:

Acid is a substance that donates a proton (H^+) to some other substance.
Base is any substance that can accept a proton from some other substance. Bronsted – Lowry acid is therefore a proton donor and a Bronsted – Lowry base is a proton acceptor.

e.g. $HCl\ (g) + H_2O\ (l) \rightarrow H_3O^+\ (aq) + Cl^-\ (aq)$

The HCl behaves like a Bronsted – Lowry acid by donating a proton to a water molecule. The hydronium ion is formed in this reaction:

$H^+ + H_2O \rightarrow H_3O^+$

The base in this reaction is water since it has accepted a proton; no hydroxide ions are involved.

4 A substance that behaves both as an acid and a base (a substance that can donate and accept a proton) is an amphoteric substance

e.g. $H_2O\ (l) + H_2O\ (l) \rightleftharpoons H_3O^+\ (aq) + OH^-\ (aq)$

PCKS 4: Strengths of acids and bases:

4.1 Acids may be classified as strong or weak depending on the number of H^+ ions (or H_3O^+ ions) they produce in aqueous solution

4.2 A strong acid dissociates 100% (completely) in solution; that is, all of the acid molecules present dissociate into ions. Because of this extensive dissociation, many hydrogen ions are present in the solution of a strong acid

4.3 A weak acid dissociates only slightly (partially) in solution; that is, most of the acid molecules are present in solution in un-dissociated form.

PCKS 5: Ionic and net ionic equations

5.1 Soluble acids and soluble bases and soluble salts all produce ions in aqueous solution

5.2 An ionic equation is an equation in which the formulas of the predominant form of each compound in aqueous solution are used; dissociated compound are written as ions, un-dissociated compounds are written in molecular form

e.g. $CH_3COOH + H_2O\ (l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+\ (aq)$

5.3 A net ionic equation is an ionic equation from which nonparticipating (spectator) species have been eliminated

e.g.$AgNO_3\ (aq) + KCl\ (aq) \rightarrow KNO_3\ (aq) + AgCl\ (s)$

Molecular equation

Three substances $AgNO_3$, KCl and AgCl are soluble salts and thus exist in solution in dissociated ionic form.

Potassium and nitrate ions appear on either side of the equation, that is, they did not undergo any chemical change. They are spectator ions.

Net ionic equation is written by canceling all spectator ions from the ionic equation:

$$\mathbf{Ag^{+}\,(aq) + Cl^{-}\,(aq) \rightarrow AgCl\,(s)}$$

Net ionic equation

PCKS 6: Reactions of acids, bases, salts and water

6.1 When acids and bases are mixed they react with each other. Their acidic and basic properties disappear when equivalent amounts have reacted to produce a neutral solution

6.2 Neutralization is the reaction between equivalent amounts of an acid and a base to form a salt and water

6.3 The hydrogen ions from the acid combine with the hydroxide ions from the base to form water

e.g. $\mathbf{HNO_3 + NaOH \rightarrow NaNO_3 + H_2O}$

Molecular equation

$$\mathbf{H^{+} + OH^{-} \rightarrow H_2O}$$

Net ionic equation

6.4 Reactions of acids with salts result in the formation of weaker acid, a new insoluble salt or a gaseous compound is formed

e.g. $\mathbf{AgNO_3\,(aq) + HCl\,(aq) \rightarrow AgCl\,(s) + HNO_3\,(aq)}$

6.5 When an acid neutralises a base an ionic compound called a salt is formed. Salt solutions can be acidic, or basic depending on the acid base properties of the constituent cations and anions

6.6 Salts that yield basic solutions: Salts such as NaF that are derived from a strong base (NaOH) and a weak acid (HF) yield basic solutions. In this case the cation is neither an acid nor a base but the anion is a weak base

e.g. $\mathbf{F^{-}(aq) + H_2O\,(l) \rightleftharpoons F\,(aq) + OH^{-}(aq)}$

PCKS 7: Dissociation of water:

7.1 In a sample of pure water a small percentage of the water molecules undergo dissociation to produce ions

7.2 The dissociation reaction of water involves the transfer of a proton from one water molecule to another H_2O^{+}

$$\mathbf{H_2O \rightleftharpoons H_3O^{+} + OH^{-}}$$ **(Bronsted-Lowry theory)**

or

$$H_2O \rightleftharpoons H^+ + OH^- \text{ (Arrhenius theory)}$$

7.3 The dissociation of water molecules is part of an equilibrium situation. Individual water molecules are continually dissociating.

