An Investigation of Zimbabwe A-level Chemistry Teachers' Epistemological Beliefs, Laboratory Instructional Practices and Students' Images of the Nature of Science.

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June 2004

DECLARATION

I hereby declare that:

''An Investigation of Zimbabwe A-level Chemistry Teachers' Epistemological Beliefs, Laboratory Instructional Practices and Students' Images of the Nature of Science''

is my own work and that all sources I have used or quoted have been indicated and acknowledged by means of complete references.

Signature Vhurumuku

Elaosi Vhurumuku

June 2004

Dedication

To Tracy, Tendai and Tinashe. May God bless you all.

'While Thompson and Rutherford did the same experiment and collected more or less the same data, their atomic models were completely different'

[Hodzi, 1991]

Acknowledgements

In the course of putting this work together, there are people to whom I am naturally indebted. Without the help, support understanding and encouragement from these people, this work would not have materialized.

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May the Lord God shower all those I have mentioned with blessings.

Elaosi Vhurumuku

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Abstract

An investigation of Zimbabwe A-level chemistry teachers' epistemological beliefs, laboratory instructional practices and students' images of the nature of science.

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Key terms and concepts

Nature of science (NOS); images of science or images of the nature of science (INOS); closed inquiry; open-ended inquiry; traditional conception of science; non-traditional conception of science; laboratory work; belief; science epistemological belief (SEB); and laboratory instructional practice.

Abstract

This study set out to investigate the nature of A-level Chemistry teachers' science epistemological beliefs, the teachers' laboratory instructional practices and their students' images of science. Science epistemological beliefs (SEBs) are the views of the teachers about the nature of scientific knowledge and the processes of its development and validation. Laboratory instructional practice was looked at from the angle of the teachers' practice of inquiry. Students' images of the nature of science are the ideas which students hold about the nature of scientific knowledge and the processes of its development and validation. The subjects in the study were twelve teachers and 72 A-level Chemistry students drawn from twelve schools in three of Zimbabwe's nine schools' administrative provinces. Teachers' science epistemological beliefs were determined through a Likert-type instrument and interviews. The nature of teachers' laboratory instructional practices was ascertained through observation of laboratory classes, a teacher Laboratory Programmes Variables Inventory, a student Laboratory Programmes Variables Inventory, and teacher and student interviews. Students' images of the nature of science were obtained through, a Likert-type questionnaire, an open-ended questionnaire and interviews of selected students. Their perceptions of their laboratory experiences were obtained through a Laboratory Programmes Variables Inventory and interviews.

Teachers were found to habour both traditional and non-traditional beliefs about the nature of science. The science epistemological beliefs (SEBs) of the studied teachers were found to be very weakly related to the teachers' perceptions of the nature of inquiry in their A-level Chemistry laboratories. No link was established between holding traditional or non-traditional SEBs and practicing instruction, which is closed or open-ended inquiry respectively. The laboratory instruction was found to be of low inquiry and examination centred. Teachers' epistemological beliefs however appeared to filter into their practices. The filtration or attenuation of teachers' beliefs into their practice appeared to be under the governance of *attenuation equilibrium* between *in vitro* and *in vivo* factors. *In vitro* factors are those variables within the instructional environment or context (resources, nature of the curriculum, administrative constraints, etc.). *In vivo* factors are variables embedded in the individual's conceptual ecology. These factors include other beliefs (for example, beliefs about teaching, motivational attributes, etc).

Students were found to habour fairly traditional conceptions of the nature of science. Their perceptions of the nature of inquiry in their Chemistry laboratories was very weakly related to their images of the nature of science. Some interaction of their laboratory experiences into their images of the nature of science was apparent. Their understandings of the Chemistry laboratory work and the nature of their learning (proximal images) showed some linkage to their understanding of the nature of science as practiced by the professional scientist (distal images). Both the interaction between students laboratory experiences and images of science and between proximal and distal understandings of science appeared to be determined or governed by the state of the attenuation equilibrium between *in vitro* and *in vivo* factors.

The thesis proposes that the conceptual ecology is replete with equilibria that govern the interactions between the investigated variables. A hypothesis of *in vitro* and *in vivo* attenuation is proposed. The hypothesis is extended to ramifications of positive and negative attenuation. Recommendations are proposed for the practice and theory of Chemistry education.

Elaosi Vhurumuku, June 2004

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Putting it all together: Summary, conclusions and recommendations

Abbreviations

AAAS--- American Association for the Advancement of Science

BUSE--- Bindura University of Science Education

CLES--- Constructivist Learning Environment

DEO--- District Education Officer

GRASSMATE--- Graduate Studies in Science, Mathematics and Technology Education

IVLs --- Inductive Verificationist Learners

LABINOS—Laboratory work Based Images of the Nature of Science

LIC--- Laboratory Interactions Categories

LPVI---- Laboratory Programmes Variables Inventory

NOS---- Nature of Science

NOSS--- Nature of Science Scale

INOS--- Images of the Nature of Science

NSKS--- Nature of Scientific Knowledge Scale

POE --- Predict, Observe and Explain

SEBs --- Science Epistemological Beliefs

sLPVI--- Students' Laboratory Programmes Variables Inventory

SKQ--- Science Knowledge Questionnaire

SPI--- Science Process Inventory

SINOS--- Students' Images of the Nature of Science

SLEI--- Science Laboratory Environment Inventory

SLOS--- Science Lesson Observation System

tLPVI--- Teachers' Laboratory programmes Variables Inventory

TNOSO--- Traditional NOS Outlook

TSEBQ--- Teachers' Science Epistemological Beliefs Questionnaire

U.Z.--- University of Zimbabwe

VOSTS--- Views on Science-Technology-Society

ZIMSEC---- Zimbabwe Schools Examination Council

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CHAPTER ONE

Introduction to the Study and Study Overview

1.0 Introduction

The major concern of the study presented here was to examine the nature of the interactions between teachers' beliefs about the nature of science and their instructional practices, and students' laboratory experiences and the images of the nature of science they develop from laboratory work. First the background and justification are discussed. Second, the Zimbabwe A-level Chemistry curriculum context is briefly outlined. Thirdly the problem is stated. The significance of the study follows. Finally, the foci of each of the chapters in the thesis are highlighted.

There is a common saying, which goes: "Research is like consuming an elephant. Each researcher takes a small chunk until the whole carcass is devoured." For this thesis, the elephant turned out to be a whale. To avoid devouring too big a chunk, it was decided that the problem be broken down into smaller pieces, with each one of the pieces contributing to the illumination and elucidation of the bigger whole. The thesis presentation is thematic. Tackling of the three major questions posed in this study is done through four mini-studies. While each of the studies (four papers) can (in its own right) stand on its own, it contributes to the bigger picture. As each paper (study) is presented, the pertinent literature is discussed. Before the study recommendations and conclusions are discussed the four studies are coalesced in the final chapter. The point of focus is the nature of interactions among the explored variables.

The thesis postulates the hypothesis of *in vitro* and *in vivo* attenuation[1] as a viable tool for explaining weaknesses or strengths of relationships or interactions occurring among the investigated variables. To attenuate is to reduce in force, make thin, reduce signal, to slender or to taper gradually (Sykes, 1988). In the context of this thesis attenuation is about reducing or decreasing of the interaction between variables. The translation of say teachers' science epistemological beliefs into

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[1] Attenuation is a concept used in a variety of fields (Geochemistry, Biology, Oceanography, Ecology, Telecommunications, Medicine, etc.) to generally refer to the lessening of amount or magnitude or strength of something. In this thesis the terms *in vivo* and *in vitro* are borrowed or adapted from Biology or Medicine and coined for describing attenuation whose source is from within the individual (internal) and from the environment (external) respectively.

classroom practice can be attenuated (reduced) by factors (resources, examination demands, nature of curricula, etc.) in the environment in which the teacher operates. The author has called this *in vitro* attenuation. The tapering or attenuation of those beliefs into practice can also come under the influence of other factors (beliefs about teaching, pedagogical knowledge, motivational attributes, etc.) located within the individual's conceptual ecology. This has been coined *in vivo* attenuation. The conceptual ecology is taken to mean the whole system of beliefs, personal theories, motivational attributes, meta-cognitive and epistemic factors, etc. embedded in the individual (Hogan, 1999). Through an examination of the nature of *in vitro* attenuation, the thesis expands the attenuation hypothesis into ramifications of positive and negative attenuation. The thesis posits that the interactions between two conceptually located variables are governed by the state of equilibrium (or achievement of *attenuation equilibrium*) between *in vivo* and *in vitro* factors. It is argued that perceptions are the conduit through which teachers and students locate contextual instructional factors or instructional environment factors (availability of resources, examination focused curricula, institutional constraints, etc.) into their conceptual ecologies. Once located in the conceptual ecology they become part of a system that is replete with competing equilibria. The issue of the universality of the hypothesis is raised.

1.1 Background and Justification

The study of teachers' and students' beliefs, images, views, perceptions and understandings of the nature of science (NOS) remains an issue in contemporary science education research (Lederman, 1992; Lederman, Abd-El-Khalick, Bell, and Schwartz, 2002). The NOS refers to "the epistemology of science, science as away of knowing, or the values and beliefs inherent to the development of scientific knowledge" (Abd-El-Khalick and Lederman, 1998, p.418). Bell and Lederman (2003) are of the opinion that the NOS has received resurgent interest from researchers over the past few years. This resurgence has witnessed NOS research focusing on a variety of foci. One area of focus has been the interactions among teacher NOS beliefs, classroom practice and students' views of the NOS (Abd-El-Khalick and Lederman, 2000; Hodson, 1993). Researchers investigating relationships between or among these variables have produced contradicting findings (Gwimbi and Monk, 2002; Schraw and Olafson, 2002) with some results showing that relationships exist and others showing that they don't.

On the subject of studies of relationships between teachers' NOS understandings and instructional practices, Abd-El-Khalick and Lederman (2000) have asserted that explorations of such relationships are unproductive for classroom practice. They argue that the translation of teachers' conceptions of the NOS into classroom practice is difficult because of constraining variables (content coverage, examinations, resources, institutional constrains, etc.). They recommend that research should instead focus on ways to improve classroom practice. The standpoint taken here is that such a recommendation is only valid when teachers' NOS understandings are considered vis-à-vis their translation into teacher practices that improve students' NOS understandings. There is not enough evidence to suggest that teachers' NOS beliefs cannot influence other areas of pedagogical endeavour. Moreover, there is also the possibility that instructional practice could influence beliefs about the NOS (Gwimbi and Monk, 2003). In any case, the assertion is largely based on studies done outside Africa.

A survey of pertinent literature reveals that only a few studies (Leach, Millar, Ryder et al., 1998; Saunders, Cavallo and Abraham, 1999; Martin, 1999; Sere, Leach, Niedderer et al., 1998; Tsai, 1999) have examined students' images or views of the NOS within the specific context of the school science laboratory. This line of research endeavour nests convictions and assumptions about the purported roles of teachers' laboratory instructional practices and students' laboratory experiences in portraying and articulating images of the NOS (Hodson, 1996a; Rudolph, 2003; Sondoval and Reiser, 2004). Historically, the school laboratory has been assumed to be of critical importance in shaping students' ideas about the NOS (Hodson, 1996a; Jenkins, 1998; Nott, 1997). While belief, conviction, assumption and history have consummated an a priori linkage between students' involvement in laboratory work and their images of the NOS; not much research has been done to explore and validate such an association or to demonstrate the association a posterior.

A number of studies have been done to examine the influence of teachers' beliefs on their instructional practices (Brickhouse, 1989; Haney, Lumpe, Czerniak and Egan, 2002; Lederman and Ziedler, 1987; Lumpe, Haney and Czerniak, 2000; Nespor, 1987). Teachers' beliefs have been classified according to their sources and nature.

Chan (1999) identifies beliefs about teaching effectiveness (teacher-efficacy), beliefs about values, beliefs about teaching and learning and beliefs about the nature of knowledge and knowledge acquisition (epistemological beliefs). While research on teacher-efficacy, beliefs about values and beliefs about teaching and learning and their relationships to teachers' decision-making and instructional practice appears to be plentiful, there is little on studies of teachers' epistemological beliefs. Of interest is the fact that very little attention has been paid to the role of teachers' beliefs in the high school science laboratory (Martin, 1999) and the Chemistry laboratory in particular. Lederman (1992) and Abd-El-Khalick and Lederman (2000), review a number of studies that have examined possible relationships between teachers' beliefs about the NOS (science epistemological beliefs) and their instructional practices. These studies however have not looked at teachers' beliefs within the specific context of the school science laboratory. Furthermore, many of these studies have erroneously lumped together teachers' beliefs about science education (teaching and learning of science) with their beliefs about the nature of science into one category of epistemological beliefs.

This thesis strands out, defines and demarcates A-level Chemistry teachers' science epistemological beliefs and nomothetically and ideographically explores their nature and possible linkage to the laboratory instruction employed by the teacher. According to Leach et al. (1998) and Bezzi (1999), either a nomothetic or ideographic methodological approach can be used in probing beliefs or images of the NOS. In the nomothetic approach questionnaire items are written around a normative 'map' of the NOS. As an example, students can be asked to respond (in true or false or Likert fashion) to such statements as: "scientific observations are free from human pre-conceptions" and "scientific knowledge is based on experiment and observation only". Statements such as these can be used to position individuals on an axis labeled "Relativism/Positivism" (Leach et al., 1998). When an ideographic methodological approach is used, respondents are asked survey questions, which do not directly lean on any one philosophical position (Bezzi, 1999; Leach et al., 1998).

Based on the assumption that teachers' laboratory instructional practice could be a lens through which the teachers' beliefs about the NOS filter onto their students; the study makes another nomothetic and ideographic exploration of a possible link between teachers' type of laboratory instruction and their students' images of the NOS. Sere, Fernandez and Leach et al. (2001) have described students' labwork images of science (labwork images of the NOS) as the episodic views about the philosophical and sociological nature of science students draw upon during their participation in laboratory work. In this thesis a variation of this understanding of labwork based images of science is taken. The term *labwork based images of science* is taken to mean the epistemological views about the NOS students develop as a result of their involvement in science laboratory work and in this case Chemistry practical work. To explicate what might appear to be a subtle distinction, let it be understood that with the former meaning, students bring their understandings or beliefs about the NOS to bear upon their doing of laboratory tasks whereas in the later case beliefs or understandings about the NOS are developed from doing laboratory tasks. This distinction charters the line of research pursued in this study as a foray into relatively virgin land. While the study is focusing on Chemistry as a subject, it has a more global view of the NOS (i.e. "nature of science" as opposed to "nature of Chemistry"). In many instances Chemistry can simply be replaced by science.

The viability of the afore-mentioned explorations was tacitly inferred from the fact that some studies (Lederman and Druger, 1985; Lederman and Ziedler, 1987) although not quite conclusive, suggested links between some teacher instructional strategies and students conceptions of the NOS. A study by Saunders, Cavallo and Abraham (1999) investigated relationships among epistemological beliefs, gender, approaches to learning and implementation of Chemistry laboratory instruction. The study came to the conclusion that the type of laboratory instruction (less inquiry or more inquiry) did not influence students' science epistemological beliefs as measured by a Science Knowledge Questionnaire (SKQ). This study however did not factor out laboratory work based images of the NOS. Moreover, the study took science epistemological beliefs to be inclusive of beliefs about teaching and learning. Adding credence to the plausibility of a fruitful exploration was the finding by Gwimbi and Monk (2002) that for a sample of Zimbabwe A-level Biology teachers, there was a weak association between some features of the teachers' classroom practice and some aspects of their philosophies of science. As O'Loughlin (1989) suggested, the hypothesis that teachers' epistemological beliefs and pedagogy (teaching practice) are related is certainly "highly probable".

It was against this background that a myriad of questions emerged. What is the nature of Zimbabwe A-level Chemistry teachers' science epistemological beliefs? What is the nature of A-level Chemistry laboratory instruction in Zimbabwe's schools? Are the teachers' beliefs about the NOS related to their styles of laboratory instruction? What images of the NOS do A-level Chemistry students hold? What images of the NOS do A-level Chemistry students draw from their participation in laboratory work? Are teachers' laboratory instructional practices related to their students' images of the NOS? Is it not possible that teachers through their laboratory practices implicitly or explicitly translate their own beliefs about the NOS onto their students?

While the study sought to answer these questions, its basic design was purely exploratory, descriptive, interpretive, and correlational. No attempt was made to establish causality.

1.2 The Zimbabwe A- level Chemistry curriculum context

In order to fully understand the context in which this study was done it is important to briefly examine the Zimbabwe A-level Chemistry practical work syllabus and its implementation. Songer, Lee and McDonald (2003) describe context as referring to the physical learning environment, including the materials, support and constraints placed upon the teachers as well as such facets of the populations (teachers and students) as social and cultural backgrounds, class sizes, ages, etc.

1.2.1 Curriculum aims and objectives

The Zimbabwe A-level Chemistry syllabus in general (theory and practical work sections) does not explicitly refer to the development of students' understandings of the NOS. Development of student understandings of the NOS is a major school science education curriculum goal in many parts of the world (DeBoer, 2000; Tao, 2003). Understanding the NOS is considered to be a constitutive dimension of scientific literacy (Laugksch, 2000; Laugksch and Spargo, 1996; Songer et al., 2003). Developing students into scientifically literate citizens is at the core of many science education reform agendas throughout the world (DeBoer, 2000, 2002; Matthews, 1998a). A closer examination of the syllabus aims however, reveals that student appreciation of the NOS is only an implicit goal. One of the aims of the syllabus is to promote awareness that the study and practice of science are cooperative and cumulative activities and are subject to social, economic, technological, ethical and cultural influences and limitations (ZIMSEC, 2002). The experimental and investigative skills the syllabus seeks to test students on are listed as abilities to:

(1) plan investigations
(2) use techniques, apparatus and materials
(3) make and record observations
(4) interpret and evaluate observations and experimental results
(5) select techniques, apparatus and materials and
(6) evaluate methods and suggest possible improvements.

In a way the syllabus aims to initiate the students into the art and practice of professional science. The assumption is that by making students practice science as scientists do it, students will come to develop explicit understandings of the NOS. Development in students of the attitudes and values inherent in the practice of science is made implicit. The practical work syllabus appears to be based on the doctrine of what Hodson and Hodson (1998) have called 'enculturation'; initiating students into the beliefs, values, practices and styles of discovery of the scientific community by doing science. Sondoval and Reiser (2004) describe it as cognitive apprenticeship into the practice of science.

1.2.2 Curriculum content

The practical work syllabus content is given separately from the theory and requires students to master three areas of experimental endeavour. The three broad areas from which the practical work examination is set are:

(i) *Volumetric Analysis.* The volumetric determination of two types of titrations, acid-base titrations and redox titrations using suitable indicators. The pairs of reagents normally used for the redox titrations are given as iron (II) salts, ethane-dioic acid (and its salts) by potassium permanganate (VII) and iodine versus sodium thiosulphate.

(ii) *Qualitative Analysis.* This is done mainly for inorganic cations and anions. Organic qualitative analysis is rarely tested on mainly due to the costs involved in acquiring the reagents. Most schools offering A-level Chemistry in Zimbabwe struggle to keep their laboratories stocked with even the simplest and commonest of laboratory reagents thanks to the country's economic

problems. Students are normally examined on abilities to identify unknown ions in a given inorganic sample. One of the questions normally requires the students to design or plan an experiment to separate cations using knowledge of the solubilities of the salts of the cations. The syllabus gives a list of the ions whose chemistry students should be familiar with.

(iii) *Experiments from physical chemistry.* Questions on this section involve determination of such quantities as enthalpy changes, rates of reaction and electrode potentials.

1.2.3 Curriculum implementation

Practical work is assessed through a two and a half-hour examination that contributes 20% of the total examination mark. The syllabus clearly states that the bulk of the marks are given for observations and accuracy of results.

In almost all the schools in Zimbabwe, practical work is allocated a period of two and half-hours per week. At all the twelve schools involved in this study, the practical work syllabus was being covered separately from the theory. Teachers plan separately for laboratory instruction. As an example, at one school the theory lessons were looking at reactions of organic compounds while during the same week the practical work was on volumetric analysis. For students taking Chemistry, practical work is compulsory. Most practical sessions involve investigating a problem taken from one or all of the syllabus areas given above. In this study all the teachers (whose students were subjects in this study) in most cases source problems for investigation from past examination papers. Very rarely do the teachers use textbooks as sources of problems for their students' labwork. During practical sessions the lab-assistants or technicians are normally present. In all the schools used in the present study students normally do the experiments individually unless there is a shortage of apparatus or chemicals. In that case the students work in pairs or in groups of three. Class sizes can be as small as ten or as large as twenty-five. Both the teachers and the students put great value in adhering to syllabus requirements and ensuring adequate preparation for the examination.

1.3 The Research Problem

1.3.1 Purpose of the study

This study had a two dimensional purpose. The first dimension was to illuminate and elucidate, the nature of A-level Chemistry teachers' epistemological beliefs, the nature of teachers' laboratory work instructional practices (which is part of the laboratory environment) and the images of the NOS held by A-level Chemistry students. As used here the term images of the nature of science (INOS) is a broader term, which includes laboratory work based images of science as defined above. Secondly, the study sought to explore possible interactions among A-level Chemistry teachers' epistemological beliefs, the type of laboratory instruction employed by the teacher and students' images of the NOS. In order to achieve the purpose of this study three major research questions were formulated.

1.3.2 The Research Questions

The three questions given below broadly capture the 'myriad of questions' stated under the section on background and justification.

1. What is the nature of A-level Chemistry teachers' epistemological beliefs and their laboratory instructional practice?
2. What is the nature of A-level Chemistry students' images of science and their participation in laboratory work?
3. What is the nature of teachers' laboratory instructional practices and their students' images of science?

1.4 Significance of the study

The full picture of the nature of interactions among teachers' epistemological beliefs and their laboratory instructional practices and students' images of the nature of science is far from being understood. In its own way this study contributes to knowledge by casting a ray on that picture. Significantly, the study contributes towards the validation of the assumption that has been made about linkage between involving students in laboratory work and their understandings of the NOS (Hodson, 1996a). This assumption has been part of science education for a long time (Deboer, 1991; Jenkins, 1998). Martin (1999) suggests that an examination of teachers' and students' beliefs, attitudes and perceptions regarding laboratory work may provide new insights into the role and effectiveness of laboratory activities. This is important for both curriculum development and instruction.

The notion of labwork-based images of the nature of science is a relatively new research area. This notion is articulated and extended in this thesis. New concepts relating to laboratory work based images are introduced, opening debate about both conceptions of the NOS and methodology.

1.5 Delimitations

For both teachers' and students' views, the study limits itself to beliefs about the nature of scientific knowledge and scientific inquiry. Beliefs about science teaching and learning (science education) are only discussed with respect to labwork-based images; otherwise these are excluded from the thesis's main focus. Additionally the study realizes the extensive nature of laboratory instructional practice. Examination of instructional practice is limited to the idea of inquiry and what happens during laboratory sessions.

1.6 Thesis chapter overview

This section gives a summary of the focus of each of the chapters making this thesis.

1.6.1 Chapter one: Introducing the study and study overview

This chapter introduces the study. An overview of the whole thesis is given. Mainly, the research problem is developed and a rationale is given for the thesis presentation format. The background and justification section introduces and defines some of the key terms used in the study. The definitions are detailed in Chapter 2.

1.6.2 Chapter two: Precipitating the concepts

Chapter 2 gives a conceptual framework of the thesis as whole. The major constructs giving shape to the study are explored and operationalized. This exploration reviews literature on contemporary term usage as a basis for distilling or precipitating the operationalized construct.

