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.

<u>Phase 2</u>

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.

<u>Phase 3</u>

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.

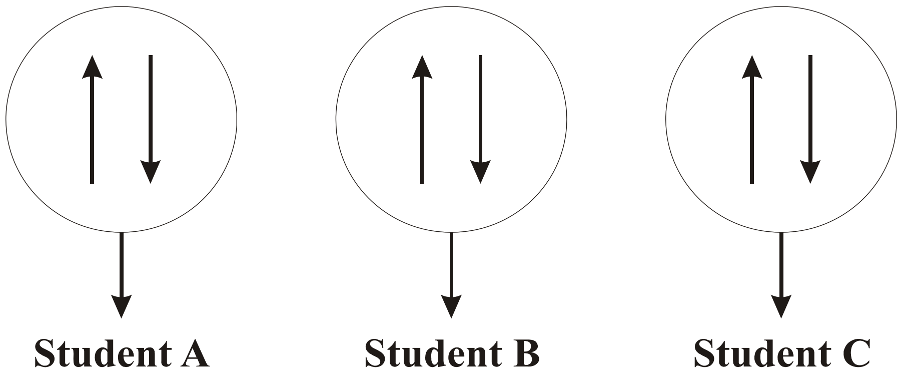

Figure 10: Selection of final sample for the study

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).

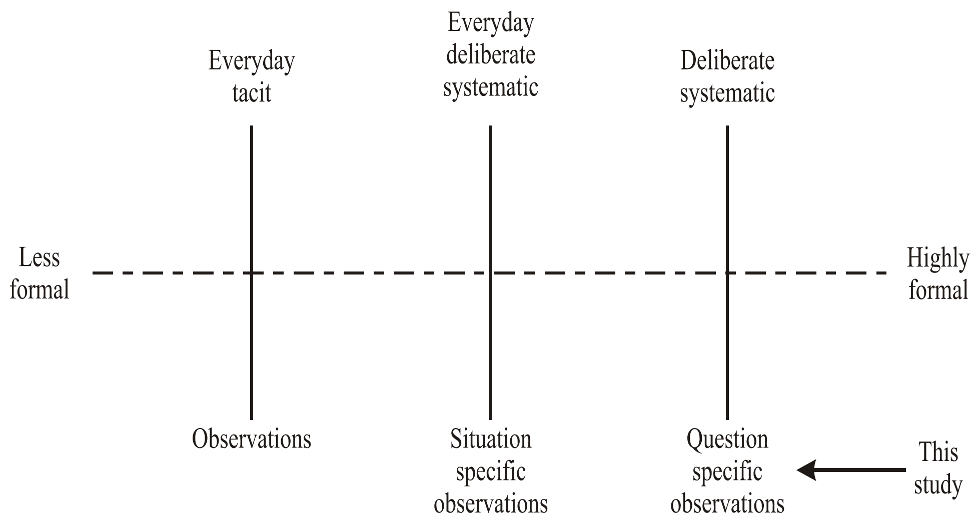

Figure 11: Continuum of observation types (Adapted from Evertson & Green, 1986).

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).

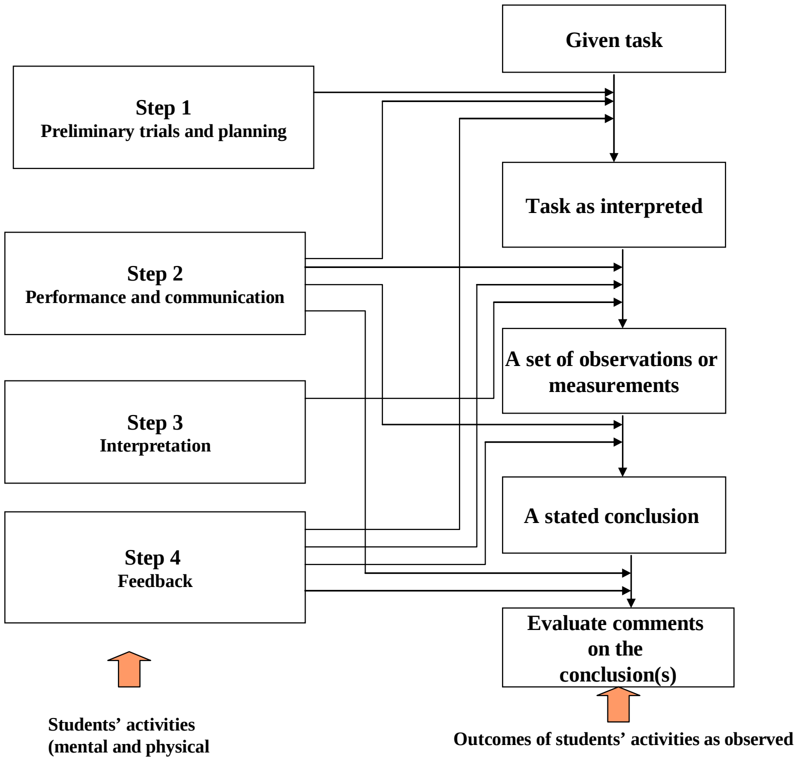

Figure 12: Data collection process (Adapted from Millar, Lubben, Gott & Duggan, 1994)

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.

[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.