7.4 At equilibrium (at 25°C), the H^+ and OH^- ion concentration 1.00 X 10^{-7} M

7.5 At any given temperature the product of the concentrations of H^+ ion and OH^- ion in water is a constant.

$$[H^+] \times [OH^-] = \text{constant} = (1.00\times10^{-7})\,(1.00\times10^{-7}) = 1.0\times10^{-14}$$

7.6 All acidic solutions have a higher $[H^+]$ than $[OH^-]$. In a similar manner, a base is a substance that increases the OH^- ion concentration in water.

7.7 All basis solutions have a higher $[OH^-]$ than $[H^+]$. In a neutral solution the concentrations of both the H^+ ions and OH^- ions are equal.

PCKS 8: The pH scale:

8.1 The term **pH** is derived from the French puissance *d'hydrogene* ("power of hydrogen") and refers to the power of 10 (the exponent) used to express the molar H_3O^+ concentration.

8.2 The pH of a solution is defined as the negative base-10 logarithm (log) of the molar hydronium ion concentration.

$$pH = -\log [H_3O^+] \text{ or } H_3O^+(-pH) = 10^{-pH}$$

thus and acidic solution having $[H_3O^+] = 10^{-2}$ M has a pH of 2, a basic solution having $[OH^-] = 10^{-2}$M has a pH of 12 and a neutral solution having $[H_3O^+] = 10^{-7}$ has a pH of 7.

PCKS 9: Acid-Base titrations:

9.1 The concentration of an acid or base in a solution and the pH of the solution are two different entities.

9.2 The pH of a solution gives information about the concentration of hydrogen ions in solution. Only dissociated molecules influence the pH value.

9.3 The concentration of an acid or base solution gives information about the total number of acid/base molecules present: both dissociated and un-dissociated molecules are counted.

9.4 The procedure most frequently used to determine the concentration of an acidic or basic solution is that of titration.

9.5 Titration is the gradual adding of one solution to another until the solute in the first solution has reacted completely with the solute in the second solution.

9.6 In order to complete a titration successfully the endpoint must be detected. Endpoint is detected with the help of an indicator.

9.7 An indicator is a compound that exhibits different colours depending on the pH of the surroundings.

9.8 Typically, an indicator is one colour in basic solutions and another colour in acidic solutions.

9.9 An indicator is selected based on the pH at which it will change colour.

PCKS 10: Acid – base calculations (expressed in molarity and/ or percent).