1.6.3 Chapter three: Giving shape to the methodology

First a critical review of the literature related to the study methodology is reported. The rationale for the methodological choices is made apparent. A methodological framework capturing the research design is given. The instrumentation and data collection framework used in the study are described together with their justifications.

1.6.4 Chapter four: Paper one

In the first paper, the first research question is attended to. Methodologically it combines quantitative instruments, interviews and classroom observations to get insights into the nature of teachers' science epistemological beliefs and laboratory work instructional practices. The theoretical framework is in the form of related studies and a synthesis of laboratory class activities constituting inquiry. Theoretical and practical implications of the study are highlighted. The attenuation hypothesis is introduced.

1.6.5 Chapter five: Paper two

This study examines the nature of students' images of the NOS and their perceptions of laboratory work. It is both quantitative and qualitative. The literature review covers studies examining possible interactions between students' images of science and their learning of science. Methodological issues about the validity of probes used in the study are raised. Results are discussed in the light of findings from related studies. The concepts of positive and negative attenuation are introduced.

1.6.6 Chapter six: Paper three

What is the nature of the images of science students develop from their participation in laboratory work? Study number 3 of the thesis tackles this question. This study is qualitative in nature. It is argued that although students build images of science from a variety of sources (the teacher, the laboratory, reading, cinema, television and out of school experiences) students' labwork-based images of the NOS can be extracted or teased out from analyzing and interpreting students' responses to interview questions. Students' images of the NOS are analyzed within the frameworks of traditional and non-traditional conceptions of science. Additionally students' images of the NOS are classified and discussed under the concepts of proximal and distal NOS understandings. The pedagogical and methodological implications of the study are discussed. The attenuation hypothesis is posited as a viable tool for explaining the interaction between students' proximal and distal NOS images.

1.6.7 Chapter seven: Paper four

This paper examines the interaction between teachers' laboratory instructional practices and their students' images of the NOS. It looks at the data used in the previous chapters through another lens. It investigates the link between a teacher's practice of inquiry and his or her students' NOS images. Instructional practice is viewed at as a consummate of teacher actions and students' experiences. The attenuation hypothesis is again utilized to shed some light onto the students' experience and images of the NOS interaction. The concept of attenuation equilibrium introduced in the previous two chapters is extended.

1.6.8 Chapter eight: Conclusions: - putting it all together

A summary is made of the thesis. This summary mainly focuses on the nature of laboratory ecological interactions. The findings of the four studies discussed in the previous chapters are woven together. The attenuation hypothesis is extended and articulated. The dimensions of attenuation are clarified. An issue is raised about the universality of the attenuation hypothesis. Study conclusions and recommendations are put forward.

CHAPTER TWO

Precipitating the concepts

2.0 Introduction

In this chapter the key terms or concepts used in this study are explored. The exploration encapsulates a literature survey of contemporary term or concept usage in science education. Naturally, this examination of concepts culminates in the terms being operationalized. The major terms explored and operationally defined are: nature of science (NOS), images of science or images of the nature of science (INOS), belief, science epistemological beliefs (SEBs), traditional conception of science, non-traditional conception of science, laboratory work, laboratory instructional practice, closed inquiry, and open-ended inquiry.

2.1 What is the nature of science?

The development of secondary school students' images or views of the NOS has been a major curriculum goal for almost 100 years (Deboer, 2000; Hogan, 2000; Matthews, 1998a). While, historians, philosophers, sociologists, scientists and science educators appear to be in consensus about student understandings and images of the nature of science (NOS) being a noble objective for science education, there is much disagreement over the exact meaning of the phrase "nature of science" (Abd-El-Khalick and Lederman, 2000; Bezzi, 1999; Hogan, 2000; Lederman et al., 2000; Meichtry, 1993, 1998; Tao, 2003). Recognizing the difficulties associated with getting a common understanding of NOS, Lederman et al. (2000) and Tao (2003) have recommended that the phrase "the Nature of Science" be simply referred to as "Nature of Science" because there is no one "nature of science". The NOS has been described as elusive, disparate, multifaceted, complex and dynamic (Abd-El-Khalick and Lederman, 2000; Hogan, 2000; Meichtry, 1993, 1998). According to Meichtry (1993) the multi-dimensional nature of the NOS construct is due largely to the variety of disciplines from which definitions have been derived. Basically, the characterization of the NOS construct has tended to be fashioned around the idiosyncratic orientations, beliefs, shifts and tastes germane to a specific discipline. This as it may, it is still possible to explore the landscape of contemporary NOS understandings and strand out a general characterization of the construct. Eflin, Glennan and Reisch (1999) have identified areas of consensus and dissensus about the basic tenets of the NOS. Within a large map of agreement and disagreement, it is possible to sieve out a general definition of the NOS that encapsulates the major tenets of the construct.

One such a definition has been proposed by Lederman (1992) and used by some authors on the subject of NOS (Abd-El-Khalick and Lederman, 2000; Murcia and Schibeci, 1999; Tsai, 1999). According to Lederman (1992, p.331), the NOS refers to the epistemology of science, "science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge". The NOS is concerned with the epistemological values, assumptions, commitments and beliefs associated with the products of science (the scientific knowledge itself) and the processes of science (activities relating to data collection, interpretation and conclusion making) (Abd-El-Khalick et al., 1998; Lederman, 1998).

It is difficult to evaluate this understanding of the NOS without foraying into the area of metaphysics and paradigms. A paradigm is a set of beliefs, assumptions, commitments and values representing an individual's view of the world (Kuhn, 1970). Epistemology is concerned with the nature of knowledge and knowledge acquisition. Questions about the certainty of knowledge, the source of knowledge and the validity of knowledge form the core of epistemology (Rozendaal, de Brabander and Minnaert, 2001). The relationship between the knower and the known is the realm of epistemology (Coll and Taylor, 2001). It is generally believed that individuals' epistemological beliefs depend on their ontological views (Coll and Taylor, 2001; Hammer and Elby, 2001). Ontology is a branch of metaphysics, which deals with the question of the nature of reality and what there is to be known (Cohen and Manion, 1994; Leplin, 1994). According to Coll and Taylor (2001), the question of methodology is also a feature of paradigms. For science, methodological considerations deal with such questions as how science comes to know what it knows? The processes through which scientists gather data and validate knowledge are interrogated. In referring to the NOS as an epistemology, it should be realized that one is committing himself or herself to questions whose features are epistemological, ontological and methodological.

Abd-El-Khalick, Bell and Lederman (1998), refer to the NOS as the epistemological commitments underlying the activities of science. In their description of NOS they allude to the fact that the NOS is about an individual's understanding of scientific knowledge (the product of science). Scientific processes such as observation, collecting and interpreting data, planning experiments, and drawing conclusions are in themselves not the NOS (Abd-El-Khalick and Lederman, 2000; Lederman, 1999). What constitutes the NOS are the epistemic assumptions, orientations, beliefs, values and views an individual attaches to or associates with scientific knowledge, the methods of science and the scientific enterprise. The *scientific enterprise* includes the social, ethical, political, religious, philosophical etc. contexts and paradigms guiding the work of scientists. Abd-El-Khalick et al. (1998) and Lederman and Lederman (2004) are careful to distinguish the NOS from scientific processes. When an individual understands, believes or views observations as theory-laden and not free from human preconceptions, the individual displays an epistemology of the scientific process. Other "epistemologies" pertaining to the scientific process would include such views, images and beliefs as: there is more than one method of science, science is the product of human inference, human creativity and imagination and is socially and culturally embedded (which includes the social, ethical, political, religious, philosophical etc. contexts and paradigms guiding the work of scientists). In this study descriptions of how scientists develop scientific knowledge (i.e. the methods used by scientists in their inquiry) and the nature of the scientific enterprise constitute what is referred to as the nature of the *process of science* or the nature of *scientific inquiry*.

Meichtry (1993, 1998) is of the view that the term "nature of science" has been used interchangeably in literature to refer to understandings of both the nature of scientific inquiry and the nature of scientific knowledge. According to her, an understanding of the nature of scientific knowledge refers to descriptions of the *product of science*. The products of science are the laws, theories, principles, models, facts and explanations making up the body of knowledge called science (Dawson, 1991; Vhurumuku, 2001). When one describes science as tentative, replicable, probabilistic, historic, public (Showalter, 1974) or as tentative and revisionary (Cotham and Smith, 1981) or as amoral, developmental, parsimonious, testable and unified (Rubba and Anderson, 1978) he or she is describing the nature of the scientific knowledge or the product of science.

The NOS is a broader term, which includes both the nature of the products of science and the nature of the scientific enterprise and nature of scientists as well. It would appear that in the broader sense, the NOS is a paradigm as well as a construct about scientific knowledge and the process of its production and validation. The realm of the NOS is concerned with individual (psychological) and socially mediated understandings, beliefs, values, assumptions, views, images, and perceptions of the *products* and *processes* of science.

2. 2 Images of the Nature of Science

Images of science have been described as the ways in which an individual thinks about the purposes of science, the nature of the products of science and the scientific process (Driver, Ryder and Leach, 1996). Ryder and Leach (1999, p. 945) view images of science as the profile of ideas about "the purposes of science, the nature of scientific knowledge, the role of scientific investigation and the social processes of science used by individuals in specific contexts for specific purposes". Writing on the same subject, Ryder, Leach and Driver (1999) have described images of science as social representations of the nature of science. Citing Moscovici (1984) they go on to explain that representations are collections of ideas, commitments, concepts, values and views which make it possible for individuals to think about unfamiliar issues and communicate them in a community. The representations are social in that they can be shared, maintained or changed through dialogue (Ryder et al., 1999). According to Moscovici (1984) individuals develop representations through questioning their own perceptions, and through dialogue with other members of the community.

Internally and externally, individuals through perception, experience and imagination develop models of the world (Greca and Moreira, 1997). A theory of mental representations by Johnson-Laird (1983) takes images as mental models of the world. Individuals can have certain mental and perceptual pictures of a scientist, a scientist's laboratory or the nature of scientific knowledge. The individual concerned can express such pictures as views. An expression of the views or beliefs or such a picture constitutes an image of science.

Secondary school students build images of science from a variety of sources; the teacher, the laboratory, newspapers, cinema, television, the curriculum, etc. (Ryder et al., 1999). The experiences from which students can draw mental representations can be episodic in that the images can be focused on particular events and episodes (Leach, Millar, Ryder et al., 1998; Ryder et al., 1999). From their participation in laboratory work students are expected to draw upon their laboratory experiences and develop representations of the NOS (Leach et al., 1998). In another way students build perceptual and mental pictures of the nature of scientific knowledge and the nature of the scientific process from their involvement in school science practical work or laboratory work. The assumption is that the laboratory is a place where individual and socially mediated epistemologies about the NOS can be developed (Leach et al., 1998; Tsai, 1999; Saunders et al., 1999).

In the study being reported here, the epistemologies of science that students develop as a result of their participation in A-level Chemistry practical or laboratory work are referred to as *labwork-based images of the nature of science* or simply *labwork-based images of science.*

2.3 Characteristics of Beliefs

In previous sections, the term epistemology has been introduced. The term epistemology has its roots in Greek philosophy. According to Audi (1997), the Greek words "episteme" which means knowledge and the word "logos", which means explanation, give rise to the word epistemology. In simple terms epistemology is the study of the nature of knowledge and its justification. As Wickman (2004, p.326) puts it, it is about answering the questions: "What is knowledge?" and "How do we get it?" While consensus about the meaning of epistemology is not difficult to generate, the term "epistemological belief" is pregnant with problems. Problems arise more from the meaning of belief than from the meaning of epistemology. These problems are exacerbated by the introduction of debates about the meaning of knowledge. It is not the intention of this thesis to get entangled in arguments about the meaning of knowledge. Suffice to mention that to have knowledge is to habour information that can be retrieved (Talsma, 1997; Wickman, 2004). Morton (2000) describes knowledge as belief that is true, justifiable and has an additional element, requiring discovery. Hofer and Pintrich (1997) distinguish knowledge from beliefs when they assert that knowledge is of higher epistemic status than beliefs as it is justifiable and supportable whereas beliefs are psychologically held understandings, premises or propositions about the world that are thought to be true.

According to Nespor (1987), beliefs are existential presumptions or personal truths generally unaffected by persuasion, more heavily on the affective and evaluative side than knowledge and reside in episodic memory whereas knowledge is semantically stored. Moreover, while knowledge changes beliefs are often static. Hammer and Elby (2002) have referred to beliefs as a form of informal knowledge. Such knowledge is personal in the same manner as educationists refer to a person as habouring "misconceptions" as different from "expert conceptions". They go on to suggest that it is possible for a person to habour "mis-beliefs". To believe that scientific knowledge is certain is to habour a mis-belief that is different from the expert belief that, scientific knowledge is tentative.

To Pajares (1992), beliefs are a complex and interrelated system of personal knowledge, implicit theories and cognitive maps for experiencing and responding to reality. In his review of research on beliefs, Pajares (1992) writes that beliefs have been associated with

> attitudes, values, judgements, axioms, opinions, ideology, perceptions, conceptions, conceptual systems, implicit theories, practical principals, perspectives, repertories of understanding and social strategy. (pp. 309)

To this list, the terms: views, images, and personal convictions can be added. Lumpe, Haney and Czerniak (2000), have pointed out that beliefs are often defined in a variety of ways. Confusion of beliefs with knowledge, attitudes, personal convictions, or acceptance or rejection, of a proposition has also been noted by Oliver and Koballa (1999). What people feel or what they believe is their attitude. According to Audi (1997), a belief is a perception of a relationship between two objects or something and a characteristic of it. To say that: "scientists are intelligent people" is not only to perceive scientists but also to habour a belief. There is a relationship here between scientist and intelligence. When several beliefs are organized around a specific object or situation they become attitudes. Shuman and Ham (1997) describe an attitude as a person's feeling towards certain behaviour. Feelings can also be towards objects and events and can be favourable or unfavourable. Beliefs translate into attitudes through values. A value is an enduring belief about a specific way of conduct being socially or personally preferable compared to another state of affairs.

Some philosophers are of the view that beliefs are partly a product of perceptual data and partly dispositional psychological states that can exist even when unmanifested (Brewer and Lambert, 2001). This supports Hume's philosophy about beliefs depending on certain determinate causes and principles over which the human being is not a master. Audi (1998) is of the view that perceptual data is linked to and feeds directly into the belief system of an individual. Others however are of the opinion that theoretical or psychological beliefs are independent of perceptual data (Brewer and Lambert, 2001). Bandura (1986) proposes that the decisions made by people throughout their lives are determined by their beliefs. Beliefs are the best indicators of decisions. The decisions become action agendas (Pajares, 1992) that guide behaviour. It is partly as a consequence of these convictions that many researchers have looked at relationships between teachers' beliefs and their classroom decisions and practices.

It appears that the construct belief is both muss and slippery. Beliefs can be classified in a variety of ways, religious and non-religious, scientific and non-scientific, psychological and sociological, philosophical, etc. Another taxonomy of beliefs according to type (Chan, 1999) has already been given (Chapter 1). Ford (1992) identified two types of beliefs; capability and context. The individual's perceptions of his/her abilities to function effectively, for example a teachers own views of his teaching skills form what Ford calls capability beliefs. The teachers' view or perceptions of how responsive the environment (people, resources, etc.) will be in supporting effective performance of his duties form context beliefs. The two types of beliefs are said to combine to form so-called personal agency beliefs (PAB) which are evaluative beliefs involving the individual's comparing his own goals (for example, instructional objectives and decisions) with the consequences of pursuing those goals. Many other belief taxonomies are in existence (Lumpe et al., 2000).

Martin (1999) categorizes teacher beliefs into internal and external. According to Martin's Teacher Belief Model, teacher beliefs about the nature of the learner, teaching, science, and laboratory experiences combine into one category of internal beliefs. These beliefs are difficult to change. External beliefs are those constraints about time, laboratory resources, safety, classroom situations, curriculum and administrative demands, etc. that can act as "impediments" to the teachers' decision-making and laboratory instructional practice. These beliefs can be changed and will vary from one teacher to the next. Tobin, Briscoe and Holman (1990) have also used the terms constraints or beliefs to describe the instructional environment factors (time, resources, etc.), which influence teacher decision-making and instructional practice. Lederman (1992) identifies these constraints (called beliefs by Martin (1999) and Tobin et al. (1990)) as discouraging the translation of teachers' NOS understandings (science epistemological beliefs) into classroom practices.

The various types of beliefs, depending on their source and nature, form a complex interrelated system. Within an individual there is a central belief or belief system around which all other beliefs can be clustered (Chinn and Brewer, 1993; Kagan, 1992). Beliefs also have a filtering effect as part of their being interrelated. Pajares (1992) writes of beliefs as composed of sub-structures that are inter-related to each other and to more central beliefs systems. Psychologists have referred to belief sub-structures, as attitudes and values. Each belief according to Hammer and Elby (2002) is not "unitary" or a unit of cognitive structure which an individual either possesses or not, but multi-dimensional and contextual.

Operationalizing the term belief as meaning a mental acceptance of a statement, a proposition, a doctrine or things as true or existing concludes this section. The individual puts trust in acceptance of truth or reality of the proposition or statement (Audi, 1997).

2. 4 Science epistemological beliefs

Any attempt to conceptualize epistemological beliefs' must of necessity cognize the multifaceted nature of the construct. Multifaceted in that the terminology that has been associated with the construct makes conceptual characterization of the construct difficult. A consideration of the understandings of "epistemological beliefs" by researchers and writers in science education reveals some commonalties as well as quite diverse meanings and interpretations. To Saunders, Cavallo and Abraham (1999) epistemological beliefs are beliefs about the processes of knowing and the nature of knowledge in science. Other writers (Chan, 1999; Hammer, 1994) also view epistemological beliefs as being about the nature of knowledge and knowledge knowing. Cobb (1999) refers to personal epistemological development as seeking to understand what individuals believe about the certainty of knowledge, the origin of knowledge and the justification of knowledge. Some authors however separate epistemological development from epistemological beliefs (Hofer and Pintrich, 1997; Hogan, 2000). It is argued that epistemological development includes personal theories about learning, which although part of an individual's conceptual ecology are more meta-cognitive than epistemic. Meta-cognition, the knowledge about one's understanding of the subject matter and learning; is according to this view outside of the domain of epistemological beliefs.

This finds support in the delineation of epistemological beliefs done by Rozendaal, de Brabander and Minnaert (2001), who map the boundaries separating epistemological beliefs from other related but conceptually distinct constructs like beliefs about intelligence and beliefs about learning. Rozendaal et al. (2001), accept that epistemological beliefs are beliefs about knowing, and the structure of knowledge as defined by Hofer and Pintrich (1997) and Schommer (1990). The structure of knowledge is comprised of the nature of knowledge and the nature of knowing. They go on to argue that for any belief to be called epistemological it must be related to the validity of knowledge. Related to the validity of knowledge and forming the core of epistemological beliefs are the aspects certainty of knowledge, source of knowledge and justification of knowledge. Certainty is about the extent to which knowledge is believed to be absolute, tentative or evolving, that is, its validity. It relates directly to the nature of the knowledge itself; *the products of science*. The source of knowledge deals with questions about whether one believes knowledge is created by the knower or exists outside the knower and about whether knowledge is individually constructed or socially mediated? Social mediation of knowledge always raises the issue of validity and in this way the source of knowledge is related to the validity. Justification of knowledge is concerned with whether the individual accepts facts without reflection or after critical evaluation of evidence. In accepting or rejecting propositions the individual makes judgements about validity. Justification is thus related to validity. Source and justification have got to do with the nature of knowing; *the scientific process*.

Beliefs about learning (how best can I learn science?) and beliefs about teaching (how best can science be taught?) should not be confused with epistemological beliefs because they do not relate directly to the validity of knowledge. These are beliefs about science education and not science epistemological beliefs. In this thesis therefore beliefs about the teaching and learning of Chemistry are excluded from the core of science epistemological beliefs (beliefs about the NOS). Science epistemological beliefs are about the certainty of scientific knowledge and the nature of the scientific process.

When research literature on studies of teachers' and students' beliefs about the NOS is closely examined it emerges that the term usage is replete with confusion. The assumptions made about the synonymity of the terms understanding, views, perceptions, images and conceptions are surprising. How can one disentangle from this confusion in the usage of the terms? Can these terms be taken to mean the same thing depending on context? Are epistemological beliefs the same as epistemological views, conceptions or perceptions? Even before an attempt is made to give answers to these questions, the "conceptual problem" at hand deepens when one examines the instruments that have been used to measure these "constructs". A problem of demarcation to use Popper's terminology arises.

Aikenhead, Fleming and Ryan (1987), Gallagher (1991), Lederman (1992) and Pemeroy (1993) refer to beliefs about the NOS. However, they do not distinguish beliefs from knowledge about the NOS. In a paper on beliefs about the NOS, Pemeroy (1993) uses the term belief as having the same meaning with view of the NOS and understanding of the NOS. Gallagher (1991), in an article entitled, "Prospective and Practicing Secondary Science Teachers' Knowledge and Beliefs about the Philosophy of Science", uses the terms knowledge of science and understanding of the NOS as meaning the same thing. In the same paper he mentions image of science and views of science in the same vein as beliefs about science. Using Pemeroy's instrument Tsai (1999) measures what Pemeroy calls beliefs and coins it scientific epistemological views (SEV). In their study Ryder, Leach and Driver (1999) describe views about the NOS as having the same meaning as images of science. The same article refers to knowledge about the NOS as meaning the same as images of science. Meichtry (1993), writing on student views of the NOS gives the impression that views about the NOS are the same as conceptions of the NOS. The same article refers to student understandings as synonymous with views and conceptions of the NOS. Moss, Abrahams and Robb (2001) have used the term conception of the NOS in the same way. Lederman and Druger (1985) make some separation of teachers' conceptions of the NOS from students' views about science. A closer examination however, shows that what is referred to, as conception and view are but different sides of the same coin. The term perception of the NOS has also been used (Gess-Newsome and Lederman, 1995; Lederman and O'Malley, 1990) to refer to the same phenomenon, as understanding of the NOS. Beliefs and understandings have also been taken to mean the same thing in a research by Tamir and Zohar (1991). A study by Sutherland and Dennick (2002) gives the impression that perception and belief is one and the same thing. What is interesting is that while different terminology has been ascribed to the NOS by these researchers, the instruments they have used to measure each of the constructs have more or less been the same. This appears to be the case irrespective of whether the research is quantitative or qualitative or both. What then have the researchers been measuring or assessing, perceptions, beliefs or understandings, or views or images?

A literal examination of the terms that have been in use precipitates two categories of terms. The terms: image, view, perception and conception form the first category. They generally refer to mental representations, ideas of entities and phenomenon. A view of the NOS can be taken to mean the same as an image, perception or conception of the NOS. Belief falls into the same category. According to Hogan (2000), images as views of the NOS are better described as beliefs because they have an affective dimension. This supports Pajares (1992) whose assertion is that epistemic conceptions with affective characteristics are better described as beliefs. The term understanding falls into a different category of meaning. Talsma (1997), describes understanding as being able to explain concepts in one's own words, exemplify and use concepts in different contexts, make analogies, generalize laws or principles, integrate ideas and relationships between the ideas, give reasons for relationships and predict phenomena. Understanding is more than just knowing or believing. What comes out to this point is that science epistemological beliefs have been taken to mean a person's views or perceptions or images, or understandings or conceptions of the NOS.

Given the detachment of the meaning of understanding from the other four terms (view, image, conception and perception), science epistemological belief is defined as what a teacher or a student views, imagines, conceives or perceives to be the NOS. Science epistemological beliefs (SEBs) are the epistemological images, preconceptions, dispositions, views, perceptions and convictions concerning the NOS, harboured by an individual. In this thesis when describing the NOS the term "understanding" can be taken to mean the same as image, perception or conception.

2. 5 Conceptions of the nature of science: The philosophical origins

Conceptions, images, beliefs or views of the products and processes of science can be traced back to the origins of philosophy itself (Malhotra, 1994). Even before the emergence of science as a discipline (from natural philosophy) in the mid-nineteenth century (Deboer, 1991), philosophers had been debating about issues of epistemology. The Greek sophists asked questions about whether it was possible to know anything. Following the sophists, Plato and Aristotle and philosophers after them took up the debate. Plato following his teacher Socrates believed that there existed a world of unchanging and invisible ideas about which it is possible to have exact and certain knowledge. He was a rationalist. Aristotle, the founder of formal logic believed that abstract knowledge was possible but it was a posterior (obtained from experience). Knowledge could be deductively obtained from experience in accordance with the rules of logic. Saint Thomas of Aquinas suggested combination of reason and experience, logic and faith into a system of beliefs, emphasizing experience as the starting point of logic. Empiricists such as Bacon and Locke developed from the philosophy of Aristotle. During the same period from the 17th to 19th centuries' rationalists such as Descartes, Spinoza and Leibniz followed the thinking of Plato.

In 1620, Bacon (often referred to as the father of the scientific method) proposed induction as the logic of scientific discovery and deduction as the logic of argumentation (Malhotra, 1994). According to Bacon it was important that scientists observe nature without preconceptions, and use inductive logic to make generalizations from the observations. In 1637, Descartes proposed accounting for observed facts through deductive reasoning. Another philosopher Kant combined empiricism and rationalism arguing that it is impossible to make observations that are free from all preconceptions. The era of Galilee, Harvey, Newton and Boyle witnessed faith in a so-called scientific method, as a way of obtaining knowledge about nature. All nature was seen as designed in accordance with mechanical laws. The major purpose of science was seen as to develop laws and theories to predict, understand and control phenomenon. Empirical regularities, law like generalizations, principles and theories were seen as produced by a scientific method. It was seen as reasonable for other scientists to put to test proposed theories and hypotheses through objective observation and empirical replication.

Two scientific conceptions emerge, each embodying a different evaluation of the nature of scientific knowledge, the scientific process and the purpose of scientific inquiry. One is the rationalist conception, which holds truth as existing in the mind of the observer. According to this conception it is the imaginative grasp of the observer that provides the incentive for problem solving inquiry (Mathotra, 1994). The other conception based on empiricism believes that truth resides in nature and is only got through the senses. It would appear that in reality the two conceptions are contradictory but in fact they tend to complement each other. A reconciliation of the two produces the hypothetico-deductive conception, which believes scientific knowledge and inquiry are creative and sceptical.

Dawson (1991) has categorized scientific knowledge as belonging to either a realist view or an instrumentalist view. The realist view described as rational, objective, positivistic, logico-empiricist, Baconian and inductivist believes the scientific method is sacrosanct. According to this view the purpose of science is to understand nature, the motive being to quench human curiosity. Asimov (1972) has said curiosity is a characteristic of living animals. The realist ontology postulates theoretical constructs about existence of entities that cannot be seen e.g. genes, electrons, black holes (Dawson, 1991). It goes on to say that scientific knowledge is ideal knowledge because it is based entirely on observation. The instrumentalist view of science on the other hand believes the purpose of science is to satisfy human needs and wants. As Dawson (1991) puts it, scientific knowledge is tentative, intuitive, subjective and value laden and questions about truth and reality are better not asked because they cannot be answered. Observations alone cannot generate scientific knowledge. Intuition, dreams, hunches, serendipity, God given ingenuity, etc. play important roles in generating legitimate scientific knowledge. This view of science aligns itself more with the hypothetico-deductive conception.

The conceptions of science described to this point have resulted from the interrogation of scientific knowledge and inquiry, which has been done by historians of science, philosophers of science, sociologists of science and psychologists of science. Malhotra (1994) gives another dichotomy of mutually competing conceptions that provide direction to the process of scientific inquiry. He writes that science can be a product of either consensus or dissension. Ziman (1978), describes science as cumulative knowledge, about consensible items over which scientists arrive at consensus. Consensus is possible because scientists share a set of norms or standards governed by the professionalism of the scientific community. The dissensionists have argued that scientific research is much more controversy-laden than what the consensualists propose.

The controversy is captured by Kuhn (1970), who writes that the emergence of new scientific ideas is a revolutionary process during which one paradigm is replaced by another. Kuhn's doctrine asserts that competing paradigms are necessarily incommensurable. Different paradigms have different methodological frameworks (Kuhn, 1970). Feyerabend (1978) negates consensuality when he asserts that science has actually proceeded through violation of the norms and canons usually called scientific. His epistemological perspective has been described as anarchistic, dadaist and pluralistic (Geelan, 1997). There is no single scientific method rich and powerful enough to describe all the ways through which human knowledge develops. Scientific methodology is pluralistic.

Scientific thinking has evolved from logical positivism through post-positivism to scientific realism to postmodernism (Geelan, 1997). Positivism is a school of thought which started with the work of August Comte and became logical positivism as a result of the influence of the Vienna circle in the 1920's. Positivism is strict empiricism, which holds that valid knowledge is knowledge that is based on experience and sensual data only. All knowledge that is true comes from the senses. Logical positivists argue that propositions are meaningful if only they can be empirically verified. Karl Popper has argued strongly against verification. According to Popper (1972), metaphysics, ontology and Marxism are not sciences because their propositions are not falsifiable. Popper has also criticized logical positivism for its adherence to inductive inference. To avoid the confirmation of induction Karl Popper (1972) suggested that science could progress better through falsifications. In falsificationism the observable consequences of a theory are put to test. A test that confirms the consequences corroborates the theory whereas one negative observation (anomaly) falsifies the theory and proves it not to be true. Against this assertion Kuhn (1970), has argued that theories are not easily overturned by one anomaly. Scientific theories have historically been shown to be resistant to change. In any case according to Kuhn, Popper's argumentation is still inherently inductivist.

Logical positivism was replaced with logical empiricism (Geelan, 1997). The logical empiricists disagree with logical positivists on the idea that scientific concepts can be verified. To them verification is not possible, but the accumulation of confirmatory evidence is. Knowledge begins with observation, which leads to generalizations; deductive formulation of theories, collection of further evidence to confirm or disconfirm theories requiring further observation. Logical empiricism has been criticized for being essentially inductive (Popper, 1972). Furthermore, it has been argued that observations can be false, that our senses cannot be trusted, and that they are always theory laden (DeBoer, 1991).

Another school of thought has been critical relativism (Malhotra, 1994). The critical relativist recognizes the existence of many methods of science, the cultural contextuality of scientific knowledge the ambiguities of empirical verification and that there is no single reality. There are different ways of exploring and analyzing reality each with its own advantages and disadvantages. The philosophy of science has also seen the emergence of scientific realism. Scientific realism attempts to reconcile realism and relativism. Basically scientific realism (as described by Malhotra, 1994), proposes that there is an independent reality (classical realism), that the purpose of science is to understand that reality although knowledge about reality will never be certain (fallibilistic realism), and that all knowledge claims need to be critically evaluated in order to determine the validity of their correspondence with reality (critical realism).

So far these conceptions of science have emerged: rationalism, empiricism, inductivism, deductivism, logical positivism, Baconianism, logical empiricism, realism, instrumentalism, critical relativism and scientific realism. To these many more can be added. As an example some science educators would want to think of constructivism as encompassing the epistemology of science (Yore, 2001). The epistemological view of constructivism basically holds that knowledge cannot be discovered but is constructed by the knower. In this context it is relativistic and post-modernistic (radical constructivism). Matthews (1998a, 1998b) views constructivism at its core as a doctrine committed to post-positivistic, post-modernistic, anti-realist and instrumentalist conceptions of the nature of science. Ontologically, constructivism accommodates both realism and idealism. To the extend that as a science epistemological theory, constructivism is almost anarchical. Sutching (1992, p.247) attacks it as unintelligible, confused and weak in argument. He goes on to describe it as "primitive, traditional, subjectivistic empiricism with some overtones of diverse provenance like Piaget and Kuhn". Matthews (2004) points out that the key philosophical elements of constructivism are inherently the same as the "core commitments of old-style positivism" and that philosophically constructivism is a case of old wine in new bottles. The position taken in this thesis is that constructivism can be useful both as a theory of teaching and learning and as a school of thought in the philosophy of science.

The exploration of the schools of thought in the philosophy of science produces a two dimensional realization. First, existing epistemological beliefs (beliefs about the NOS) can be viewed as forming a dichotomy. On the one hand are the Baconian, positivist, logical positivistic, logico-empirical, and largely inductive conceptions that believe there is reality out there for science to understand. The other side encompasses the relativistic, instrumentalistic, constructivistic and largely hypothetico-deductive understanding, which is of the view that science, is another human enterprise in which human imagination and creativity play a role. This view has largely been influenced by the modern historians and philosophers of science (Feyerabend, Lakatos, Kuhn etc). In a similar dichotomization of beliefs about the nature of science Pemeroy (1993), has called the former understandings, the traditional view (conception) of science and the later the non-traditional view (conception) of science. According to her, categorization statements such as the ones below, would fall under the traditional view:

- Scientific knowledge is based entirely on observations.
- Scientific knowledge is ideal knowledge because it is based on observations.
- Nature strictly obeys laws.
- Scientists always follow the scientific method.

Statements falling into the non-traditional view of science include:

- Intuition plays a part in scientific discovery.
- All observations have a theoretical frame of reference.
- Legitimate scientific knowledge can come from dreams, guessing and play.
- There is no one scientific method.

The second dimension of the realization is that science epistemological beliefs can be taken as forming a continuum. The traditional and non-traditional become opposite poles of a continuum. As we traverse from pole to pole we pass through axes of reconciliation where apparently contradictory ideas are actually reconciliatory and complementary. Scientific realism would form planes on those axes.

2. 6 Contemporary conceptions of the nature of science

NOS conceptions have changed over the past forty years from equating the NOS with scientific processes to characterizing the nature of scientific knowledge (Tao, 2003) and the scientific process and enterprise. During this period, some authors defined the NOS as an understanding of the nature of scientific knowledge (Cotham and Smith, 1981; Rubba and Anderson, 1978; Showalter, 1974). Others had the view that the NOS was about describing the nature of the scientific process (Klopfer, 1969). The current conceptions describe the NOS in terms of both the nature of scientific knowledge and the nature of the scientific process, which (according to the understanding adopted in this thesis) includes the scientific enterprise.

Critiquing the Baconian, positivist-empiricist traditions, philosophers of science such as Khun, Popper, Lakatos and Feyeraband made attempts to describe science as it had historically occurred. These philosophers have influenced the development the NOS tenets of today (non-traditional conceptions) as described by Lederman (1998) and Tao (2003). The current philosophical position of what constitutes an acceptable conception of the NOS is located somewhere between avoidance of positivism and rejection of post-modernism. Historians of science and sociologists of science have also made their contributions in moulding this understanding. Also influential in shaping the contemporary (non-traditional) face of the NOS has been the theoretical models developed by such researchers as Cotham and Smith (1981), Kimball (1968), Klopfer (1969), Rubba and Anderson (1978) and Showalter (1974).

Kimball (1968) developed his model from a study of the philosophy of science. According to his model science is viewed as having the following characteristics.

1. Curiosity is the fundamental driving force in science.
2. Science is dynamic and ongoing activity.
3. Science aims at comprehensiveness and simplification.

4. There are many methods of science.
5. The methods of science are characterized by attributes that are more in the realm of values than techniques.
6. A basic characteristic of science is a faith in the susceptibility of the physical universe to human ordering and understanding.
7. Science has a unique attribute of openness.
8. Tentativeness and uncertainty mark all of science.

Showalter (1974) used the terms; tentative, public, replicable, probabilistic, humanistic, historic, unique, holistic and empirical to describe the nature of scientific knowledge. Extending the work of Showalter, Rubba and Anderson (1978), identified six factors as characterizing the nature of science namely; creativity, developmental (tentative), parsimonious (attempts to achieve simplicity of explanation not complexity), testable (empirically testable), amoral (cannot be judged as good or bad) and unified (disciplines of science contribute to an intergral form of knowledge). Cotham and Smith (1981) have also described science as "tentative" and "revisionary". By "revisionary" it is meant that present scientific knowledge can be altered depending on context.

The principal components of the NOS were defined in a report prepared by the American Association for the Advancement of Science (AAAS), Project 2061: Science For All Americans report in 1989. These components are:

- *Scientific worldview* – the world is understandable, scientific ideas are subject to change, scientific knowledge is durable, and science cannot provide answers to all questions
- *Scientific methods of inquiry* – science demands evidence, science is a blend of logic and imagination, science explains and predicts, scientists try to avoid bias, and science is not authoritarian and
- *Nature of the scientific enterprise*- science is a complex social activity, science is organized into content disciplines and conducted in various institutions, there are generally acceptable ethical principles of conduct of science, and scientists participate in public affairs both as specialists and as citizens.

This description of the NOS has the weakness of being too broad and almost captures all that is described under the concept of scientific literacy (Deboer, 2000; Laugksch, 2000; Laugksch and Spargo, 1996). It is now generally accepted that the NOS is one of the constitutive dimensions of scientific literacy (Laugksch, 2000). Over the last ten years, the AAAS report has had more influence on understandings of the NOS and scientific literacy than any other document. For example, Alters (1997) and Matthews (1998a) give descriptions of tenets of the NOS whose origins can be traced to the AAAS report. Almost all the papers written on the NOS during the last decade refer to this document with a large number of the published research articles citing the AAAS report and the goals of Project 2061 in the first paragraph. This is one of the clear cases of American hegemony on the issue of the NOS. Many contemporary science educators hold this document with such reverence as if divine perfection of NOS understanding has been achieved.

Eflin, Glennan and Reisch (1999) have identified four tenets of the NOS where science educators show consensus and two tenets were dissensus is shown. The areas of consensus about the NOS are identified as:

1. The main purpose of science is to acquire knowledge of the physical world.
2. Science is dynamic, changing, and tentative.
3. There is an underlying order in the world, which seeks, to science seeks to describe in a simple and comprehensive way.
4. There is no one method of science.

Areas of dissensus about the NOS are:

1. The generation of scientific knowledge depends on theoretical commitments and social and historical factors.
2. The truth of scientific theories is determined by features of the world which exist independently of the scientist.

Whether or not science educators can ever reach consensus on the tenets suggested by Eflin et al. is open to debate. What can be established with plain clarity for both areas of agreement and disagreement are the strands of association to the philosophies of Popper, Kuhn, Lakatos and Feyeraband and others. It is also clear that the most recent lists of NOS tenets (Tao, 2003; Lederman, 1998) are collated from the characterizations originally done in the 1960s and 1970s by Kimball, Showalter, Rubba and Anderson, etc. The AAAS report forms part of the list.

Lederman's list of tenets adds the additional dimensions of descriptions of the nature of observation and inference, scientific laws and theories. Describing the characteristics of scientific knowledge, as tentative, empirical, objective, imaginative, creative, inferential and culturally embedded, Lederman (1998) goes on to expound six factors important for the characterization of observation and inference and the functions of and relationships between scientific theories and laws. According to Lederman (1998) students of science should be:

- aware of the crucial distinction between observation and inference.
- able to distinguish law from theory.
- able to understand that although scientific knowledge is derived partially from observations of the natural world, it also involves human imagination and creativity.
- aware of the fact that scientific knowledge is subjective, and the theoretical commitments, beliefs, previous background of the scientist actually influence their work.
- aware that science is a product of human culture and scientific knowledge is culturally embedded.
- able to understand that scientific knowledge is never absolute or certain.

Tao (2003) lists NOS aspects as:

- scientific discoveries are for understanding nature, solving problems or changing peoples' lives.
- science cannot answer all questions.
- scientists work collaboratively.
- scientists carry out experiments to test ideas.
- creativity and imagination play a role in science.
- theories are created to explain and predict phenomena, they don't represent reality.
- scientific knowledge is durable and tentative.

For both lists (Lederman, 1998; Tao, 2003), the linkage of each statement to the philosophies of science or to the tenets of Kimball and others can easily be detailed. These two lists capture those aspects whose understanding by teachers and students would result in them being described as harbouring adequate or desirable or sophisticated or *non-traditional* NOS conceptions or beliefs. NOS views or beliefs dissonant with the tenets given in these two lists can be described as *traditional,* inadequate, undesirable and unsophisticated.

2.7 Laboratory work in school science

Science educators have used the *terms*, practical work, laboratory work (labwork), experiments, "hands-on" activities and practical activities interchangeably. That these terms have been used synonymously is acknowledged by some of the re-knowned scholars on the subject of school science laboratory work (Woolnough, 1991; Millar, 1991). Loosely, the terms have been used to refer to the teaching and learning of science inside or outside a laboratory during which experiments or practical exercises with science apparatus are done (Woolnough, 1991). Millar, Le Marechal and Buty (1998), recognize the problem of separating laboratory work from the other teaching and learning activities associated with science instruction. According to Millar et al. (1998) demarcation of laboratory work from other science teaching and learning activities is problematic because almost all science teaching/learning activities can be viewed as either preparation for practical work or a reflection on some practical activity. They describe labwork as encompassing those teaching and learning activities, which involve students in doing or watching someone doing a practical task, or designed to prepare students for some specific aspect(s) of such a task inside or outside a laboratory. By their own admission, this is clearly a very loose definition. Although literature on laboratory or practical work in school science is both extensive and intensive, none of that surveyed has made an effort to give precise and exact definitions of the *terms* in usage. Such a precise definition of terms is not about satisfaction of an appetite for semantics but a discursive necessity. Perhaps there has been too much of an a priori assumption that everyone will understand the other irrespective of whatever term is chosen.

The truth of the question is, do these terms mean the same? Is practical work the same thing as laboratory work and experimental work? Are science practical activities the same thing as laboratory work or experimental work? As a way of answering some of these questions there is need to define laboratory work. A definition of laboratory work is given elsewhere (Vhurumuku, 2001). That definition is extended and articulated below.

Laboratory work or labwork is about all those instructional activities done by the teacher, the teacher together with the students or by the students on their own (individually or in groups) in order to accomplish experiments or demonstrate or illustrate scientific phenomena. The activities can be done inside or outside the classroom or laboratory. Laboratory work activities are activities during which there is physical manipulation of apparatus, chemicals, living organisms, objects and materials in general. As a result of the manipulation, the apparatus, chemicals, organism, object or material must exhibit some observable phenomenon. The observer must be able to qualitatively or quantitatively record his/her observations. Essentially, observation and manipulation form the core of school science labwork. Gage (1963) recognizes the centrality of observation and manipulation in laboratory work and asserts that laboratory teaching assumes first-hand experience in observation and manipulation of the materials of science and is superior to other methods of developing understanding and appreciation.

All laboratory tasks have psychomotor and cognitive components (and it could be argued, an affective component). They involve manipulations using hands and employment of the senses: taste, touch, smell, sight and hearing. When students and/or teachers, use a pipette to transfer a measured volume of a liquid, set up distillation apparatus, control a Bunsen burner flame, record temperature with a thermometer, measure the viscosity of a liquid, observe solid crystals with a hand lens, perform a titration, carry out synthesis of organic molecules and perform many other practical procedures and techniques, and observe objects, materials and events, they employ both psychomotor and cognitive abilities. These tasks are cognitive in that the individual is engaged in the processes of estimation, assessment, and evaluation. Both manipulation and observation make demands on the individual's cognitive faculties.

In many cases school science laboratory work involves experiments. Such laboratory work can be referred to as "experimental work". All experiments involve manipulation and observation. The traditional school science experiment has an aim, a method, and is expected to produce results and a conclusion. Not all school laboratory activities however, are experiments. When students are asked to examine the leg of a grasshopper and draw its diagram or dissect a rat to examine the alimentary canal no experimental activity will be taking place. These are however typical laboratory work activities. Laboratory work therefore includes experimental and non-experimental activities. To narrow laboratory work only to experiments will be to fall into the trap of positivistic epistemology. The common denominator for all laboratory activities (experimental and non-experimental) is observation and manipulation. Activities during which there is no physical manipulation and observation fall outside the domain of school science laboratory work. In this thesis practical work is taken to mean the same thing as laboratory work.

2.8 Laboratory instructional practice

It is logical that in attempting to give meaning to the concept of "instructional practice" a description be given of the term "instruction". The term *instruction* has been used synonymously with *teaching* (Bruner, 1966). Currently, debate rages on about, whether or not the two terms mean different things and which of them is the broader and more encompassing term. This debate is generally unproductive and specifically irrelevant to the present thesis. Gagne, Briggs and Wager (1988), are of the view that instruction should be taken to mean all that is done by the instructor (and others for example, teachers, curriculum developers, headmasters, education officers, etc.) to support and facilitate students' learning. In this view, instruction encompasses the whole process of communicating information to the learners, planning and stimulating relevant learning activities and assessing and evaluating the effect of those activities (Romiszowski, 1984). Instruction can take place in the absence or presence of the individual called a teacher. Teaching has been described as what an individual called a teacher (T) does to and/or with another individual (or other individuals) called student (S) in order to facilitate the student's acquisition of knowledge or skills previously absent in the individual (Fenstermacher, 1986). Taken in this sense, the presence of the teacher becomes a pre-requisite for the occurrence of teaching. This conception of teaching accepts that teaching is part of instruction and instruction is the broader and more encompassing concept.

The concept instructional practice is in itself elusive. Careful analysis of some of the literature on science and Chemistry laboratory work instruction (Domin, 1999; Haury, 1993; Hinrichsen, Jarrett and Peixotto, 1999; Mahajan and Shankar, 2003; Shiland, 1999) reveals that *instructional practice* has been associated with the terms strategy, approach, style, method, skills and technique. These terms are also in themselves problematic. Trying to explicate each one of them might cause undesirable digression. Let them be used synonymously, bearing in mind that each one might take an idiosyncratic distinction depending on context. For a teacher, instructional practice is a summation of the models, strategies, approaches, methods, styles, skills and techniques employed by the teacher on a day-to-day basis in order to support and facilitate students' learning. Irrespective of the scientific discipline (Physics, Chemistry, Biology) instructional practice for science teaching has meant teachers' crafting of a large repertoire of teaching methods, strategies, approaches, techniques, styles, etc. into their daily practice; according to their beliefs and situations. Laboratory instructional practice has been about teacher use of such methods or approaches or styles or techniques as exposition, discovery, guided discovery, problem solving, investigative approaches, closed inquiry, open-ended inquiry, hands on activities and constructivism. The pedagogical tradition has been to contrast these teaching strategies according to openness of inquiry (closed or open-ended) or teacher centered-ness or student centered-ness of the instruction (Haury, 1993; Ravitz, Becker and Wong, 2000).

Laboratory instructional practice has also been associated with the learning environment created by the teacher (Fraser, 1998; Fraser, Giddings and McRobbie, 1995). The connection is that what the teacher does in planning and executing instruction is a determinant of the laboratory learning environment. This in turn is assumed to shape the nature and characteristics of the students' participation in laboratory work.

Given the above attributes of instructional practice, laboratory instructional practice can be defined as: What the teacher does before, during and after Chemistry laboratory work sessions in creating a learning environment and the teacher's use of the various forms of inquiry (teaching strategies) in order for students to go through those experiences that will enable them to attain the instructional objectives stipulated by the practical work curriculum or syllabus. This definition is further refined in Chapter 4.