10.1 Concentration refers (in molarity) to the number of moles per given volume of solution

C= n/v where

n= number of moles, v= volume

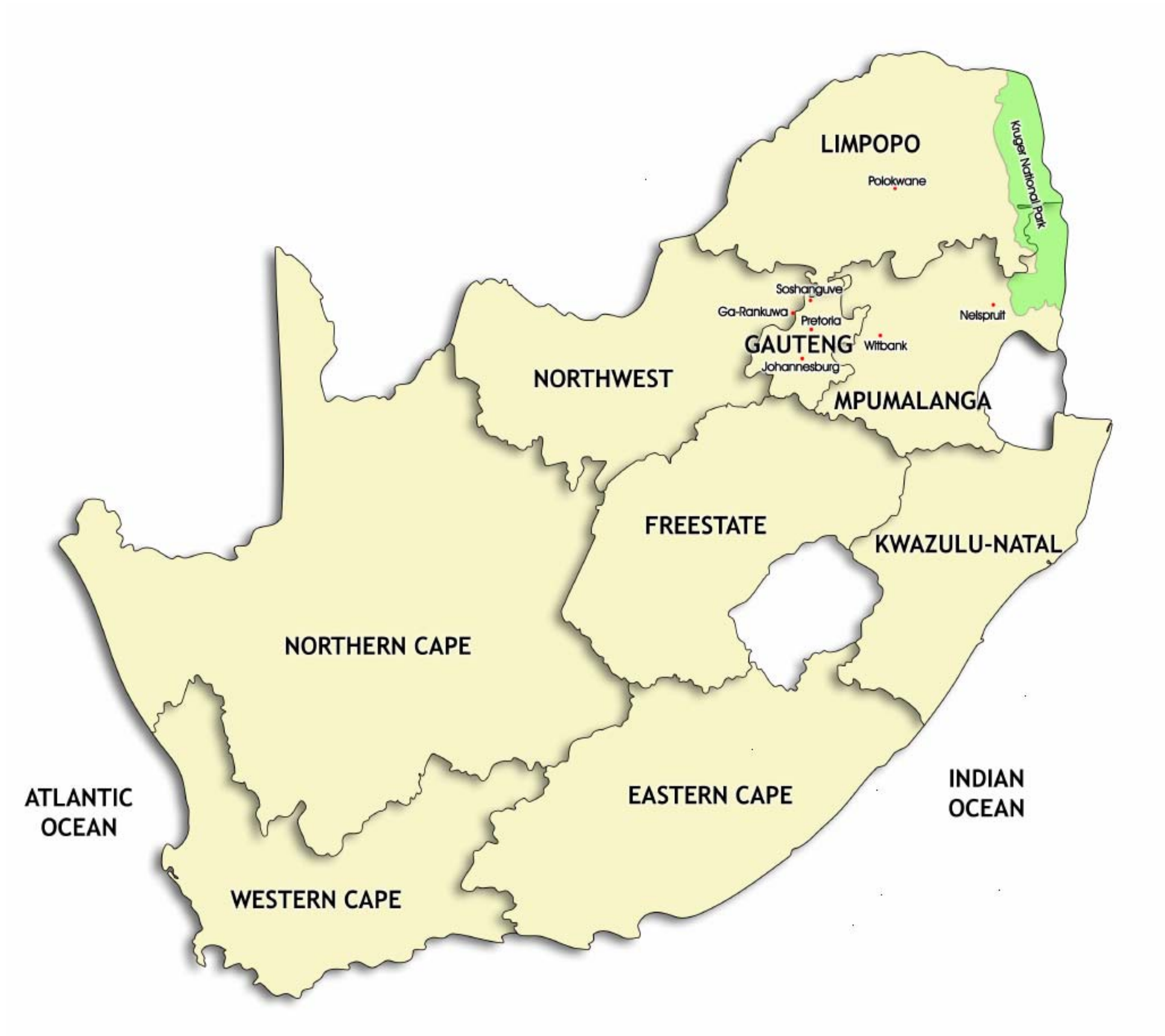
Molarity = n/dm^3

10.2 Concentration can also be expressed as % mass/mass; % mass/volume; % volume/volume.

10.3 A concentrated solution is a solution with more moles per given volume whereas a dilute solution is a solution with less number of moles per given volume.

APPENDIX E

Geographical map of South Africa



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APPENDIX F
Approval to conduct interviews

Tshwane University of Technology

Directorate of Research of Directorate

Department of Focus Area Support
Department of R&D Administrative Support
Department of Statistical Support

Ref. number: CRIC Q4/06
Enquiries: Mrs Dilla Wright
Tel. (012) 318-5154
wrightd@tut.ac.za

04 May 2006

Mr TDT Sedumedi
Department of Chemistry
Faculty of Natural Sciences
Tshwane University of Technology
Garankuwa Campus

Dear Mr Sedumedi,

APPLICATION TO CONDUCT INTERVIEWS WITH FIRST YEAR CHEMISTRY STUDENTS

We refer to your request for the approval to conduct interviews with first year chemistry students on the Garankuwa Campus to determine the effect of prior knowledge in practical work.

We are pleased to confirm that the study is approved. Kindly furnish the Directorate of Research & Development with a copy of your findings on completion of the study.

Please direct all enquiries to the undersigned.

Yours faithfully,

PDF Kok (Prof)
Acting Director of Research & Development

cc. Prof Pieter Marais, Dean: Faculty of Natural Sciences
Ms Tanya Coetzee, Faculty Research Officer
Prof Danie du Toit, Chairperson: Ethics Committee

TSedumedi evaluation feedback 040506

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APPENDIX G

Ethics clearance certificate

UNIVERSITY OF PRETORIA

FACULTY OF EDUCATION

RESEARCH ETHICS COMMITTEE

CLEARANCE CERTIFICATE	**CLEARANCE NUMBER :** CS06/10/07
DEGREE AND PROJECT	PhD Curriculum Studies A study of first year students' use of prior knowledge in the learning of chemistry
INVESTIGATOR(S)	Thomas Sedumedi - 24428389
DEPARTMENT	Curriculum Studies
DATE CONSIDERED	16 March 2007
DECISION OF THE COMMITTEE	APPROVED

This ethical clearance is valid for a period of 3 years and may be renewed upon application

CHAIRPERSON OF ETHICS COMMITTEE	Dr S Human-Vogel
DATE	19 March 2007
CC	Prof A Hattingh Jeannie Beukes

This ethical clearance certificate is issued subject to the following conditions:

1. A signed personal declaration of responsibility
2. If the research question changes significantly so as to alter the nature of the study, a new application for ethical clearance must be submitted
3. It remains the applicant's responsibility to ensure that all the necessary forms for permission and informed consent are kept for future queries.

Please quote the clearance number in all enquiries.