2.9 Traditional laboratory instruction: closed inquiry

For over a century laboratory work has played a central role in science teaching and learning (Hofstein and Lunetta, 2004; Jenkins, 1998). According to Jenkins (1998), a Sir Thomas Thompson introduced the teaching of Chemistry using the laboratory at Glasgow University in 1818. Before then Chemistry experiments were used to entertain the rich at parties. By 1897 practical work had, in England, become a feature of school science instruction (Jenkins, 1998; Nott, 1997). The history of laboratory work in school science provides fascinating and entertaining reading. School science laboratory work has a tradition. In Zimbabwe Chemistry laboratory work instruction follows the British tradition, a heritage of the legacy of colonialism.

Ever since the introduction of laboratory work into the school science curriculum, a variety of instructional methods, strategies, styles and approaches have been in use in school Chemistry. As has been mentioned, the large repertoire of instructional strategies at the disposal of teachers include, exposition, discovery, guided discovery, problem solving, open-ended inquiry, closed inquiry, use of learning cycles, and constructivism. It has also been stated that the pedagogical tradition has been to contrast these strategies with the teacher centered, expository, traditional, transimissionist and verificationistic methods (Domin, 1999; Haury, 1993) that have dominated and still dominate a large number of Chemistry laboratories throughout the world. These methods have been described broadly as traditional approaches (Domin, 1999; Muth and Guzman, 2000). The major goal of laboratory instruction is student acquisition of Chemistry content knowledge. Most of the practical work is a follow up of ideas introduced in the theory lessons. Students follow a procedure provided by the teacher, the laboratory manual, handout or worksheet. The students and the teacher already know the outcome of the laboratory activity. Students record observations and data in provided spaces and answer post-laboratory questions. As Jenkins (1998) put it, much of the activity is about repetition of "cook book recipes" where over elaboration of the obvious is made manifest. Domin (1999) describes transimissionistic and traditional laboratory practices as appealing to the lowest three cognitive levels of Bloom's taxonomy; recall, comprehension and application. Traditional methods of laboratory instruction have also been called non-inquiry-oriented laboratories (Saunders et al, 1999). Expository, verificationistic and transimissionistic laboratory instruction has been accused of putting little emphasis on student thinking, giving students no room to plan investigations and interpret results (Domin, 1999), having little or nothing to do with inquiry, and portraying the often despised positivistic and empiricist image of the NOS (Hodson, 1996a; Newton et al, 1999).

2.10 Inquiry and constructivism in school Chemistry laboratory work

The laboratory instructional practices given above can be examined through a lens of the nature, form and extent of inquiry woven through the teaching and learning activities. Inquiry oriented instruction has been associated with constructivism (Hinrichsen, Jarrett and Peixotto, 1999; Shiland, 1999). Both inquiry and constructivism have traces to Dewey's philosophy (Dow, 1999; Hinrichsen et al., 1999). According to Dow (1999), inquiry has its deeper roots in the Socratic inquisitiveness of Athenian times. It can be understood as the search for truth or knowledge by questioning which Socrates and his disciples sought to do. Another view of inquiry (Hinrichsen et al, 1999; Windschilt, 2003), takes it to be synonymous with the scientific process and enterprise. According to this view, science is man's endeavour to understand the nature of nature through inquiry and discovery. Inquiry is said to start from something that is intriguing, that raises questions, something not understood, that does not fit expectations or that which the learner wants to know (Exploratorium, 1996). The process of inquiry involves using tools, collecting data, analyzing data, processing answers and explanations, prediction and communication of results as well as identifying assumptions and use of logical and critical thinking (Songer et al., 2003). Given this understanding of inquiry it is not surprising that inquiry has been a theme in science and Chemistry laboratory instruction for many decades.

The common trait of inquiry is curiosity. Wonder, interest or passion to understand an observation or solve a problem drives it. The incongruities that arise from the disequilibrium (or state of perturbation) between prior knowledge and new information (from observations, something which does not make sense, something surprising, etc.) are said to catalyze the learner's preparedness to learn (Hinrichsen et al., 1999). When the learner's state of mind is perturbed, the learner acts so as to eliminate the state of disequilibrium. The learner goes through an investigative process involving more observations, questioning, predicting, collecting data, constructing meaning, explaining, reflecting and comparison of information with other sources (Dow, 1999; Heylighen, 1997; Hinrichsen, et al., 1999). As can be seen this is constructivism or at least a form of it. It was mentioned earlier that inquiry is associated with constructivism.

The nature, form and extent of inquiry in the common laboratory instructional styles, approaches or practices are aptly captured by Shiland (1999) and Domin (1999). In one variation of inquiry called guided-inquiry or guided discovery (Domin, 1999; Hodson, 1996a) which gained prominence in the 1960's, the teacher gives students the procedure to follow, and tells them what data to collect and record. Students collect data and draw conclusions regarding the phenomena under investigation. As a result of post laboratory discussions, students are guided towards the target concept. Students go into the activity without any theoretical background from the teacher. The use of teacher directed learning cycles, during which students start from exploration of their own ideas and work with the teacher to investigate the ideas they would have explored is another form of guided inquiry (Gabel, 2000).

An alternative approach to guided inquiry or guided discovery is open-ended inquiry. This can also be referred to as open-ended discovery or unguided inquiry. This type of inquiry requires that students with very little help from the teacher (Matheis and Nakayama, 1998), formulate the problem of the investigation, link it to past knowledge or experience, formulate the aim of the investigation, predict the result, design and plan experiments, collect data (Domin, 1999) and arrive at conclusions enabling them to generate knowledge as well as acquire skills associated with the processes and methods of science. According to Domin (1999), the differences between guided and open-ended inquiry are that; in open-ended inquiry, the outcome of the investigation is unknown to both the teacher and the students, the procedure is not given by the teacher and is more student involving than guided discovery. Both approaches are however inductive in that students start from specifics and arrive at conclusions. Newton et al. (1999) are of the view that the use of the discovery method enables students to access an understanding of the NOS through experience. Calling it full inquiry/investigation, Duschl (2000), characterizes open-ended-discovery as useful in making explicit, students' understandings of the NOS.

Hodson (1996a), however is of the opinion that in whatever form, discovery teaching and learning distorts and confuses the NOS as it promotes a realist, inductivistic, empiricist and Baconian image of science.

Another common form of inquiry in laboratory instruction is problem solving. It is an instructional delivery system that aims to develop students' problem solving skills as well as develop requisite knowledge and scientific skills (Domin, 1999). Problem solving became very popular in Europe and the United States in the 1970s. In problem solving instruction, the teacher formulates the problem to be investigated and expects the students to use previously acquired knowledge, skills and experience to find a solution to the problem. Students formulate their own hypotheses, design experimental investigations, collect data, analyze the data and arrive at conclusions about the solution to the problem. The role of the teacher will be to be available to answer students' questions, probe students when necessary but at the same time showing them that the responsibility of solving the problem is theirs. There is no one method of arriving at a solution to the problem. The problem can also have several solutions. In practice however, (as with guided discovery) the outcome of the investigation is usually predetermined by the teacher (Domin, 1999). Problem solving according to Domin (1999) is different from guided-inquiry in that the procedure is student generated and the approach to inquiry is deductive rather than inductive. Additionally, guided inquiry aims to develop a knowledge base whereas problem solving has a knowledge base as a pre-requisite for success.

According to Shiland (1999), constuctivist Chemistry laboratory instruction should increase the learners' cognitive activity, identify and challenge their naïve theories or prior knowledge, involve learners in group and whole class activities and allow learners to apply and demonstrate acquired knowledge and skills. The constructivist strategies suggested by Shiland (1999) are in many ways similar to those given by Gabel (2000); writing on the use of problem solving in Chemistry instruction. Gabel (2000) describes problem-based instruction during which students work collaboratively to investigate a problem. Newton et al. (1999) and Duschl and Osborne (2002), view the collaboration and argumentation that goes together with group activities as essential for developing in students, constructivist images of the NOS.

To conclude this sub-section, laboratory instructional practices can be dichotomized into traditional/ non-constructivist/ less inquiry oriented and non-traditional/constructivist/ open-inquiry oriented. Transimissionistic, expository, verificationistic, demonstrative and guided inquiry laboratory instructional strategies can be grouped together as belonging to the first category. This category is classified in this thesis broadly as closed-inquiry. Open-ended discovery, problem solving and constructivist approaches as described by Shiland (1999) belong to the second category. This category constitutes open-ended-inquiry. In the literature dichotomization of instructional practices (Hinrichsen et al., 1999; Ravitz et al., 2000; Yore, 2001) has been made. Practically, teacher instructional practices exist along the surfaces of a continuum whose poles are expository methods and open-ended constructivist inquiry, which is termed here "constiquiry". Constiquiry is naturally derived from a combination of inquiry and constructivism. On this continuum, where positions are determined by the extent of openness of inquiry; guided discovery and problem solving occupy more or less the same niche. The figure below shows the nature and form of this continuum.

Figure 2.1: The continuum of teacher instructional practices

CHAPTER THREE

Shaping the research methodology

3.1 Introduction

The research design, the instrumentation, the data collection procedures, and the data analysis and interpretation were fashioned from literature on contemporary studies on the nature of science (NOS) and laboratory work. Although the leading international journals in science education appear to be encouraging (through publishing more qualitative than quantitative studies), a methodological shift towards qualitative studies, the age-old faith in the quantitative paradigm lingers on with rejuvenated hope and confidence. Many of the recent studies in the fields of the NOS and laboratory work studies have been combining quantitative and qualitative methods. Following this line, the present study combined quantitative and qualitative data collection procedures.

The use of more than one method to collect data for the same study has been referred to as triangulation or multi-methodology (Cohen, Manion and Morrison, 2000; Hitchcock and Hughes, 1995). Tobin and Fraser (1998) have called it ''bricolage'' after what a cobbler does in weaving patterns or things together. If it is allowed this author would prefer to call it *hybridization*; as the picture emerging from the methodological combination has a characteristic identity although reminiscent of the features of its parentage. One major advantage of hybridization or multi-methodology is that it can greatly improve descriptive validity; the accuracy and authenticity of what in fact the research set out to unravel (Hitchcock and Hughes, 1995). As the methodology in this study is guided by the literature, a review of the literature on the methodology and instrumentation that has been used in studies of teachers and students' NOS views and understandings, and laboratory instructional practices is discussed in the first two sections. The following sub-sections describe the research design, the data collection procedures, the sample, and the data analysis framework. Because of the format of presentation adopted for this thesis (thematic rather than monographic), the description of methodology given here details the rationale for the strategies used and the justification for the instrumentation. A reflective overview of the relevant features of validity and reliability for quantitative and qualitative studies is given. In the subsequent chapters, as each research paper (theme) is presented, the details of the instrumentation and data collection procedures given in this chapter are again described and put into perspective. This repetition is done purposely.

3.2 A review of the methodological approaches and instruments used to study teachers and students' NOS conceptions

3.2.1 Quantitative approaches

Reviews of literature done on studies of teachers and students' views or conceptions of the NOS (Lederman, 1992; Abd-El-Khalick and Lederman, 2000; Lederman, Abd-El-Khalick, Bell and Schcwartz, 2000), show that most of the quantitative studies have adopted the methodology and instruments developed in the 1960's and 1970's by such people as Kimball, Aikenhead and Ryan, and Rubba and Anderson. Some of these instruments include; the Science Process Inventory (SPI) (Welch, 1967), Nature of Science Scale (NOSS) (Kimball, 1968), and the Nature of Scientific Knowledge Scale (NSKS) (Rubba, 1977). Many of the studies reported in the literature up to the mid 1990's have used these instruments or their adaptations or variations. Examples of such studies include Lederman and Druger (1985), and Boujaoude (1996). The instruments have one feature in common. They are all objectively scored items. In objectively scored tests, each question has only one right answer.

Rubba (1977) developed an instrument to measure pre-college students' understanding of scientific knowledge, the NSKS. The instrument yielded a total score as well as sub-scores for understandings about the amoral, creative, developmental, parsimonious, testable and unified nature of scientific knowledge. This instrument has had its validity and reliability ascertained and has been used by many researchers all over the world (Meichtry, 1998). The instrument developed by Kimball (1968), the NOSS, is of Likert-type and requires students to respond to statements about the NOS in three ways agree, neutral, and disagree. The assertions to which students had to respond were developed from literature on the nature and philosophy of science.

Other objectively scored instruments have been developed (Aldridge, Chen and Taylor, 1997; Pemeroy, 1993) to quantitatively determine the NOS. The instrument developed by Pemeroy (1993) to measure beliefs about the NOS is of Likert-type. The instrument is based on the NOSS developed by Kimball (1968). A version of Pemeroy's instrument has been used to elicit students' scientific epistemological views (Tsai, 1998; 1999). Tsai used scores obtained on questionnaire items to classify students as holding empiricist (low scores) or constructivist beliefs (high scores) about the NOS. The original version by Pemeroy classified respondents as holding "traditional" (low scores) or "non-traditional" (high scores) beliefs. Descriptions of traditional and non-traditional views of the NOS were given in Chapter 2. Another instrument to identify teachers and students' beliefs about the NOS has been developed by Aldridge, Chen and Taylor (1997). On this instrument respondents indicate their opinions about NOS statements by choosing from almost never, seldom, sometimes, often, and almost always. This instrument is scored along the same lines as the NSKS by Rubba (1977) and can yield a total score as well as two sub-scores on the nature of scientific inquiry and the nature of scientific knowledge.

A convergent instrument (scoring is objectively done; based on one correct answer) which is slightly different from those described to this point is the Views on Science–Technology–Society (VOSTS) whose earliest version first appeared in the 1970s but was fully developed by Aikenhead, Fleming and Ryan (1987) and Aikenhead and Ryan (1992). It is an inventory of multiple-choice items, which requires the respondent not only to indicate his or her view but also to give reasons for the viewpoint or to justify the position by choosing from a list of alternatives. The VOSTS has been used in a number of researches (Aikenhead and Ryan, 1992; Botton and Brown, 1999; Fleming 1987; Haidar and Balfakih, 1999).

The use of these convergent types of instruments to assess beliefs or conceptions of NOS has come under a barrage of criticism (Bezzi, 1999; Chan, 1999; Haidar and Balfakih, 1999; Lederman, 1992; Lederman et al., 2000). This criticism has partly been responsible for the increasing popularity of qualitative methodology in NOS studies. As Rennie (1998) has pointed out, quantitative results have not been of much educational value because statistical figures cannot easily answer questions requiring qualitative answers. As an example a test might yield a result showing that say 56 % of the students had misconceptions on the issue of how scientists settle disputes but will do little to inform educators about the thinking of students on the issue, which is more helpful to teachers in organizing instruction to address the misconceptions. It has also been pointed out that the researcher who develops the questionnaire or multiple- choice item has a different background to the respondents (teachers or students). According to Chan (1999) this produces the likelihood of respondents interpreting items in ways different from the intentions of the researcher. The instruments might not actually be measuring what they purport to measure (lack validity). Lederman et al. (2000) point out that these convergent instruments label respondents' views as adequate or inadequate without clarifying the basis on which such labeling is based. Since the instrument items are constructed with certain philosophical positions in mind, respondents end up being ascribed to views which are not theirs but artifacts of the instrument. Moreover, limiting respondents to pre-defined categories does not give them a chance to elaborate on their views providing researchers with little understanding of respondents' views (Chan, 1999; Lederman et al., 2000). This limits the usefulness of convergent instruments in assessing gains in NOS conceptions that might arise as a result of instructional intervention. Additionally, the NOS is complex and its understanding is influenced by many factors (society, religion, media, teachers, curricula, folk stories, etc). The use of quantitative methods and instruments is seen as being unable to unravel how these factors could influence the views of the respondents (Lederman, 1992).

Although there has been this criticism, quantitative instruments continue to be used. They have the advantages of studying large numbers of subjects and easy data analysis. Moreover well-made quantitative instruments have the added advantage of being more reliable than most qualitative procedures. Zealots of qualitative research perhaps need to be soberly reminded that no one method is methodologically correct no matter how clearly it is presented in a handbook (Wallace and Louden, 1997).

3.2.2 Qualitative approaches

Some researchers (Abd-El-Khalick, Bell and Lederman, 1997; Bezzi, 1999; Fleming, 1987; Lederman and O'Malley, 1990; Saunders et al, 1999; Song and Kim, 1999) have used the approach of eliciting NOS beliefs by asking teachers and/or students to give written responses to open-ended questions. Open-ended questions give the respondent significant latitude, to express his or her views. It is generally believed that qualitative approaches can achieve greater validity than quantitative methodologies (Cohen et al., 2000). They have the disadvantage that the analysis of responses can be both time-consuming and difficult. Another disadvantage of qualitative methodology is that reliability tends to be poor as it is determined by too many variables, for example, the nature and experience of the researcher. In designing open-ended questions, Bennet and Ritchie (1975) and Cohen and Manion (1994) have warned of the dangers of leading questions, ambiguous questions, bad wording and grammatical complexity on the validity of responses. Failure to take care of these aspects can result in respondents providing mis-leading answers or answers they really don't want to give or should not give. Kvale (1996) however has argued strongly for use of leading questions, reasoning that they are effective in eliciting the information required by the researcher, something similar to police interrogation. The merits and demerits of such an approach can be debated up to the end of time.

In recent times the use of interviews has gained popularity (Bezzi, 1999; Hogan, 2000). According to Lederman et al. (2000), interviews serve as a better choice to assess students' understandings of the NOS as they give students a better chance to elaborate on their views, giving the researcher a deeper interpretation of the response. Moreover the researcher can follow up student responses during the interview, something paper and pencil tests cannot do. Interviews can be structured, unstructured or semi-structured. A major disadvantage of interviews is that they are time consuming (data collection and analysis) especially when large numbers of respondents are involved. For this reason many researchers have tended to avoid them.

When the interview is structured, the same predetermined questions are asked across the subjects, in exactly the same sequence and in the same wording with little room for variation (Morse, 1994). In unstructured interviewing, there are no predetermined questions. The questions can vary according to the interviewee and situational differences (Patton, 1980). The interview atmosphere is much more informal and depends to a large extent on the skills of the researcher compared to the structured interview. Semi-structured interviewing is somewhere in between structured and unstructured. The interviewer starts with a set of core questions to guide the interview process but there is room for probing in order to get clarifications or get a deeper understanding from the respondent. Not much emphasis is given to strict adherence to the sequence of questioning. It is important to emphasize that in whichever way interviewing is done the interviews are planned and not the kind of chat about anything. An interview guide with the topics to be covered is usually used.

Lederman et al. (2000) have developed a Views of the Nature of Science Questionnaire (VONS) based on the VOSTS items of Aikenhead, Fleming and Ryan (1992) which combines respondents giving answers to written open-ended questions and follow-up interviews to elicit NOS conceptions. A combination of open-ended paper and pencil tests and interviews has also been used to elicit students' images of science in a laboratory setting (Sere et al., 2001). The combination of various data collection techniques is currently in fashion for NOS studies. Tao (2003) has recommended a combination of traditional Likert-type instruments with interviews. This study is aligned with this trend.

3.3 A review of methodological approaches and instruments in determining labwork instructional practices

The approaches that have been used to determine what happens in classrooms during learning (the learning environment) are reviewed by Fraser (1998) and Tobin and Fraser (1998). Murray (1938) introduced the terms alpha press and beta press to describe approaches to assessment of what happened in the classroom. In alpha press, the classroom environment is described as assessed by a detached observer (e.g. a researcher). With beta press, the classroom environment is described as assessed by milieu inhabitants (the students and the teachers). Classroom environments can also be studied using case study, naturalistic, ethnographic and interpretive approaches. Commenting on the advantages of the beta press approach, Fraser (1998), has written:

> Defining the classroom or school environment in terms of the shared perceptions of the students and the teachers has the dual advantage of characterizing the setting through the eyes of the participants themselves and capturing data which the observer could miss or consider unimportant. Students are at a good vintage point to make judgments about classrooms because they have encountered many different learning environments and have enough time in class to form accurate impressions.[…] teachers usually project a consistent image of the long-standing attributes of the classroom environment. (pp. 528)

This gives the impression that more valid information about the nature of classroom instructional practices can be obtained from eliciting information from teachers and students (through interviews, and questionnaires) than from classroom observations. Students' and teachers' perceptions of the classroom environment are assumed to be reliable indicators of the nature of instructional practice. However, Tobin and Fraser (1998) have rightly pointed out that any one method of educational research provides only one possible window into the classroom environment. The use of multiple methods has been recommended (Lawrenz et al., 2003; Tobin and Fraser, 1998; Wallace and Louden, 1997).

3.3.1 Use of students' and teachers' perceptions

During the last quarter of the twentieth century, a number of instruments to assess and determine secondary school classroom learning environments were developed (Fraser, 1998). Basically the instruments determine the nature of the classroom environment through eliciting teachers' and/or students' perceptions of the environment. Among the instruments are the *Constructivist Learning Environment Survey* (CLES) (Taylor, Fraser and Fisher, 1997), the *Science Laboratory Environment Inventory* (SLEI) (Fraser Giddings and McRobbie, 1995; Fraser, McRobbie and Giddings, 1993) and the *Laboratory Programs Variables Inventory* (LPVI) (Abraham, 1982). The CLES assesses students' perceptions of the constructivist nature of their classroom-learning environment. The instrument has since been used in studies assessing the science classroom-learning environment (Tsai, 1998, 2000; Aldridge et al., 1997). The SLEI elicits students' perceptions of the nature of the environment in science laboratory classes. The *actual form* of the inventory assesses students' perceptions of the laboratory environment as they actually experience it and the *preferred form* determines what students would like their laboratory-learning environment to be (what they would like to experience). The SLEI assesses students perceptions of what they actually experience or would prefer to experience according to the extent to which students are supportive and helpful to one another (student cohesiveness), laboratories emphasize open-ended and divergent approach to experimentation (open-endedness), laboratory activities are integrated with non-laboratory or theory classes (integration), laboratory behaviour is guided by formal rules (rule clarity) and the extent to which laboratory equipment and materials are adequate (material environment) (Fraser, 1998; Fraser, Giddings and McRobbie, 1995). The SLEI has been used to assess the learning environments in school

Chemistry laboratories (Riah and Fraser, 1998; Tsai, 1999; Wong and Fraser, 1996, 1997).

Although both the CLES and the SLEI can be used to describe science-learning environments, they do little to capture students' perceptions of the nature and extent of laboratory inquiry. For assessing and determining the nature and extent of inquiry during laboratory instruction, the LPVI developed by Abraham (1982), specifically for the Chemistry laboratory is a more useful tool. It can be used to place students' perceptions of laboratory work practices along a continuum ranging from verificationistic, expository, transimissionistic and non-inquiry to open-ended inquiry. In its original form, the instrument asks students to rank a set of 25 statements referring to the activities they and their teacher do during laboratory or practical work. The activities are ranked according to how often they occur. Students' rankings are then used to determine the non-inquiry or "open-inquiryness" of laboratory instruction. This is the instrument used in the current study.

3.3.2 Classroom and laboratory observations

A variety of laboratory class observation instruments (Lawrenz, Huffman and Robey, 2003; Newton, Driver and Osborne, 1999; Ogunniyi, 1983) have been developed to characterize the nature of teaching and learning during laboratory work. Ogunniyi (1983) used a modified version of Flander's (1970) Laboratory Interactions Categories (LIC) instrument to obtain detailed qualitative and quantitative descriptions of the teacher-student interactions in Nigerian school science laboratories. Newton, et al. (1999) developed an instrument called, Science Lesson Observation System (SLOS) that captures how teachers organize their laboratory classes, the nature of pupil activities and the kind of teacher-pupil interactions occurring during the lesson. Scharmann et al. (2003), have used an observation schedule which is a checklist documenting the most common form of instruction that occurs during five minute intervals of a lesson. The schedule is designed to capture instances of lecture, lecture with demonstration, hands-on activities, small group discussions, administrative activities, teacher-pupil interactions and various other activities occurring during laboratory instruction. Similar laboratory observations schedules have also been used in the European Commission funded, Labwork in Science Education Project (Tiberghien et al., 2002). A common feature of these schedules is their dependence on inter-rater reliability. All of them also have the common feature of looking at the nature of classroom interactions. They however do very little to specifically capture the nature of inquiry.

Many other techniques of capturing what occurs in the classroom are in use. Some researchers have made use of video recording of laboratory classes (Gwimbi and Monk, 2002, 2003; King, Shumow and Lietz, 2001; Zody, Portes and Dan Ochs, 2003). Cohen et al. (2000), have described the use of observation schedules as structured observation. In structured observation the observer looks for specific instances, events, behaviours, etc. as guided by predetermined criteria (for example, using a checklist). The researcher or researchers can also record what happens in the classroom, by simply manually taking notes (Gall, Borg and Gall, 1996; Riley, 1990). The advantage of manual note taking is that the researcher can concentrate on observing the lesson proceedings instead of spending more time ticking spaces on a checklist, as is the case with many of the classroom observation instruments.

When lesson observation is unstructured the observer simply captures the lesson as it is without necessarily following a checklist (Cohen et al., 2000). The nature of the instruction comes out from the data analysis. There is no guideline as such. Nevertheless lesson observations are normally based on a predetermined and predefined theoretical focus. Lesson observations can also be semi-structured when the observer operates within the parameters of a loose guideline but is free to note other events outside the specifics of an instrument or schedule.

3.4 The research design

A methodological framework is a distinctive summary of the approach to the research in such a way that the research purpose, the data collection procedures, the data analysis and the relationships between data can be understood (Gubba and Lincoln, 1994). Diagram 3.1 below summarizes the methodological framework used in this study. As the diagram shows data was collected from three areas namely; teacher epistemologies, laboratory instruction and students' images of the nature of science. The interest was not only to find out about the nature of each of these areas but also to unravel the interactions among the areas.

This study has the characteristics of a survey, in that it sought to describe teachers' NOS beliefs and instructional practices and students' images of the NOS at a particular point in time. According to Gall, Borg and Gall (1996), surveys can be quantitative or qualitative depending on the research design and the instruments and techniques used in data collection.

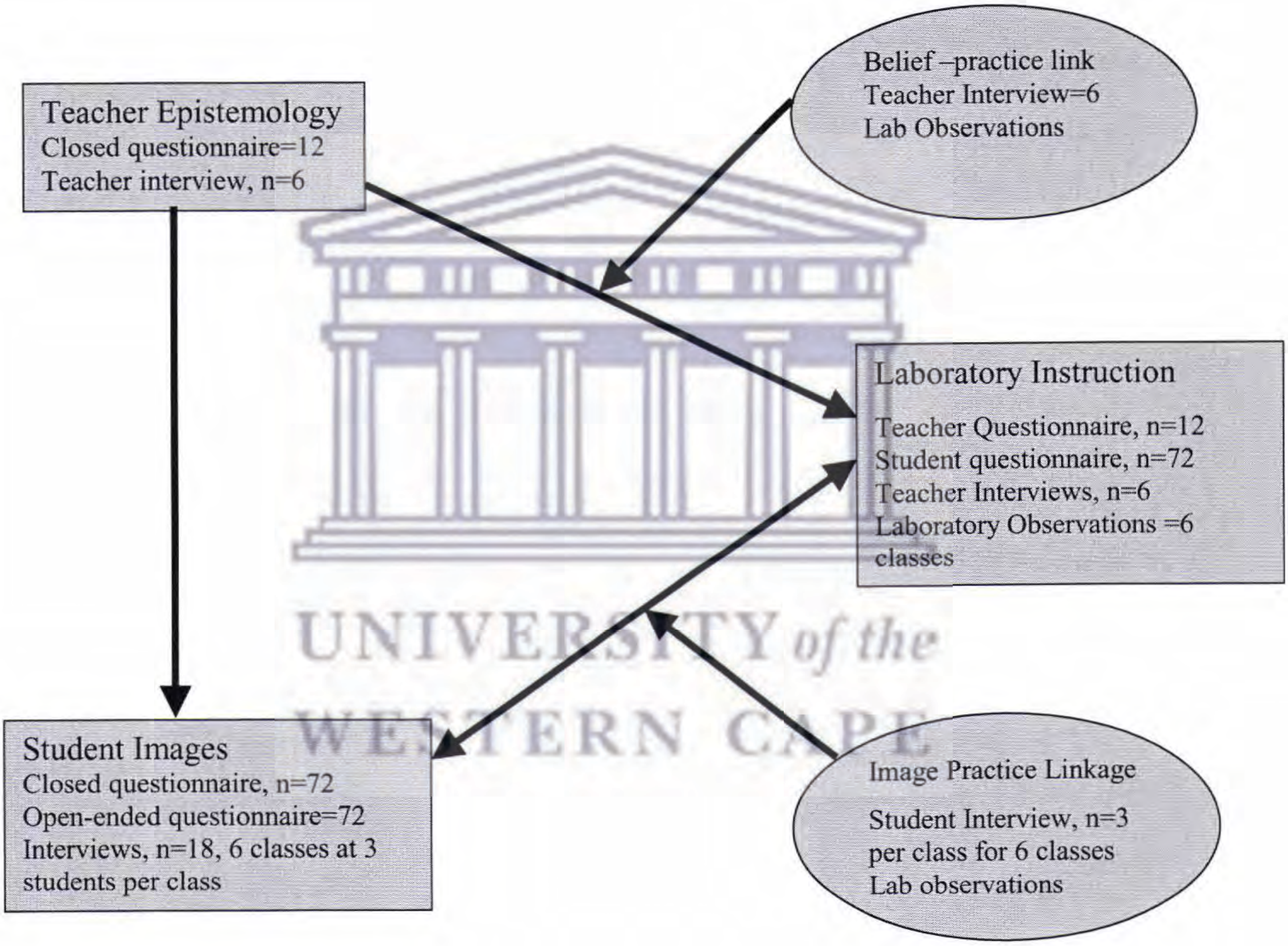

Figure 3.1 A summary of the methodological framework.

N.B. n = number of students or teachers

This study also had at least two features of an exploration. First the nomothetic and ideographic probe made of teachers' and students' NOS views was inherently exploratory since the real nature of the beliefs was unknown at the beginning of the investigation. Secondly the search for interactions among the variables or aspects of the variables (teacher beliefs, instructional practice and students' images) was also an explorative process. The study is also correlational in its treatment of the relationship between teachers' beliefs of the NOS and their perceptions of instruction; and students' images of the NOS and their perceptions of instruction.

Students' images of the NOS were obtained by means of a closed Likert-type questionnaire, an open-ended questionnaire and semi-structured interviews. The student closed questionnaire entitled, Student Images of the Nature of Science (SINOS) (Appendix A) was adapted from a combination of the instruments by Pemeroy (1993) and Aldridge, Chen and Taylor (1997). The contents of items on this questionnaire were similar to that of the teacher questionnaire, but the syntax was different. Item statements were taken as they are from the original instruments (Pemeroy and Aldridge et al.) for the teacher questionnaire but modified slightly for the student questionnaire. It was considered necessary to suit the wording of the student questionnaire to the A-level Chemistry laboratory setting. Questions for the open-ended questionnaire (Appendix E) and the interviews were solicited and synthesized from literature (Hogan, 2000; Leach et al, 1998; Ryder et al., 1998; Saunders et al., 1999). For the semi-structured interviews, teachers and students were asked basically the same core questions about their beliefs or images of the NOS.

The open-ended and interview questions sought to elicit teachers' and/or students' views on the issues: the purpose of experiments in science, the role of the laboratory in generating scientific knowledge, the nature of scientific observations, the nature of experimental data, how scientists developed and validated scientific knowledge, the static or dynamic nature of scientific knowledge and the nature of laboratory instruction and learning.

Teachers' science epistemological beliefs were elicited and described through a combination of a questionnaire and semi-structured interviews. The teacher questionnaire used is a quantitative, Likert type, Teachers' Science Epistemological Beliefs Questionnaire (TSEBQ) (Appendix B) adapted from the instruments of Pemeroy (1993, p. 274) and Aldridge, Chen and Taylor (1997).

To get insight into the nature of teacher laboratory instructional practice a combination of alpha and beta press was used. To determine the nature of inquiry in the A-level Chemistry laboratories, sampled students were asked to complete a Laboratory Programs Variables Inventory (sLPVI) (Appendix C) adapted from the instrument of Abraham (1982, p.157). Class teachers for the sampled students also completed the same inventory as their students with the syntax of the teacher inventory (Appendix D) changed to reflect teachers' description of their practice. Teachers' laboratory classes were observed (by the researcher) to corroborate data from the inventories. The teachers were also asked questions about their laboratory practices.

3.5 Research instruments: development, validity and reliability

In this section the instruments and techniques used to collect data in this study are described. As each instrument is described attention will be given to questions of validity and reliability. These are questions, which any serious research cannot afford to ignore. An overview of validity and reliability for both quantitative and qualitative approaches is appropriate.

3.5.1 Validity and reliability

In quantitative research **validity** refers to the ability of an instrument or test to measure what it is set out to measure (Gall et al., 1996). If an instrument is designed to measure students' NOS understanding, does it actually measure understanding and not opinions or beliefs? According to Moskal and Leydens (2000), validity is about gathering evidence that can support the correctness and appropriateness of interpretations and inferences that can be made from the responses to an assessment instrument.

For the instruments used in this study, the evidence of relevant concern relates mainly to three types of validity, *face validity*, *content validity* and *construct validity*. The relevance of instrument items to what they are to be used for measuring on the "face of it" is referred to as the *face validity* (Gall et al., 1996). It is about the "superficial looks" of the instrument or test. *Face validity* can be established simply by asking other individuals in the researcher's field of study or even those who are going to complete the test (population of interest) about the relevance of the items to the construct the researcher intends to measure. Closely related to *face validity* is *content validity*. *Content validity* refers to the extent to which the items of the instrument cover the subject representing the concept or construct, which is to be measured (Amy, 1999; Gall et al., 1996). In the case of determining beliefs or views of the NOS, *content validity* addresses the question of whether the instrument's items actually capture (are relevant to) the constitutive tenets of the NOS. That capture should also be cognized in terms of the statistical balance and representation of the product and process dimensions of the NOS. According to Gall et al. (1996), the assessment of *content validity* is essentially a matter of judgement. Gall et al. (1996) are of the opinion that judgements about content validity can be done by experts or experienced researchers in the subject or construct under consideration.

Construct validity, refers to the extent to which the instrument measures an abstract concept or a theoretical concept or trait or construct. A construct is an abstract idea, an unobservable, presupposed or underlying trait that a researcher or some other individual invokes to describe an attribute, observable or measurable behaviour or phenomenon (Gall et al., 1996). It is important to point out that measures of *construct validity* refer to the concept as it has been operationalized. Science epistemological belief and image of science are theoretical constructs, which cannot be measured directly. In reality what constitutes *construct validity* is the correlation between the conceptual construct and an observable behaviour or a manifestation such as a student's response to the Kimball or Pemeroy instrument. Here correlation is assumed between for example getting a high score on Pemeroy's instrument and harbouring non-traditional beliefs of the NOS. The existence of the construct is established by inference. Judgements about the appropriateness of inferences drawn from test scores regarding individual standings on the construct or variable constitute *construct validity* (Gall et al., 1996; Munby, 1997). Although science educators have had faith in the use of a panel of judges to ascertain *construct validity*, Munby (1997) has strongly argued for the need to invest in additional approaches to ascertain *construct validity*. He recommends convergence validity (agreement with other measures of the same construct) and *discriminant* or *divergence validity*. *Discriminate validity* being disagreement (lack of correlation) between scores obtained by a test measuring the construct and scores obtained by another test measuring a construct not related to the one under consideration.

Another approach to demonstrate construct related validity is to show that the items within a measure are inter-related (measure the same attribute) by calculating a so-called inter-item correlation coefficient (Amy, 1999). Factor analysis is often used to demonstrate relationships among items. Suffice to mention that validity can only be estimated and is not determined with outmost precision. As will be apparent, so-called inter-item correlation (validity) is actually a form of reliability.

Cohen et al. (2000) are of the view that for *qualitative research validity* is about matching the data to: the meanings given to data by subjects, the explanations and interpretations given to the data by the researcher (s) and the inferences drawn from the data by the researcher (s). For qualitative research validity addresses such issues as whether or not the findings are trustworthy, credible, plausible, fair and honest. The depth, richness and scope of data presentation are important elements of validity. When the data presented can actually explain the particular events or issues the researcher is presenting, the research is said to have *internal validity*. The extent to which the data can be used to make generalizations, translated for making meaning in other situations or settings and used for making comparisons with similar findings or situations constitutes *external validity*. Absolute validity is never possible. Researchers seek to minimize invalidity and maximize validity. Triangulation and peer examination of data are some of the ways through which researchers can improve the validity in qualitative research. Validity can also be demonstrated by giving extensive quotations from field notes or interview transcripts. The current study invested in these ways to improve and demonstrate validity.

Reliability refers to how consistently repeated measures with an instrument can give the same result, under constant conditions (Gall et al., 1996; Moskal and Leydens, 2000). What this means is that an individual's score on the test or instrument should be the same irrespective of who scores the test, when the test is taken or when the test is scored (Moskal and Leydens, 2000). If the individual does not get the same score in the same test under similar conditions, then the instrument is unreliable or inconsistent. There are various ways or forms of establishing the reliability of a test. One form is the *test-retest reliability* in which the same test is administered to the same group of respondents at two different times and a correlation between the two scores obtained by the group is an estimate of test-retest reliability. Care should however be taken to ensure that the time interval between the first administration and the second is not too short (at least three or more weeks is appropriate), lest the respondents' memory becomes an intervening variable.

Other reliability procedures are designed to find out whether the items in the test measure the same thing (Ary, Jacobs and Razavieh, 1996). These are so-called internal consistency measures. One such a procedure is the *split-half reliability*. The split-half reliability is computed by dividing the items on the instrument into two halves randomly (or by making an odd even choice) and computing the correlation between the scores of each half as if there are two tests. The Spearman-Brown formula is normally used to calculate the reliability coefficient. For assessing the inter-item consistency or homogeneity (items measure one trait or attribute) of Likert-type instruments such as the ones used in this study, the Cronbach alpha is widely used. Suffice to mention that the Cronbach alpha coefficient can also be used to compute inter-item homogeneity for items that are scored as right or wrong, yielding the same result with Kuder-Richardson K-R 20 and K-R 21 procedures, which are based on the proportion of correct and incorrect responses to each of the items on a test. The formula for Cronbach alpha is basically similar to the Kuder-Richardson formulae except that with Cronbach alpha the concept of sum of variances of item scores replaces the sum of the proportions of wrong and correct answers. High inter-item coefficients (e.g. Cronbach alpha) are said to be indicators of construct validity (Amy, 1999). They help in describing the extent to which the same trait or attribute is being measured. This is not to say validity and reliability is the same thing. A test can be reliable without being valid. When a test is valid it is most likely to be reliable.

Nowadays, there are a variety of computer packages for determining reliabilities of test items. Such packages as SPSS (Statistical Program for Social Sciences) and EXCEL save the researcher the cumbersome task of manually calculating inter-item reliabilities from first principles using formulae like the K-R 20. The computer performs the calculation once there is a data input and specified parameters for the desired analysis. It is only important for the researcher to input data correctly and know the appropriate statistic to use. In this study the EXCEL 2000 programme was used to perform the correlational calculations. For computing Cronbach alphas the SPSS programme (Version 11.0) was used.

According to Bogdan and Bilken (1992) for *qualitative research reliability* is the fit between what actually happens in settings, events or the actual nature of phenomena and what is recorded as data by the researcher (s). Questions have been raised about whether or not reliability is an issue for qualitative research (Cohen et al., 2000). That aside, Cohen et al. (2000) argue that it is necessary for qualitative researchers to give detailed accurate and honest descriptions of events, settings, etc., so as to raise the level of other peoples' confidence in the data. To put it simply, researchers must present their data in such a way that it is easy to convince others that their account of events or phenomena is reliable. Although different people see things differently. Ratcliff (1995) is of the opinion that reliability in qualitative research can be improved by different people examining the same thing and coming to some form of inter-rater agreement for example, two people listening to an audiotape and making transcriptions of the tape and coming to some agreement about the captured data. In this instance then reliability has the features of qualitative validity described above. The accounts of the two people could show low reliabilities but still produce high validity. Qualitative researchers should invest more in validity than in reliability.

3.5.2 Student Images of the Nature of Science Instrument (SINOS)

This instrument (Appendix A) comprises a questionnaire in two parts. For both parts students indicated their responses by ticking in appropriate boxes. The first part (PART A) asked for information about three demographic variables, gender, the subjects the student was doing at A-level and the type of school (Boarding or Day School). Exploration of linkage of students' conceptions of the NOS to similar demographic variables is reported in some studies of students' NOS conceptions (Lederman, 1992; Tsai, 1999) and was seen as appropriate in this study. Part B of the questionnaire solicited students' views on selected aspects of the NOS. The questionnaire specifically asked students to reflect on their Chemistry laboratory work experiences in answering this part of the questionnaire. Students were asked to indicate their views on a five point Likert scale ranging from strongly agree to strongly disagree (Pemeroy, 1993).

As has been mentioned, items for the SINOS questionnaire were drawn from the instruments of Pemeroy (1993) and Aldridge et al. (1997). Selection of items from an instrument for studying students' science epistemological views has been done successfully by Tsai (1999), who selected seventeen items from the Pemeroy instrument in his study of eighth grade Taiwanese students. For the current study, thirty-one (31) items were selected from both Pemeroy's and Aldridge et al's instruments. Items pertaining to the nature of learning were deliberately excluded from the selection because, as has been argued, beliefs about the nature of learning are not epistemological beliefs. The items were chosen to represent both the product and process dimensions of the NOS. Minor changes were made to the wording of the items to suit the Chemistry laboratory context. For example the word "science" was replaced with "chemistry" and scientist with "chemists". For purposes of illustration, the statement: "scientific knowledge is absolutely true because it is based on observations" (from Pemeroy, 1993, p. 274) became; ''chemistry knowledge is absolutely true because it is based on observations''.

It was mentioned earlier that Pemeroy's instrument categorizes items into traditional and non-traditional. Examples of items falling into each category have been given (Chapter 2). The instrument by Aldridge et al. (1997), categorizes items into two groups of process of scientific inquiry (for example, scientific/chemistry knowledge starts from observation of nature) and certainty of scientific knowledge (for example, currently accepted chemistry/scientific knowledge will be changed in the future). Within the context of the dimensions of the NOS defined in this thesis, the certainty of scientific knowledge category falls under the dimension of the product of science and the process of scientific inquiry under the dimension process of science. As can be seen from the examples of statements, categorization of items for both instruments can be done in either way, i.e. traditional /non-traditional or process of inquiry/ certainty of knowledge (product of science). In the version of the instrument used in the current study, this categorization was not shown on the instrument itself, as is the case with the instrument of Aldridge et al. The statements were presented as mixed and the separation into categories only done at the stage of analysis.

Scoring was done as follows: *strongly agree* = 1, *agree* = 2, *not decided* = 3, *disagree* = 4 and *strongly disagree* = 5 (Tsai, 1999). Items representing the non-traditional conception of science were scored in reverse. These items are: 2, 3, 4, 6, 8, 9, 16, 17, 22, 24, 25, 28, 29, and 31 (Appendix A). A low total (minimum score = 31) score meant agreement with traditional views of science and a high total score (maximum score = 155) meant views that were more non-traditional or constructivist. Tsai (1999, 2002) has used this scoring technique. The scoring also meant the same thing when sub-scales of the nature of scientific knowledge and the nature of the scientific process were considered. Items representing the nature of scientific knowledge are: 1, 7, 9, 10, 13, 15, 21, 22, 23 and 28. Here the maximum score is 50 and the minimum is 10. The remainder of the items represents the nature of scientific inquiry (which includes nature of scientific enterprise and scientists according to the definition already given). For this sub-scale the maximum score is 105 and the minimum is 21. A high score on each of the sub-scales meant the student's images were more non-traditional. The results reported in the current study do not include assessment of NOS conceptions on products and processes dimensions. Computation of scores is only done along the lines of traditional and non-traditional.

For the A-level students who formed the population of the study English is a second language after either Shona or Ndebele, the two major indigenous languages in Zimbabwe. It was thought necessary to check on students' understandings of the meanings of some of the English words used in the questionnaire.

A version of the instrument was administered to ten Lower Sixth Chemistry at a High School (the school was not part of the sample for the study), in Bindura, where the researcher was based. After completing the instrument the students were asked as a group and individually about whether or not they had difficulties with understanding the meanings of any of the words in the questionnaire. When none of the students indicated lack of understanding, the researcher went on to ask the students individually (in the absence of the other students and also ensuring that the students did not mix to share answers) to explain the meanings of some words chosen from the questionnaire. The words, intuition, myth, and inference were chosen because the researcher thought they could cause problems for the respondents. All the students gave satisfactory meanings of the words, although some of them did so in vernacular. The researcher's fear about the language level of the items was allayed. As the researcher later found out, a course in General Paper (mainly use of English) which is compulsory for all A-level students does a lot to improve the English Language proficiency of the students.

The ten students were also asked to comment on what they thought the instrument was designed to measure. It came out that the students understood that the questionnaire sought to elicit their views on what science is, based on what they did during Chemistry laboratory work. On the same issue their class teacher concurred. The instrument was taken to have *face validity*. Without making any changes to the instrument, three colleagues, one of them an experienced science education researcher were asked to make judgements about the content and construct validity of the questionnaire items. It was generally agreed that the instrument had content and construct validity.

The internal consistency of the items chosen for this study was determined using the Cronbach alpha. This was done with the 72 questionnaires administered to the students. Determination of alpha was done after reverse scoring. A Cronbach alpha of 0.59 was obtained. This appears to be a very low value but is actually consistent with determinations of alpha made by Pemeroy and Aldridge et al. In her study Pemeroy (1993) reported internal consistencies (Cronbach alpha) of 0.59 and 0.69 for the traditional and non-traditional items respectively. For an early version of their questionnaire, Aldridge et al. (1997) determined Cronbach alpha reliability coefficients ranging from 0.51 to 0.71 (for the part on epistemological beliefs). It could be argued that the alpha values quoted for Pemeroy and Aldridge et al. were from results of studies with teachers. But, Tsai (1999) reports more or less the same range of alpha values (0.59, 0.65) with Taiwanese grade eight students. Although the alpha value obtained here is consistent with determinations by Pemeroy and Aldridge et al., it is low enough to point towards relatively high homogeneity of the sampled students in terms of the trait under consideration. Reliability is said to be lowered by greater homogeneity of the sampled group (Ary et al., 1996).

3.5.3 Teacher Science Epistemological Beliefs Questionnaire (TSEBQ)

The teachers' questionnaire (Appendix B) was in two parts. Part A required the teachers to provide information on demographic variables. Information was sought about the gender, academic and professional qualifications, teaching experience, and teacher exposure to the History and Philosophy of Science. The literature on studies of teachers' beliefs about the NOS (Adb-El-Khalick and Lederman, 2000) shows that many studies have explored the possibility of these variables being related to teachers' NOS views. Information on these variables was therefore sought with such an exploration in mind. Part B of the instrument required teachers to respond to thirty (30) items about the NOS, on a five point Likert scale; ranging from strongly agree to strongly disagree. For both parts of the questionnaire, teachers were asked to indicate their responses by ticking in the spaces provided.

The thirty items were selected from the instruments of Pemeroy (1993) and Aldridge et al. (1997). Items were selected so as to capture both the nature of scientific knowledge and the nature of the scientific process. The set of items was also mixed with some representing the traditional view of science and others the non-traditional view. For example, item 16 read: scientific knowledge is tentative. This item represents the nature of scientific knowledge but it is also written in a way that represents a non-traditional view of science. Unlike the student instrument, item statements were taken as they are and no changes (except one item) were made to the wording. The only change made was the addition of the word African (to suit the African context) to item 14 which now read with the added word in square brackets: There is a significant amount of scientific knowledge in [African] traditional folklore and medicine.

In scoring, each item response was allocated 1, 2, 3, 4 or 5 points for each of the response categories *strongly disagree, disagree, not decided, agree* and *strongly agree* respectively. Items representing the non-traditional view were scored in the reverse. These items are: 2, 3, 4, 6, 8, 9, 14, 16, 17, 19, 20, 21, 22, 24, 26, 27, and 28. A total high score (maximum = 150) therefore meant beliefs which were more towards non-traditional and a low score (minimum = 30) traditional beliefs (Tsai, 1999). As with the student questionnaire sub-scores were also obtained for the nature of scientific knowledge and the nature of scientific inquiry sub-scales. Items representing the nature of scientific knowledge are: 1, 6, 7, 10, 11, 13, 14, 17, 21, 24, and 26. For this sub-scale the maximum was 50 and the minimum 10. The remaining 20 items belong to the nature of scientific inquiry sub-scale (maximum = 100 and minimum = 20). The results reported in this study do not include assessment of teachers' beliefs along the product and processes dimensions. Only the traditional/non-traditional dimension is pursued.

The content and construct validity of the questionnaire items was corroborated (both Pemeroy and Aldrigde et al., ascertained the items validity) by the same a group of science educators who considered the student questionnaire. For the version of the instrument used in this study a split-half reliability coefficient (using Spearman-Brown Formula) of 0.69 was obtained. This compares favourably with the Cronbach alpha values quoted by Pemeroy (1993) (0.51 to 0.71) and Tsai (2002) (0.69). There is need for further development of both Pemeroy and Aldridge et al.'s instruments to raise the reliability coefficients.

3.5.4 Student Laboratory Programs Variables Inventory (sLPVI).

The instrument of Abraham (1982, p.157) (Appendix C) was adapted for use in this study. To determine the nature of inquiry in students' laboratory classes, Abraham (1982) asked Chemistry students to rank a group of 25 statements describing the educational setting in their laboratory. Examples of the statements are:

1. Students follow the step-by-step instructions in the laboratory guide.
10. The instructor or laboratory guide identifies the problem to be investigated.
21. Students identify the problem to be investigated.

The rankings given to the statements by a class are used to categorize the type of laboratory they experience into verificationist, guided inquiry or open-ended inquiry. As an example students exposed to more open–ended laboratory work would be expected to rank statement 21 (see Appendix C) very highly and those in low inquiry laboratories to rank statement 10 very highly. There are various ways in which the rankings could be computed (Abraham, 1982). One way is to use the rank of each statement. Stepwise discriminant analysis of the rankings can be done. Another way is to convert the individual rankings into scores and use the scores to determine the nature of the laboratory setting. This is the approach used in this study.

In adapting Abraham's instrument for the study some slight changes were made to the instrument and method of scoring. First syntactical changes were made to the statements to suit the A-level classroom situation. For example statement 10 was changed to read: Our teacher identifies the problem to be investigated. In this instance teacher replaces the word instructor. Some other examples of statements on the instrument are as follows (with the statement number in square brackets), ''Our teacher allows us to go beyond regular laboratory exercises and do experiments on our own" [7], "Students identify problems to be investigated" [21], "Students follow the step by step instructions of the laboratory guide or handout given by the teacher" [1] and "Students generally know the outcome of an experiment before doing the experiment" [24]. Second, students were asked to indicate how often a given activity occurred in their laboratory classes by responding to each of the 25 statements on a bipolar Likert- scale ranging from; (1) almost never, (2) seldom, (3) sometimes, (4) often, to (5) almost always.

In scoring each item response is allocated 1, 2, 3, 4 or 5 from *almost never* to *almost always* respectively. Scoring is done in reverse for those statements representing non-inquiry or closed inquiry laboratory. Examples of such items are, 1and 24 above. A high score (maximum = 125) is taken to mean that the nature of instruction in that laboratory is generally perceived as open-inquiry and a low score (minimum = 25) means laboratory work is verificationist or closed inquiry. Reverse scoring was done for the following items: 1, 3, 4, 5, 9, 10, 12, 22, 24, and 25. The scores were used to place instructional practice (or students' perceptions of that practice) along a continuum ranging from verificationist/ expository to open-ended inquiry.

While the validity of the instrument items was ascertained (Abraham, 1982), there was need to corroborate the content and construct validity of the instrument especially given the age of the instrument. Abd-El-Khalick and Lederman (2000), have strongly criticized researchers who use instruments developed more than three decades ago, arguing that the time lapse is a critical enough variable to influence relevance and hence validity. Perhaps there is need for a reminder from the annals of the history of science, that many ideas were retrieved from the archives, only for them to be pivotal in the development of scientific knowledge (Asmov, 1972). Mendel's work is a case in point. That aside, the three colleagues who adjudged the validity of the TSEBQ also corroborated the content and construct validity of the adapted version of Abraham's instrument. Additionally the instrument was administered to five A-level Chemistry students at a school, which was not part of the study sample. This was the same school used in validating the SINOS but this time different students were used. Discussions held with the students about their interpretation of the meanings of the item statements. For all the 25 items, the students showed that they did not have any problems with the language of the statements.

Before the instrument was used in the study, an estimate was made of its internal consistency. The instrument was administered to 25 Lower Sixth Chemistry students at a school in Bindura, where the researcher was based. A Cronbach alpha value of 0.71 was obtained. The actual questionnaire responses used in the study produce a Cronbach alpha of 0.71 for the whole test and Cronbach alpha values of 0.69 and 0.68 for the open-ended inquiry items and the verificationist items respectively.

3.5.5 Teacher Laboratory Programmes Variables Inventory (tLPVI)

This instrument had the title: Laboratory Programmes Variables Inventory, Teacher Questionnaire (Appendix D). The teacher instrument was similar to the student questionnaire with the only difference being the syntax. For example, instead of saying: "Our teacher identifies the problem to be investigated" (item 10 of the student questionnaire), the statement: "I identify the problem to be investigated", was written for the teacher questionnaire. Other examples are:

1. My students follow step by step instructions in the laboratory guide or handout.
18. I ask students to state alternative explanations to observed phenomenon

The instrument required the teachers to indicate how often they did what the item statement said with their students in their laboratories by responding to a bipolar Likert scale ranging from *almost never, seldom, sometimes, often*, to *almost always*. Responses were shown by, ticking in appropriate boxes. Scoring was done in the same way as the student LPVI.

As was the case with the student questionnaire the content and construct validity of the instrument was established through the consensual judgement of colleagues.

3.5.6 The student open-ended questionnaire

The questionnaire (Appendix E) was designed to serve the purposes of:

(i) corroborating students' responses to the SINOS instrument,
(ii) getting a deeper understanding of students' images of the NOS in general,
and
(iii) eliciting students' labwork based images of the NOS.

The questions were structured in line with the open-ended questioning used in studies of teachers' and/ or students' images, beliefs or views of the NOS (Hogan, 2000; Leach et al, 1998; Ryder et al, 1998; Saunders et al, 1999). In choosing and structuring the questions, there was an underlying focus on the laboratory vis-à-vis students' NOS images.

An initial batch of eight questions was administered to a sample of six Lower Sixth Chemistry students at a school, which was not part of the study sample. After analyzing the responses the researcher interviewed the six respondents on their answers and their understanding and interpretation of the questions. Feedback from the questions enabled the researcher to eliminate three questions, which appeared to have given students problems of understanding and interpretation. The remaining five questions elicited students' views on selected aspects of the following broad issues: the purpose of experiments, the nature of scientific knowledge from laboratories, the nature of scientific observations, the development and validation of scientific knowledge (nature of the scientific process) and the nature of data collected during laboratory work. The five questions used were:

1. Do you think the Chemistry laboratory is a place where scientific knowledge can be generated? Explain your answer.
2. Is the knowledge obtained from the Chemistry laboratory always true? Give reasons for your answer.
3. What can you say about the observations you make during Chemistry laboratory work?
4. How do scientists arrive at conclusions in building scientific knowledge?
5. Comment on the data you collect during Chemistry practical work.

There are methodological issues and challenges surrounding the use of these questions to elicit students' labwork based views of the NOS. For example how can one be sure that the views given by the student are based on his/her laboratory experiences and not other sources e.g. lectures, television, reading and other out of school experiences. These issues and challenges are discussed in Chapters 5 and 6 of this thesis.

3.5.7 Student Semi-structured Interviews

Semi-structured interviewing of sampled students was done for the purposes of getting a deeper understanding of students' views of the nature of science as well as corroborate open-ended and Likert instrument (SINOS) responses. Interviewing was done around a set of five core questions. The structuring of the core questions was informed by the literature (Hogan, 2000; Leach et al, 1998; Ryder et al, 1998; Saunders et al, 1999). Three of the questions asked in the open-ended questionnaire (questions 3, 4, and 5 above) were also asked in the interview (questions 3, 4, and 5 below). The five questions formed the basis for the student probing and other questions were also asked as a way of following up to get clarifications or to get a deeper understanding. Additional questions such as "How do scientists settle disputes?'' were asked as part of the probing. For example this question was asked as a follow up to question 5 below. Questioning was not done in the same sequence for all the interviewed students. The five questions are:

1. Why do scientists do experiments?
2. Does the knowledge known in Chemistry change with time?
3. From what you do in Chemistry practical work, what can you say about scientific observations?
4. What can you say about the data you collect during practical work in Chemistry?
5. Where does scientific knowledge come from?

The methodological challenges surrounding the use of such interview questions as given above to elicit students' laboratory work-based images of the NOS are raised in Chapters 5 and 6 of the thesis.

During the same interview students were also asked questions about their perceptions of how their laboratory work was being conducted. The theoretical guideline was assessment of students' perceptions of the nature of inquiry.

3.5.8 Teacher Semi-structured Interviews

Teachers were interviewed for the purposes of:

(i) Corroborating responses from the TSEBQ and tLPVI and

(ii) Getting a deeper understanding of teachers' science epistemological beliefs and laboratory instructional practices.

In order to get information about teachers' beliefs about the NOS (science epistemological beliefs) each teacher was asked a set of core questions around which probing for clarification and deeper understanding was done. The semi-structured interviewing was done around the following questions:

1. Why do scientists do experiments?
2. Do experiments always tell us the truth about the nature of things?

3. Are scientific observations theory- free?
4. Do you think what you do in the Chemistry laboratory with your students is similar to what is done in scientific laboratories?
5. How do scientists build scientific knowledge?
6. Will the knowledge we know in Chemistry today one day change?
7. Is scientific knowledge culture free?
8. How is scientific knowledge validated?

In order to get information relating to teacher laboratory instructional practice, the interviewing for this part revolved around the following questions:

1. Can you briefly describe your teaching of A- level Chemistry practical work.
2. Do you think the way you teach Chemistry practical work helps students understand what science is all about?

3.5.9 Laboratory Class Observations

A-level Chemistry laboratory sessions were observed for the purposes of triangulating information from the teachers' LPVI, students' LPVI as well as the information obtained from the teacher interviews. Semi-structured, non-participatory observation (Cohen et al., 2000) was done. The aim was to capture as much as possible of the laboratory class events as well as determine the nature of inquiry. For each of the observed classes, the researcher sat at the back of the laboratory and took detailed notes of the proceedings. While the observations were done without the guidelines of an observation schedule (in the tradition of a checklist or adaptation of a schedule used elsewhere), the capture of lesson proceedings was guided by a deliberate effort to examine the following issues (Abraham, 1982; Scharmann and Smith, 2002):

(i) source of problem for practical activity or activities
(ii) distribution of apparatus, chemicals, etc.
(iii) how the teacher gave out instructions and other information
(iv) the role of the laboratory assistant
(v) nature of student-student interactions

(vi) nature of teacher- student interactions
(vii) how students recorded information
(viii) group activities if any
(ix) pre and post laboratory activities
(x) what was expected of students' reports
(xi) how students made observations
(xii) how students interpreted data
(xiii) skills and techniques displayed by the students
(xiv) students' performance of frequent experimental tasks e.g. transferring of aliquots, turning burette taps, controlling Bunsen flames, etc.
(xv) lesson introduction and lesson closure
(xvi) the open-endedness of tasks or activities (degrees of freedom given to students to make decisions)

The researcher's notes were later analysed to get a picture of the nature of instructional practice.

3.6 Sampling

3.6.1 Students

For this study, twelve schools were randomly sampled from a total of 30 schools (N=30), offering A-level Chemistry in three of Zimbabwe's nine schools' administrative provinces. The provinces were chosen because of their proximity to the researcher, and in order to cut on research costs. The 30 schools had a total of 496 students doing Lower Sixth Chemistry. At each of the twelve schools, six students were randomly selected from the Lower Sixth Chemistry class giving a total of 72 students. It should be mentioned that data collection started when students were in Lower Sixth (last term of Form 5) and continued into the following year (first term of Form 6) when the same students were now in Upper Sixth. All the 72 students completed the SINOS, the sLPVI and the open-ended questionnaire.

For the interviews, six of the twelve schools were selected. The selection was on the basis of proximity. From each of the six schools, three students who had also completed the three instruments given above were purposefully sampled (ensuring gender balance) to take part in the semi-structured interviews, giving a total of 18 students.

3.6.2 Teachers

Twelve teachers, one from each of the twelve sampled schools formed the study sample. The teachers involved in this study were the Chemistry class teachers of the sampled students. Thus at each school the study involved a Chemistry teacher and six students. Six of the teachers, whose students were involved in the interviews, were also interviewed about their science epistemological beliefs and laboratory instructional practices. Laboratory sessions observations were done for the classes of these six teachers. Each teacher was observed during one practical lesson in Lower Sixth and three practical lessons in Upper Sixth.

3.7 Subjects demographics

3.7.1 Students

Of the 72 students, 24 were females (33%) and 48 were males (67 %). Of the 18 interviewed students, seven were females (39 %) and eleven were males (61 %). The average age of the students was 18 years (age range 17 to 19 years). In addition to Chemistry the students were also studying Biology and Mathematics (39 or 54 %), Physics and Mathematics (27 or 38 %), and Geography and Mathematics (6 or 8 %). In addition to these subjects all students at A-level study General Paper, which includes the use of English. Eighteen of the students (25 % of 72) where at three Day Schools and the rest where in Boarding Schools.

3.7.2 Teachers

Of the twelve teachers only one is female. Six of the teachers were trained in Cuba in the Zimbabwe-Cuba Teacher Education Programme. They held a qualification equivalent to the Bachelor of Education degree offered by the University of Zimbabwe. Three of the teachers were graduates from the newly established

Bindura University of Science Education (BUSE). They held Bachelor of Science Education degrees. One teacher held a Bachelor of Education degree in Chemistry from the University of Zimbabwe. Two of the teachers did not have any formal teacher education. One of these held a pure Bachelor of Science Honours degree in Chemistry from the University of Zimbabwe and the other a Masters degree in Analytical Chemistry in addition to a Bachelor of Science general degree in Chemistry (both from the University of Zimbabwe). These two teachers are the only ones who said they had never been exposed to the History and Philosophy of Science as part of their training. The NOS, it was mentioned (Chapter 2) has its roots in the philosophy of science. Five of the teachers from the Cuba programme had more than five years of A-level Chemistry teaching experience. The rest of the teachers had less than five years teaching experience. In addition to A-level Chemistry, the sampled teachers were also teaching science classes at O-level. Each teacher had on the average total teaching load of 24, 40-minute periods per week.

3.8 Data collection

Before data collection could be done permission to carry out research in the schools was applied for and granted by the Ministry of Education Regional Office in each of the three school's administrative provinces (see Appendix F, p. 280 for sample letter of approval). This letter was taken to the District Education Officer (DEO) and the School Head at each of the sampled schools. For each of the provinces both the DEOs and the School Heads approved of the researcher doing the study in the schools. All the teachers and students who participated in the study did so willingly. Each one of the participants was given assurance that his/her responses would be kept in strict confidence and were for research purposes only. Data collection was done over a period of eight months starting during the last term (third term) of Lower Sixth in 2002 and continued into the first term of Upper Sixth in 2003. In Zimbabwe A-level is a two-year course.

The students' SINOS and open-ended questionnaires were administered during the last term of Lower Sixth. Teachers' science epistemological beliefs questionnaires were also administered during this period. The students' LPVI, the teachers' LPVI were administered towards the end of the data collection period during the first term of Form 6. Teacher and student interviews were also done when the students were in Upper Sixth. For the teachers whose laboratory sessions were observed, one session (practical lesson) was observed in Lower Sixth and three sessions in Upper Sixth for the same class. It is important to point out that questionnaires, interviews and observations were done independently. By this it is meant that there was no analysis of, for example the student SINOS questionnaire before the interviews were done or analysis of teachers' responses to the tLPVI before lesson observations were done. All the data was gathered first and triangulation done from the point of data analysis.

3.8.1 Administration of student questionnaires

Before visiting the school to administer the questionnaire, the researcher telephonically made a prior arrangement with the school's headmaster. At each school the sampled students sat in one classroom and completed the questionnaire in the presence of the researcher. The researcher attended to any queries raised by the respondents. Before completing the questionnaires, students were verbally reminded that their answers should be based on what they did during Chemistry practical work and that their ideas about science were sought. As can be seen from the appendices all questionnaires also had written instructions to this effect. On the average students took 25 minutes to complete the SINOS, 20 minutes to complete the sLVPI and 30 minutes to complete the open-ended questionnaire. The student questionnaires were administered on a different day for each of the schools. Each completed questionnaire was given a student as well as a school code, ensuring that different questionnaires completed by the same student got the same code.

3.8.2 Administration of teacher questionnaires

Before each administration, the researcher made an appointment with the teacher through a telephone conversation. For the TSEBQ and the tLPVI, each teacher sat in his office and completed the questionnaire in the presence of the researcher, who responded to any queries raised by the respondent. The teachers took about 25 minutes to complete the TSEB questionnaire and 20 minutes to complete the tLPVI. The teacher questionnaires were administered on different days from the administration of the student questionnaires. Each of the teacher questionnaires was also administered on a different day. This was seen as necessary to avoid teacher fatigue and in order not to use too much of the teachers' time. For each teacher the TSEBQ and tLPVI were given the same code.

3.8.3 Student Interviews

The researcher in person conducted all student interviews. Student interviews were held after all the laboratory sessions had been observed. This gave the researcher the opportunity to probe students with what he had observed in the practical sessions in mind. For each school, interviews were completed in one day. The purpose of the interview was explained to the student. It was also made known to the student that the interview was to be tape-recorded. During the interview, the researcher also took notes of the student's answers. The student was given the assurance that the interview was confidential and for research purposes only. Interviewing started off with the researcher introducing himself and asking the respondent to do likewise. Thereafter an attempt was made to create a relaxed atmosphere. It was pointed out that the interview was not an interrogation but rather a discussion of the student's ideas about science and his/her laboratory learning. Before the questioning and the probing which had to do with the object of the study some conversation was made about such general things as the student's life and schoolwork. This was seen to have the effect of opening up the student and informalizing the conversation. On the average each student interview took between 25 and 30 minutes.

The researcher and a male technician employed in the same University department as the researcher did the verbatim transcription of tape-recorded interviews. Where the technician did the transcription alone, the researcher compared the transcription with the field notes and when there was disagreement the researcher and the technician together listened to the tape and made the necessary corrections. The handwritten transcription was then word-processed by the researcher.

3.8.4 Teacher Interviews

Teacher interviews about beliefs of the nature of science were done at the beginning of the first Upper Sixth term. Questions about their instructional practices were posed to teachers after each laboratory session observation. The researcher handwrote all responses to questions. Responses were transcribed verbatim and word-processed.

3.8.5 Laboratory lesson observations

Each teacher was observed teaching different practical work content areas. Before (about one week) each laboratory session observation, the teacher in question gave the researcher a copy of the practical work or practical exercise that was to be done. The teacher also briefed the researcher on the approach he/she was going to use. In most cases the teacher also provided the marking scheme by which he/she was going to assess the student's reports. After each lesson observation the researcher (on the same day whilst things were still fresh in mind), read through and summarized the laboratory session observation notes. Table 3.1 below gives a summary of the practical work content areas that were covered by each of the 6 teachers for those laboratory sessions that were observed. The observation was not done consecutively, that is, one lesson after the other. There were breaks in between observed sessions during which the teacher did some other practical activity not shown in the table.

Table 3.1. Observed laboratory sessions shown by title of practical work content

Teacher Code	School	Lower or Upper Sixth	Practical Exercise Title (s)
T1	L	Lower	1.Determination of the enthalpy of reaction: Hess's Law
		Upper	2. Acid–Base titration: Determination of the concentration of solution FA1 (HCl) 3.Qualitative analysis: Identification of ions and separation of cations 4. Redox titration: Hydrogen peroxide vs potassium permanganate
T2	K	Lower	1.Electrochemistry: Determination of Electrode potential
		Upper	2. Mock examination: 3 Questions on (i) Acid-Base titration (ii) inorganic tests for ions and (iii). Electrochemistry-determining electrode potential 3. Mock examination: 3 Questions on (i) Iodine vs Sodium thiosulphate titration (ii). Separation of cations through precipitation (iii) Reaction kinetics determining the order of a reaction 4. Teacher demonstrations of aspects of practical 3 above and discussion of students' answers
T3	J	Lower	1. Reaction kinetics: Studying the decomposition of hydrogen peroxide
		Upper	2. Redox titration: Iodine vs. sodium thiosulphate 3. Mock examination: 3 Questions on (i) Titration Acetic acid vs. NaOH (ii) Determination of water of crystallization of $BaCl_2.\ nH_2O$ (iii) Identification of ions and separation of cations by precipitation 4. Qualitative analysis: identification of ions and planning an experiment to separate ions in solution FA7

T4	I	Lower	1. Redox titration: Iron (II) vs. Ethane dioc acid salt
		Upper	2. Acid-Base titration: Acetic acid vs. NaOH 3. Redox titration: Iodine vs. sodium thiosulphate 4. Qualitative analysis: Teacher demonstrations and discussions
T5	H	Lower	1.Qualitative Analysis of Anions, CO_3^{2-}, Br^-, Cl^-, I^-
		Upper	2.The iodine clock reaction 3. Standardization of Hydrogen peroxide solution 4. Mock examination: 2 Questions on (i) Determination of the water of hydration in $BaCl_2$. nH_2O (ii) Qualitative analysis: Identification of anions and separation of cations
T6	G	Lower	1. Titration: Sodium hydroxide versus HCl
		Upper	2. Studying the effect of concentration of reactants for the thiosulphate ions reaction with acid (HCl) 3. Questions on (i) determining enthalpy of neutralization (NaOH vs. HCl) (ii) Qualitative analysis planning separation of cations (iii) Acid – Base titration: Acetic acid vs. NaOH 4.Qualitative Analysis of Inorganic Cations.

3.9 Data Analysis and Presentation

3.9.1 Quantitative data

The EXCEL 2000 programme was used in the data analysis and drawing of graphs for data presentation.

Teacher questionnaires

Quantitative data presentation and analysis mainly involves descriptive statistics. Data on teachers' science epistemological beliefs is presented in the form of frequency counts, graphs and tables. Relationships between item scores and the total score on the TSEBQ were determined by means of the Pearson correlation coefficient and the Spearman rank order correlation coefficients. All tests are two-tailed and alpha was set at .05. Crude item analysis involving correlations of TSEBQ items was done using the Pearson r. The common beliefs among the sample of teachers are determined from counting the frequencies of teachers subscribing to a TSEBQ item. Data on teachers' perceptions of their laboratory practices is similarly presented and analysed. Crude item analysis is also done using the Pearson correlation coefficient. Correlation of teachers' scores on the TSEBQ and the tLPVI was done with the Pearson r. with alpha set at .05 for a two-tailed test.

Student questionnaires

All statistical tests are two-tailed and alpha was set at .05. Data from the SINOS questionnaire responses, the student Laboratory Programmes Variables Inventory (sLPVI) and open-ended questionnaires is presented in the form of tables and graphs. Data analysis is mainly descriptive statistics involving frequency counts. The Krukulas Wallis test was employed to determine whether there was a difference between being male or female and scores obtained on the SINOS and sLPVI. Tests for correlations between students' scores on the SINOS and scores on the sLPVI were done using the Pearson correlation coefficient. The Spearman rank order correlation coefficient was also used to determine relationship between students' scores on non-traditional or traditional items and the total score on the SINOS. Crude item analysis is also done using the Pearson correlation coefficient.

3.9.2 Qualitative data

Analysis of data from the student open-ended questionnaire, student interviews, and teacher interviews was done using the combined techniques of analytic induction (Murcia and Schibecci, 1999), sequential analysis (Harwell, 2000) and interpretational analysis (Gall et al., 1996). The process of analytic induction involves continued readings of responses so as to unveil common patterns. Clusters of common responses are placed into similar categories. The emerging patterns are then used to develop categories. Responses are then classified on the basis of the formed categories. Frequency counts are made for each category. The normal practice is that two or more people develop categories independently for the same data. They then compare and negotiate the categories and the definitions of categories. The adopted categories are a result of consensus (Abell and Smith, 1994). Sequential analysis (Harwell, 2000) is a slight variation (roughly a similar technique) to analytic induction and involves the procedure of reading through the responses from all participants for each question. The responses are re-read and remarks and interpretations written in the margins for each response to a question. Formed marginal phrases are reduced to clusters based on the responses. Cluster phrases emerge from the responses. The reading and re-reading is continued and clustering and sub-categories formed. Responses are quantified using frequency counts. Responses are again read and re-read with the objective of selecting statements for use in exemplifying clusters or categories. In sequential analysis after clustering and categorization another person looks at the data relating to each possible cluster. From the discussion concerning the evidence of the existence of a cluster, adjustments to the categorization can be made and final categorization done on the basis of consensus. Interpretational analysis is about getting meaning out of the data. The researcher asks the question: What does this mean? Meaning is found by going beyond the face value of words or phrases. Insight is required.

In analysing students' responses to open-ended and interview questions the following sequence[2] was roughly followed.

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[2] The data analysis sequence followed in the current study was largely based on the analysis done by Harwell (2000) in her sequential analysis of middle level schoolgirls' responses to interview questions. She was studying their perceptions of teaching and learning in science. Details on sequential analysis can be found in Miles, M. and Huberman, M. (1994). Qualitative data analysis. Thousand Oaks, CA: SAGE Publications, Inc. pp. 85-88.

1. All responses to each open-ended or interview question were continuously read through and phrases and sentences making reference to the NOS underlined.

2. Each response to each protocol was read through and the context in which the student was expressing the identified NOS aspect (phrase or sentence) classified as based on the student's A-level Chemistry laboratory experiences or non-laboratory experiences.

3. Responses to each protocol were continuously read through again and from the common patterns that emerged clusters of common ideas were used to form categories. Each formed category was given a code or name (written in the margins) to capture the main ideas expressed by the students. For example the name or code 'learner verificationism' was assigned to represent the idea that the laboratory was a place where students could learn science through experiments that verified theory.

4. Responses were quantified using frequency counts. Each NOS issue raised by the student was counted as a frequency. The issue was counted only once for that student even if the student raised it several times e.g. in both open-ended and interview responses or twice in a response to one protocol item.

5. For each of the formed categories a statement was written to capture the general ideas expressed by the students for that category. For example the category 'learner verificationism' consisted of students' views, which generally said "The laboratory helps the students to learn and understand theory by verifying or proving Chemistry theory".

6. The categorized responses were sorted out according to the broad NOS aspects explored by the protocol items namely: the purpose of laboratory work (experiments) in science, the truthfulness of knowledge from laboratories, the nature of scientific observations, the nature of experimental data and the validation of scientific knowledge.

7. Responses were read through again with the purpose of selecting those statements, which could be used to illustrate and exemplify the formed categories and the interactions between students' NOS images and participation in laboratory work.

The researcher (author) and an education graduate sophomore studying in the same university with the researcher first analysed the data separately following the above sequence. Discussions were then held concerning the categorizations, the labelling phrases and classification of the possible source of the expressed student NOS image. From the discussions and further re-examination of the responses, agreement was sought on the categorizations, the phrases to use for the codes, the inferences made about the source of a student's NOS image, the context in which the student was giving a response (referring to school science or professional science) and the framing of statements to capture the general ideas expressed by the students. Consensus was also sought in deciding which response statements best illustrated and exemplified the students' NOS views and the images/laboratory work experiences linkages. The finally agreed upon categorization, labelling phrases and descriptive statements were adopted.

CHAPTER FOUR

Paper One

A Study of Zimbabwe A-level Chemistry Teachers' Science Epistemological Beliefs and Laboratory Instructional Practices.

4.0 Introduction

There is a growing body of literature pointing towards science teachers' beliefs about the nature of science (NOS) having some influence on classroom instructional practice (Schraw and Olafson, 2002). This is not to say there are no voices of dissent. The association between teachers' NOS beliefs and instructional practice is a subject in a number of articles (Abd-El-Khalick, Bell and Lederman, 1998; Abd-El-Khalick and Lederman, 2000; Cronin-Jones, 1991; Gwimbi and Monk, 2002, 2003; Hodson, 1993; Howard, McGee, Schwartz and Purcell, 2000; Lederman, 1992; Tsai, 2002; Young, 1981). Young (1981), for example, suggested the existence of interactions among teachers' understandings of scientific knowledge, instructional practices and students' views of the NOS. In their study Howard, McGee, Schwartz and Purcell (2000) demonstrated links between teachers' epistemological beliefs in general and teacher instructional practices. The linkage between teachers' science epistemological beliefs (beliefs about the NOS) and instructional practices is also supported by a number of studies (Brickhouse, 1989; Gwimbi and Monk, 2002; Hashweh, 1996; Tsai, 2002). Other studies however, have shown that teachers' beliefs about the NOS do not influence instructional practice (Duschl and Wright, 1987; Gess-Newsome and Lederman, 1998; Lederman and Ziedler, 1987, King et al., 2001). Teachers' beliefs in general (e.g. beliefs about teaching and learning, etc.) have also been found not to be related to their decision-making and classroom instructional practices (Wilcox-Herzog, 2002).

The literature reveals that when examining instructional practice, researchers have not made a deliberate attempt to specifically factor out laboratory instruction. Hofstein and Lunetta (2004) have listed the development of students' NOS understandings as an important goal of laboratory work. Rudolph (2003) is of the opinion that the image of science is articulated and given life through the laboratory. Teacher beliefs could be the most critical factor in influencing teachers' decision-making and instructional practice (Lumpe, Haney and Czerniak, 2002; Duschl and

Wright, 1989). Knowledge of typical laboratory instructional practice is valuable to anyone wishing to introduce innovation into the practice of science teaching (Tirberghien, et al., 2002). The reform of laboratory teaching practices is a science education reform agenda (Leach et al., 1998; Jenkins, 1998) in many parts of the world, Zimbabwe included. This makes an exploration of teachers' science epistemological beliefs and laboratory work instructional practices an interesting proposition. Moreover, as far as can be ascertained such a study has not been done within the context of a Zimbabwe school Chemistry laboratory.

This paper reports on a study investigating the nature of A-level Chemistry teachers' science epistemological beliefs (SEBs) and laboratory work instructional practices. The study involved twelve teachers sampled from three of Zimbabwe's nine school's administrative provinces. In particular the study surveyed teachers' beliefs about selected aspects of the nature of scientific knowledge and scientific inquiry, the nature of inquiry in the teachers' laboratories and possible interactions among these variables. It had a specific interest in what happened during the teachers' A-level Chemistry laboratory sessions.

4.1 Refining the concepts

In order for the reader and the writer of this paper to be on the same page, there is need to give precise definitions or descriptions of some terms introduced in the preceding paragraphs. While it is normal to refer to definition of concepts or terms, the author believes that in the context of this paper such an effort should actually be called precipitation, as each of the major concepts relevant to this study is formed from elements, which crystallize into an intricately interwoven entity.

4.1.1 Science epistemological beliefs

Although the term or phrase nature of science (NOS) has been defined in various ways (Lederman, 1992; Matthews, 1998a; Meichtry, 1998), this author believes that two aspects of the NOS described by Meichtry (1993, 1998) can form part of the construct of NOS relevant to this study. These aspects are scientific knowledge (product of science) and scientific inquiry. Scientific knowledge refers to the facts, principles, laws, theories and models constituting the body of knowledge called science (Lederman et al., 2000). The methods and practices through which *scientific knowledge is developed* form scientific inquiry (Lederman and Lederman, 2004). In the context of this paper, the conception of scientific inquiry broadens and overlaps into description of the nature of scientists and the scientific enterprise, for example, that science is just another human activity done by normal beings, who are called scientists.

According to Lederman (1998), the NOS refers to the epistemology and sociology of science, science as a way of knowing or the values and beliefs inherent to scientific knowledge and its development. This author takes it that scientific knowledge and its development means the same thing as "scientific knowledge and scientific inquiry". A common understanding of epistemology is that it has to do with what an individual believes about knowledge and how it is acquired (Hammer and Elby, 2001). Epistemological beliefs are individually held understandings, propositions, views, and dispositions (Hofer and Pintrich, 1997; Pajares, 1992) regarding knowledge and how it is developed and validated. Beliefs about scientific knowledge and its development and validation (scientific inquiry) are beliefs about the NOS. In this study these beliefs are termed science epistemological belief (SEBs).

4.1.2 Laboratory work instructional practice

Science is a form of inquiry. According to Hinrichsen et al. (1999), to engage in inquiry is in essence to be involved in science. Windschilt (2003), views inquiry as involving the whole process of hypothesizing, problem solving, collecting data, analyzing data, processing answers and explanations, engaging in Socratic dialogue, prediction and communication of results as well as identifying assumptions and use of logical and critical thinking. Given the nature of science as inquiry, the use of inquiry as a strategy for science teaching and learning follows naturally. Fostering a laboratory learning environment conducive to the promotion of inquiry has been associated with teacher use of such inquiry oriented teaching and student-centered approaches or strategies as open-ended discovery, problem solving, investigative approaches and constructivism (Abd-El-Khalick, Boujaoude, Duschl et al., 2004; Domin, 1999; Shiland, 1999; Windschilt, 2003; Windschilt and Andre, 1998). These methods are in themselves forms of inquiry. This is in contrast to the closed non-inquiry oriented, teacher centered strategies described as closed, verificationistic, transimissive and expository (Domin, 1999). If this line of thinking is accepted, laboratory instructional practice is about what the teacher does in creating and facilitating a laboratory learning environment that enables students to engage in inquiry so as to achieve those curriculum aims and objectives relevant to the process of inquiry. In this study laboratory instructional practice is limited to what the teacher does to or with students during laboratory sessions and what the students do as a result of the teachers' actions. Student laboratory experiences are part and parcel of the teacher's instructional practice.

4.1.3 Instructional decision-making

Decision-making is part and parcel of a teacher's practice. It is inseparable from instructional practice (Vhurumuku, 2002). On a daily basis, teachers make decisions about how to plan, which content to select, what strategies to use, which questions to ask students, how to organize instruction, how to implement decisions, how to assess students' learning, how to react to a student's answer and evaluate student learning, which instructional resources to use, choice of instructional media and many more aspects. Broadly decision-making is at the planning, implementation and evaluation stages of instruction.

According to Matthew (2001) decision-making is a socio-cognitive process that includes, problem identification, reflection and action. This is in line with the decision-making process outlined by Duschl and Wright (1989), which is based on the information processing theory of human decision-making by Simon and Newell (1970). According to Simon and Newell (1970), decision-making is a problem solving process during which the teacher selects certain components of the problem task environment and integrates them with his conception of the problem space. The problem task environment comprises of the various sundry factors comprising teaching. Such factors include: information about students, student behaviour problems, use of available resources, and the nature of the curriculum. The problem space is the teacher's own conception of what makes effective teaching. Both the task environment and the conceptual understanding of teaching by the teacher are said to form the basis for pedagogical decisions. In making pedagogical decisions the teacher makes judgements about the consequences of those decisions for both himself/herself and the students. Duschl and Wright (1989) are of the view that teacher decision-making determines their instructional behaviour consciously or unconsciously.

Teachers' decision-making and behaviour are said to be influenced by their beliefs about teaching (Duschl and Wright, 1989; Lumpe et al., 2002; Martin, 1999; Schraw and Olafson, 2002).

4.1.4 Closed and open-ended inquiry in Chemistry laboratory instruction

Since teacher instructional practice is being examined through a lens of inquiry, it is imperative that typical laboratory class teaching and learning activities be briefly examined. What teacher and student activities would make laboratory instruction be described as closed inquiry or open-ended inquiry? Previously it was mentioned that the various styles or approaches to laboratory instruction are in themselves forms of inquiry. Instructional practices characteristic of the various forms of inquiry can be gleaned from literature on Chemistry and science laboratory instruction (Abraham, 1982; Domin, 1999; Muth and Guzman, 2000; Newton et al., 1999; Shiland, 1999; Tamir, 1991; Tsai, 2002). This literature associates verificationistsic, *closed inquiry* laboratories with a frequency of such activities as:

- students following step-by-step instructions from the teacher or laboratory guide
- students are required to answer specific questions
- use of textbook or teacher explanations for observed phenomena
- problems that come up in class are not investigated
- no search for alternative explanations to phenomena
- teacher lectures to the class or to groups of students within the class
- low levels of student-student and student-teacher argumentation
- outcome of experiment known prior to the experiment

Closed inquiry laboratory instruction mainly aims to achieve the goals of: verifying textbook knowledge (Domin, 1999; Muth and Guzman, 2000), student acquisition of content knowledge and mastery of basic experimental skills. It is based on the philosophy that knowledge can be transferred from the teacher to the learner. Newton et al. (1999) have shown that, in closed inquiry laboratories the level of student-student and teacher-student argumentation is very low. Muth and Guzman (2000) have asserted that closed inquiry laboratory work appeals to the lowest levels of cognitive demand according to Bloom's taxonomy; recall, comprehension and application.

In contrast to closed inquiry laboratories is *open-ended inquiry* instruction in which the following activities are a frequent occurrence:

- students formulate the problem for investigation
- students discuss data during laboratory sessions
- students design their own experiments
- students go beyond the regular laboratory exercises and do their own experiments
- investigations start from the prior knowledge of the student
- high levels of student-student and teacher-student argumentation
- teacher plays role of facilitator
- outcome of experiment not known to the students

Broadly, the nature of open-ended inquiry can be gauged by the extent to which students are allowed to: connect new knowledge to past experience, design and plan investigations to solve problems, formulate hypotheses, decide which observations to make and how to record the observations, independently interpret data, engage in discourse among themselves and with the teacher (openness of argumentation), seek alternative explanations to problems, and apply information to solving novel problems (application of experimental findings).

While inquiry teaching and learning activities can be categorized as falling under closed or open-ended, the categories are not mutually exclusive. There are certain activities common to both inquiry and non-inquiry laboratories. As an example, it has been observed that the problem for investigation in most cases always comes from the teacher whether or not the instruction is closed or open-ended (Abraham, 1982; Domin, 1999). It is also a common practice in Chemistry for students to perform calculations during laboratory work irrespective of whether instruction is closed or open-ended inquiry. Tamir (1991) is of the view that the 'open-endedness' of inquiry can be judged by the extent to which (or degrees of freedom) students are allowed to choose the problem of the investigation, design and plan experiments, collect data, record results, interpret and communicate findings. In closed inquiry the degrees of freedom are lower for the students compared to open-ended inquiry. It is reasonable to talk about a teacher's laboratory instructional practice as located at points along a continuum of inquiry rather than exclusive categories of practice. The activities given above should be considered illustrative rather than exhaustive.

4.2 Research linking teachers' beliefs about the NOS and instructional practices

Gwimbi and Monk (2002) report a study by Dibbs in 1989 in which a questionnaire eliciting views about the philosophy of science was administered to teachers, followed by interviews to determine whether there was a link between teachers' philosophical orientations and their reported teaching styles. The questionnaire clustered teachers into four groups of philosophical orientation; verificationists, inductivist, hypothetico-deductivist and no discernible orientation. One of the findings of this study was that there was a relationship between being verificationist (for example, believing that scientific knowledge can be proved through experimentation) and frequent use of a teacher centered approaches (closed inquiry approach), and being hypothetico-deductive and frequent use of problem solving approaches (more on open-ended inquiry side). Dibbs concluded that there was a relationship between teaching styles and beliefs concerning the philosophy of science. In their own study with Zimbabwean A-level Biology teachers, Gwimbi and Monk (2002) came to the conclusion that teacher classroom practice was associated with some aspects of teachers' philosophy of science. By philosophy of science Gwimbi and Monk (2002) meant the attitudes towards the status, generation and value of scientific knowledge. Their examination of classroom practice covered both theory lessons and laboratory work. The teachers' philosophies of science were also seen to be associated with other variables such as, the contexts in which the teachers worked, academic qualification and professional training.

A study by Tsai (2002) showed that fifty percent of the sampled teachers held what he called traditional views (empiricist or logical positivist, e.g. scientific knowledge can be proved experimentally) about the nature of science, and the nature of teaching and learning. The same study showed some relationship between holding constructivist views of the NOS (for example, science is a way of knowing about the world; which is consistent with non-traditional or contemporary views as described in Chapter 2) and constructivist views of the nature of teaching and learning. Some association was also found between holding traditional views of the NOS (for example, science is composed of established truths) and seeing teaching as transferring knowledge, and learning as receiving knowledge. This gives support to the findings of Hashweh (1996), who found that teachers could be classified as either empiricist or constructivist in accordance with their views of learning and construction of knowledge. Constructivist teachers tended to use more student-centered approaches. These findings give credence to a teaching model proposed by Newton, Driver and Osborne (1999). The model connects teachers' beliefs about the NOS to the teaching approaches they are most likely to utilize in classroom instruction. For example holding the belief that science is a fixed body of knowledge is related to a teaching approach in which the teacher tells students information. This is called transmission. Tsai (2002) uses the term traditional to describe this kind of instruction. Teachers believing that science is accessed through personal experience are more likely to organize practical activities for students to draw conclusions. Newton et al. (1999) refer to this as discovery teaching. The constructivist epistemological position that science is a plausible explanation for phenomena is linked to teaching through providing students with opportunities to negotiate experiences and explanations with other students and with the teacher.

The studies mentioned in the last two paragraphs do not support the results of a study by King, Shumow and Lietz (2001). In their study of the beliefs and instructional practices of urban elementary science teachers, King, Shumow and Lietz found that there was a disconnection between teacher employment of inquiry-based instruction and teacher beliefs about the NOS and their practice. It was found that teachers' change of practices from expository to inquiry oriented was limited by teachers' own content knowledge (knowledge of the subject matter) and pedagogical skills and knowledge. The teachers in this study mentioned inadequate classroom materials and problems of student behaviour as barriers to effective practice of inquiry. These barriers or constraining variables, which tend to have an influence on teacher decision-making and instructional behaviour, have been called 'external beliefs' (Martin, 1999). Ford has called teachers' perceptions of how responsive their teaching environment (resources, people, etc.) is to their effective functioning context beliefs.

Some studies (Abd-El-Khalich, Bell and Lederman, 1998; Brickhouse, 1989; Duschl and Wright, 1989; Gess-Newsome and Lederman, 1995) have concentrated on examining the association between teachers' beliefs about the NOS and their teaching or not teaching in a way that promotes students' understandings of the NOS. Instructional practice in these studies is looked at not through a lens of closed versus open-ended inquiry but the extend to which teachers taught students about the NOS.

Brickhouse (1989) investigated the relationship between beliefs about science and technology and instructional practice of three secondary school science teachers. Data was collected through interviews, classroom observations and analysis of curriculum materials (teachers' plans, students' written work, etc,). Teachers' instructional practices were found to be related to their beliefs about the NOS.

A study done by Gess-Newsome and Lederman (1995) showed that even when teachers had adequate conceptions of the NOS, they did not necessarily teach in such a way as to promote students' NOS understandings. In this longitudinal study Gess-Newsome and Lederman followed the NOS understandings of a sample of pre-service science teachers over a period covering one year. The participants went through a course on the NOS, which was seen to have a positive effect on their NOS understandings. But when their teaching practice was studied through a combination of classroom observations, teacher semi-structured interviews and analysis of curriculum materials (lesson plans, teaching practice portfolios, etc.), it was seen that exposure of teachers to NOS did not influence their classroom practice. The study found that teacher practice was constrained by other variables such as pressure to cover content, availability of resources, pressure of examination, teacher management skills and other curriculum and school variables. Another study by Duschl and Wright (1989) with 13 urban secondary school science teachers also came to the conclusion that teachers' NOS beliefs had no influence on classroom practice. Abd-El-Khalick, Bell and Lederman (1998) found that even when teachers had an adequate understanding of the NOS, that understanding did not necessarily influence classroom practice. This was consistent with earlier studies (Duschl and Wright, 1995; Gess-Newsome and Lederman, 1995; Lederman and Ziedler, 1987). The in-service teachers who participated in this study revealed that the translation of NOS understandings into instructional practice was constrained by such factors as: teachers viewing NOS understanding as less important than other curriculum goals, teachers discomfort with their own NOS conceptions, teachers preoccupation with management and routine chores, and lack of resources and experience for teaching the NOS. Accepting that the interaction between NOS understanding and instructional practice is a complex one, Abd-El-Khalick et al. (1998) recommended that development of preservice teachers NOS understandings and learning to teach about the NOS should be done separately. Their study however did not specifically examine the interaction between teachers NOS conceptions and their practice of inquiry in laboratory instruction.

4.3 Research questions

This study sought to answer the following research questions:

1. What is the nature of the A-level Chemistry teachers' science epistemological beliefs?
2. What is the nature of the teachers' laboratory instructional practice?
3. What is the nature of the interaction (if any) between teachers' science epistemological beliefs and their laboratory instructional practices?

4.4 Research Methodology

4.4.1 Participants

The twelve teachers (1 female and 11 male) who participated in the study were from twelve A-level schools (3 Boarding and 9 Day Schools) randomly sampled from three of Zimbabwe's nine administrative provinces. Each of the teachers was at the beginning of the study teaching a Lower Sixth Chemistry class. Of these twelve teachers, six were selected for interviewing and detailed study of laboratory instruction.

Six of the twelve teachers were trained in Cuba in the Zimbabwe-Cuba Teacher Education Programme. They held a qualification equivalent to the Bachelor of Education degree offered by the University of Zimbabwe. Three of the teachers were graduates from the newly established Bindura University of Science Education (BUSE). Each held a Bachelor of Science Education degree. One teacher held a Bachelor of Education degree in Chemistry from the University of Zimbabwe. Two of the teachers did not have any formal training in teaching. One of these held a pure Bachelor of Science Honours degree in Chemistry from the University of Zimbabwe and the other a Masters degree in Analytical Chemistry in addition to a Bachelor of Science general degree in Chemistry (both from the University of Zimbabwe). These two teachers are the only ones who said they had never been exposed to the History and Philosophy of Science as part of their training. The NOS has its roots in the philosophy of science. Five of the teachers from the Cuba programme had more than five years of A-level Chemistry teaching experience. The rest of the teachers had less than five years teaching experience. In addition to A-level Chemistry, the sampled teachers were also teaching science classes at O-level. Each teacher had on the average a total teaching load of 24, 40-minute periods per week. Table 4.0 below summarizes the demographic variables for the interviewed teachers who for ethical reasons are given the indicated pseudonyms.

Table 4.0 Summary of demographic variables for the six interviewed and observed teachers.

Teacher code	Name	Qualifications	Type of School	Teaching experience
T1	Martin	B.Sc.Ed (BUSE)	Boarding	2yrs
T2	Kundai	B.Ed (U.Z.)	Boarding	4yrs
T3 (Female)	Abongile	B.Sc.Ed. (BUSE)	Boarding	1yr
T4	Fidel	Lit. Cert (Cuba)	Day	8 yrs
T5	Mawonde	Lit. Cert (Cuba)	Day	4 yrs
T6	Zivanai	Lit. Cert (Cuba)	Day	6yrs

4.4.2 Instruments and data collection

4.4.3 Teachers' science epistemological beliefs

Teachers' beliefs about the nature of science (science epistemological beliefs) were obtained through a quantitative (Likert-type) instrument called Teacher Science Epistemological Beliefs Questionnaire (TSEBQ) and interviews. Interviews were done to triangulate the responses to the Likert instrument.

The teacher quantitative questionnaire was administered during the third (last) term of Lower Sixth (Form 5). In Zimbabwe A-level is done over a period of two years covering Form 5 and Form 6 (Upper Sixth). Teacher interviews were done during the first term of the Upper Sixth year.

For both beliefs of science and perceptions of instructional practice, interviewing of teachers was done before their responses to the Likert instruments had been analyzed. The search for congruency between TSEBQ and interview responses was done at the stage of analysis.

The Teacher Science Epistemological Beliefs Questionnaire (TSEBQ)

The teachers' questionnaire consisted of two parts. Part A required the teachers to provide information on demographic variables. Information was sought about the gender, academic and professional qualifications, teaching experience, and teacher exposure to the History and Philosophy of Science. The literature on studies of teachers' beliefs about the NOS (Adb-El-Khalick and Lederman, 2000) shows that many of the studies have explored the possibility of these demographic variables being related to teachers' NOS views. Information on these variables was therefore sought with such an exploration in mind. Part B of the instrument required teachers to respond to thirty (30) items about the NOS, on a five point Likert scale: ranging from strongly agree to strongly disagree. For both parts of the questionnaire, teachers were asked to indicate their responses by ticking in the spaces provided.

The thirty items were selected from the instruments of Pemeroy (1993) and Aldridge et al. (1997). Items were selected so as to capture both the nature of scientific knowledge and the nature of the scientific process. The set of items was also mixed with some representing the traditional view of science and others the non-traditional view. For example, item 16 read: scientific knowledge is tentative. This item represents the nature of scientific knowledge but it is also written in a way that represents a non-traditional view of science. Item statements were taken as they are and no changes (except one item) were made to the wording. The only change made was the addition of the word African (to suit the African context) to item 14 which now read with the added word in square brackets: There is a significant amount of scientific knowledge in [African] traditional folklore and medicine.

In scoring, each item response was allocated 1, 2, 3, 4 or 5 points for each of the response categories *strongly disagree, disagree, not decided, agree* and *strongly agree* respectively. Items representing the non-traditional view were scored in the reverse. These are 2,3,4,6,8,9,14,16,17,19,20,21,22,24,26,27 and 28. A total high score (maximum = 150) therefore meant beliefs which were more towards non-traditional and a low score (minimum = 30) traditional beliefs (Tsai, 1999).

Although the items had been previously validated (Pemeroy, 1993; Aldridge et al., 1997), the content and construct validity of the questionnaire items was still ascertained through the consensual judgment of three science educators, one of them an experienced researcher. For the version of the instrument used in this study a split-half reliability coefficient (Spearman-Brown Formula) of 0.69 was obtained.

Teacher Interviews

In order to get information about teachers' beliefs about the NOS (science epistemological beliefs) each teacher was asked a set of core questions around which probing for clarification and deeper understanding was done. Interview questions were drawn and synthesized from the literature (Leach et al, 1996, 1999; Martin, 1999; Ryder et al, 1998; Saunders et al, 1999). The researcher took handwritten records of the teachers' responses. Semi-structured interviewing (Cohen, Manion and Morrison, 2000) was done around the following questions:

1. Why do scientists do experiments?
2. Do experiments always tell us the truth about the nature of things?
3. Are scientific observations theory- free?
4. Do you think what you do in the Chemistry laboratory with your students is similar to what is done in scientific laboratories?
5. How do scientists build scientific knowledge?
6. Will the knowledge we know in Chemistry today one day change?
7. Is scientific knowledge culture free?
8. How is scientific knowledge validated?

4.4.4 Laboratory instructional practices

Teacher laboratory instructional practices were determined through three data sources. Each of the twelve teachers completed a Laboratory Programmes Variables Inventory (tLPVI), which sought information about how the teacher conducted his or her laboratory classes. Laboratory class observations were done for six teachers who were chosen mainly because of their proximity to the researcher. These six teachers were also interviewed about their instructional practices. Questionnaire administration, interviewing and laboratory class observations were done during the first term of Upper Sixth.

The teachers' Laboratory Programmes Variables Inventory (tLPVI)

The instrument was adapted from Abraham (1982, p. 157). It has a set of 25 items. The instrument required the teachers to indicate how often they did what the item statement said with their students in their laboratories by responding to a bipolar Likert scale ranging from *almost never, seldom, sometimes, often,* to *almost always.* Responses were shown by, ticking in appropriate boxes. Examples of statements are:

1. My students follow step by step instructions in the laboratory guide or handout.
18. I ask students to state alternative explanations to observed phenomenon

In scoring each item response is allocated 1, 2, 3, 4 or 5 from *almost never* to *almost always* respectively. Scoring was done in reverse for those statements representing non-inquiry or closed inquiry laboratory (traditional approaches). A high score (maximum = 125) was taken to mean that the teacher perceived the nature of instruction in his/her laboratory as generally being open-inquiry and a low score (minimum = 25) meant laboratory work was verificationist or closed inquiry. The scores were used to place instructional practice (or teachers' perceptions of their practice) along a continuum ranging from verificationist (very low inquiry)/ expository to open-ended inquiry (very high inquiry).

The content and construct validity of the instrument was established through the consensual judgment of three colleagues.

Laboratory class observations

A-level Chemistry laboratory sessions were observed for the purposes of triangulating information from the teachers' LPVI, and the teacher interviews. Semi-structured, non-participatory observation (Cohen et al., 2000) was done. The aim was to capture as much as possible of the laboratory class events as well as determine the nature of inquiry (i.e. the extend or degree of open-endedness of the laboratory inquiry). For each of the observed classes, the researcher sat at the back of the laboratory and took detailed notes of the proceedings. While the observations were done without the guidelines of an observation schedule (in the tradition of a checklist or adaptation of a schedule used elsewhere), the capture of lesson proceedings was guided by a deliberate effort to examine the following issues:

(i) source of problem for practical activity or activities
(ii) distribution of apparatus, chemicals, etc.
(iii) how the teacher gave out instructions and other information
(iv) the role of the laboratory assistant
(v) nature of student-student interactions
(vi) nature of teacher- student interactions
(vii) how students recorded information
(viii) group activities if any
(ix) pre and post laboratory activities
(x) what was expected of students' reports
(xi) how students made observations
(xii) how students interpreted data
(xiii) skills and techniques performed by the students
(xiv) students' performance of frequent experimental tasks e.g. transferring of aliquots, turning burette taps, controlling Bunsen flames, etc.
(xv) lesson introduction and lesson closure
(xvi) the open-endedness of tasks or activities (degrees of freedom given to students to make decisions)

The researcher's notes were later analysed to get a picture of the nature of instructional practice or extend of inquiry.

Each teacher was observed teaching different practical work content areas. Before (about one week) each laboratory session observation, the teacher in question gave the researcher a copy of the practical work or practical exercise that was to be done. The teacher also briefed the researcher on the approach he was going to use. In most cases the teacher also provided the marking scheme by which he was going to assess the student's reports. After each lesson observation the researcher (on the same day whilst things were still fresh in mind), ready through and summarized the laboratory session observation notes.

Teacher Interviews

At the end of each laboratory class observation, the researcher asked the teacher some questions based on aspects of his/her lesson delivery. The purpose of questioning was to get clarifications and further understand the teacher's practice. Additionally, each of the six teachers was asked to give responses to the following:

1. Can you briefly describe your teaching of A-level Chemistry practical work.
2. Do you think the way you teach Chemistry practical work helps students understand what science is all about?

4.5 Data Analysis and Results

4.5.1 Teachers' science epistemological beliefs

4.5.2 Results from the TSEBQ

Each teacher's total score was used to place the teacher along a continuum of science epistemological beliefs ranging from traditional, fairly traditional, fairly non-traditional to non-traditional or constructivist. Scores below the theoretical midpoint of 90 (minimum = 30, maximum = 150) were taken to mean beliefs, which are more on the traditional side. Within the traditional category a score within the range 30-60 was taken to be traditional and the 61-90 range to be fairly traditional. Above the theoretical midpoint scores within the range 91-120 were categorized as representing fairly non-traditional beliefs and 121-150 range non-traditional or constructivist beliefs. As Figure 4.1 below shows, three teachers were in the range 61-90 and can be classified as holding fairly traditional views. The other nine teachers fell into the fairly non-traditional category.

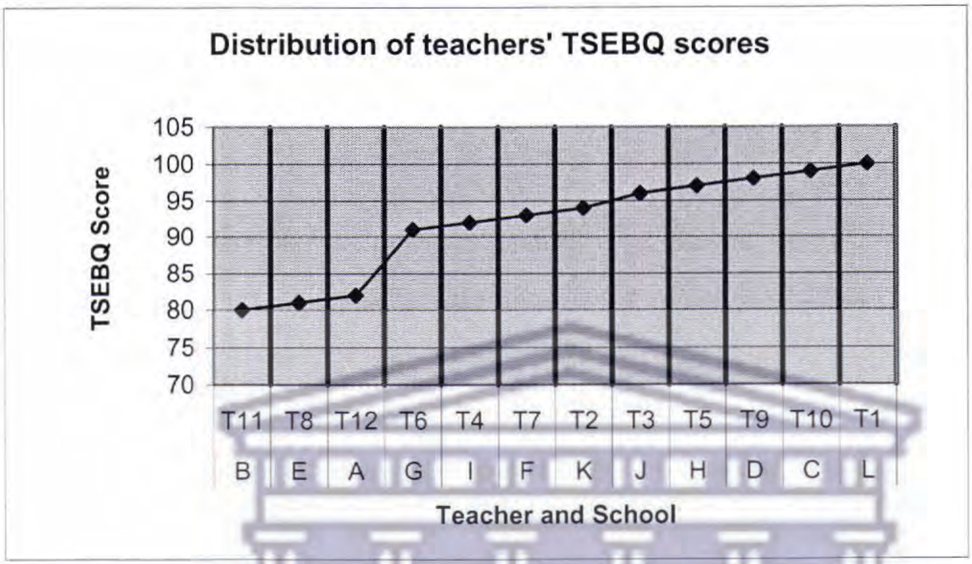

Figure 4.1 Distribution of teachers' scores on the TSEBQ (n = 12)

As a group the teachers can be said to have been harbouring beliefs that are slightly fairly or moderately non-traditional (mean = 91.9, median = 93.5, s.d. = 7.14). Figure 4.1 shows that the nine fairly traditional teachers were reasonably homogeneous with respect to their beliefs about the NOS.

The small sample size was prohibitive of statistical explorations of relationships between the beliefs score and the demographic variables. However, by using a data reduction technique, it came out that teacher scores on 2 of the items, item 4 (intuition plays a role in scientific inquiry) and item 18 (the aim of scientific knowledge is to control nature) got bigger as teaching experience increased (from 0-2 years to over 5 years). The more experienced teachers appear to be the ones strongly agreeing with these 2 statements. This is interesting, as item 4 is non-traditional and item 18 traditional? Scoring of items was on five distinct ordinal positions. Given the small sample the apparent association between teacher experience and responses to the two statements needs to be taken with caution. At best it might form a hypothesis for further studies.

Additionally, the author employed a robust method in which the teachers' score on an item is correlated (Spearman r.) to the total score and an analysis done to determine which items have positive correlations, negative correlations or are neutral. When this technique was employed with the items sorted according to whether they were traditional or non-traditional, it came out that the real strong negative correlations were with the traditional items (see Table 4.1 for the items showing correlations greater than 0.40 contribute significantly to explanation of variance between item score and total score) and strong positive correlations were with non-traditional items (Table 4.1). Non-traditional items were reverse scored. There was a tendency by the teachers not to agree so much with the non-traditional items. The teachers' total score on non-traditional items was related to the total score (traditional + non-traditional) (r = 0.75, p = 0.005, 2-tailed significance). Caution is again called for in interpreting these findings because of the small sample size. It would be interesting to look at the nature of these correlations with a larger sample of teachers.

Table 4.1: TSEBQ items showing fairly strong positive and negative correlation coefficients.

Item Number	Item statement	Item type	Correlation coefficient	p value
1	Scientific knowledge starts with observation of nature	Traditional	-0.83	0.15
7	Scientific knowledge is true and objective description of the natural world because it is based on observations	Traditional	-0.43	0.03
9	Legitimate scientific ideas sometimes come from dreams and guesses	Non-traditional	0.54	0.08
16	Scientific knowledge is tentative	Non-traditional	0.68	0.01
19	Most scientists rely on theories to guide them in interpretation of experienced	Non-traditional	0.54	0.06
22	When working in the laboratory scientists always do not follow the scientific method	Non-traditional	0.46	0.13
28	The evaluation of scientific knowledge always varies with changes and situations	Non-traditional	0.45	0.14

Two items achieved total agreement (actually strongly agree and agree collapsed with all teachers showing agreement) from the teachers. The items are:

1– scientific knowledge starts with observation of nature and

19– most scientists rely on theories to guide them in interpretation of experience.

No item received total disagreement (disagree and strongly disagree collapsed) from the teachers. Only one teacher disagreed with the idea that African traditional folklore and myth can play a part in generation of scientific knowledge (item 14). This could be attributed to the current debate going on in Zimbabwe about the inclusion of 'traditional science' in the school curriculum. The teachers could have been merely expressing political orientation rather than legitimate NOS epistemological views. Only 4 of the teachers thought scientists were extremely intelligent people. The majority (10) of the teachers thought scientific knowledge could be proven (item 10). An equal number (10) of the teachers held the view that scientists eliminate their beliefs when making scientific observations (item 5). For the sample of 12 teachers, the common beliefs held by the teachers can be seen from Table 4.2. The table shows those items on which at least ten of the teachers were in agreement (agree and strongly agree collapsed). Common here means beliefs where the large majority (10 or more) of the teachers indicated agreement. In using the word common care should be taken not to generalize the interpretation given here to the wider population of Zimbabwe A-level Chemistry teachers. The trend shown with this small sample can be considered to be a hypothesis since there is the probability of chance having played a part in producing the observed trend. A study with a larger sample size would be required to make a reasonable conclusion on this matter.

As Table 4.2 shows, the teachers held both strong traditional beliefs and non-traditional beliefs. The teachers appeared to contradict themselves by believing that scientific knowledge starts from observations (item 1) and at the same time expressing the view that science ideas come from science and non-science sources (item 6). There is also the possibility that teachers differ between their perceptions of the context of discovery (e.g. ideas from dreams) and context of verification (e.g. knowledge from observations.). The responses to items 1 and 7 could be indicative of consistency in the way in which the teachers looked at scientific observations.

Table 4.2: The common beliefs held by the sample of teachers (n =12).

Item Number	*Item statement*	*Frequency Agreeing*	*Frequency Not decided*	*Frequency Disagreeing*
1	Scientific knowledge starts with observation of nature*	12	0	0
3	The process of scientific investigations involves the ability to look at things which are not commonly accepted	11	0	1
5	When making observations scientists eliminate their beliefs and values*	10	1	1
6	Scientific ideas come from science and non-science sources	10	1	1
7	Scientific knowledge is true and objective description of the natural world because it is based on observation*	11	0	0
10	Scientific knowledge can be proven*	10	1	1
13	Science is based on experiments which any other competent scientist should be able to repeat at will*	11	1	0
14	There is a significant amount of scientific knowledge in African folklore and myth	11	0	1
17	The process of scientific inquiry often involves playfulness	10	1	1
19	Most scientists rely on theories to guide them in interpreting experience	12	0	0
24	Currently accepted scientific knowledge will be modified in the future	10	2	0
28	The evaluation of scientific knowledge varies with changes in situations	11	1	0

*** Traditional items**

4.5.3 Teachers' science epistemological beliefs: Interview results

The NOS beliefs of the six interviewed teachers are summarized in Table 4.3 below. All the six teachers involved in the interviews are categorized by the TSEBQ as holding fairly non-traditional views of science (Figure 4.1). The interview scripts were analysed using a combination of sequential analysis, analytic induction and interpretational analysis (Gall et al., 1996; Harwell, 2000; Murcia and Schibecci, 1999). Each teacher's responses to the questions were read and re-read. A search was made for agreement or disagreement between the teacher's response to the TSEBQ and what the teacher said to corresponding items in the interview. By reading and re-reading the six teachers' responses to each core question together with the responses to subsequent following up or probe questions coded categories of ideas emerged. The researcher and a post-graduate science education sophomore in the same university with the researcher did coding and re-coding of the responses. The teachers' responses are discussed under the sub-headings of the major NOS issue(s) raised in the interviews. Six aspects were raised in the interview namely:

- the purpose of experiments in science
- the nature of scientific observations
- the generation of scientific knowledge
- the validation of scientific knowledge
- the static or dynamic nature of scientific knowledge
- the cultural 'contextuality' of scientific knowledge

On Table 4.3, the aspects of the generation of scientific knowledge and the validation of scientific knowledge are combined into one "issue" of "nature of scientific process". Generation of scientific knowledge refers to how scientific knowledge is given birth to. It includes the question of the source/origin of the knowledge. The aspects of the static/dynamic nature of scientific knowledge and the cultural contextuality of scientific knowledge are combined into one "issue" of "the nature of scientific knowledge".

Each of the six teachers' beliefs on these issues was considered, and an overall decision made about the traditional or non-traditional nature of a teacher's beliefs. This consideration resulted in placement of the teachers along a normative map ranging from traditional, fairly traditional, fairly non-traditional to non-traditional. Such a nomothetic categorization of the teachers was considered necessary for two reasons. First it aided the triangulation of the nomothetic placement of teachers done using the TSEBQ. Second, it aided the search for patterns in the relationship between teachers' science epistemological beliefs (SEBs) and their instructional practices.

Three of the teachers Martin, Abongile and Kundai were considered to be traditional as they held traditional views on all the issues except the nature of scientific observations and the dynamic nature of scientific knowledge. Fidel was considered fairly traditional. He displayed a positivist view on the issue of the purpose of experiments and viewed scientific knowledge to be culture free. He also believed that scientific knowledge was obtained through a method of inquiry. Mawonde was categorized as fairly non-traditional (fairly constructivist) and held traditional views on two of the raised issues; the nature of scientific observations and how scientists settled disputes. Zivanai was taken as non-traditional (constructivist) on all the issues raised.

Table 4.3 Summary of teachers' beliefs on selected NOS issues (from the interview of 6 teachers)

	NOS belief			
Teacher	Purpose of experiments in science	Nature of scientific observations	Nature of the scientific process	Nature of scientific knowledge
Martin	Positivist/ verificationist	Subjective/Influenced by scientist's prior knowledge/ Relativist	Inductivist/ disputes settled by repeating experiments	Dynamic / culture free
Kundai	Positivist/ verificationist	Subjective/Influenced by scientist's prior knowledge/ Relativist	Inductivist/ disputes settled by repeating experiments	Dynamic / culture free
Abongile	Positivist/ verificationist	Subjective/Influenced by scientist's prior knowledge/ Relativist	Inductivist/ disputes solved by repeating experiments	Dynamic/ culture free
Fidel	Positivist/ verificationist	Subjective/Influenced by scientist's prior knowledge/ Relativist	Research methodologist/ disputes settled by repeating experiments	Dynamic / culture free
Mawonde	Instrumentalist	Objective/ Realist	Anarchism/ disputes settled by repeating experiments	Dynamic/ culture depended
Zivanai	Instrumentalist	Subjective/Influenced by scientist's prior knowledge/ Relativist	Anarchism/ disputes settled by negotiation consensus and agreement	Dynamic/ culture depended

The purpose of experiments in science

On this issue, four of the teachers, Martin, Kundai, Abongile and Fidel gave responses, which can be described as traditional and verificationist. This was in line with their agreement with the item saying scientific knowledge can be proven in the TSEBQ. All the four mentioned either the word prove or verify. This is how Abongile and Fidel responded to the question: "Why do scientists do experiments?"

> Abongile: To verify some concepts, to show that what is said is really true. Vanenge vachida kutaridza kuti ruzivo nderwe chokwadi [Shona for "They would want to show that knowledge is really true"] Or maybe to explain some phenomenon.
>
> Fidel: Maybe the main reason is to prove hypothesis or theories or discover certain scientific phenomenon.
>
> Interviewer: Why are you saying maybe?
>
> Fidel: Yaa! Eee I think the main reason really is to show that their theories are correct.

The other two teachers Mawonde and Zivanai gave responses, which can be described as non-traditional. This was in spite of the fact that both had agreed to scientific knowledge being proven in the TSEBQ. There is a possibility that the two teachers' views could have changed during the time lapse between administration of the TSEBQ and the interview (3 months). This is surprising since beliefs have been known to be static (Hammer and Elby, 2002; Lumpe et al., 2000). It could point towards the unreliability of item 10 of the TSEBQ. Teacher Mawonde's view on this issue can be described as instrumentalist (Dawson, 1991). To him the purpose of experiments is to study and understand the materials of nature so that they can be used for man's benefit. This was his response.

> Mawonde: They try to investigate the nature of [...] substances with the aim of identifying properties and structure so that they can be used, or improve materials and also discover new materials and compounds that can be used [by people].

Zivanai had almost identical ideas although his answer is tainted with the realist and traditional conception of the purpose of science as being to quench curiosity. Like Mawonde, he was of the opinion that experiments do not always tell the truth.

> Zivanai: The reason why scientists do experiments is out of curiosity or to find out why certain things happen and for development purposes for example produce a new product for example polymers or a new drug which can be of use to man.

It's possible (or so it appears) that the teachers who gave 'traditional' answers to the question: "Why do scientists do experiments?" might have been thinking of the purpose of experiments in terms of the generation of scientific knowledge (the process of science). Zivanai and Mawonde who gave "instrumentalist" answers could have been thinking about the purpose of science in terms of the broad dimension of: "Why do scientists do science?" or "Why does man need science?" This could raise questions about the validity of this probe. Zivanai's response could also mean that he views science as inseparable from technology. His understanding of the similarity or difference between science and technology was not explored.

The nature of scientific observations

The six teachers' responses to questions about the nature of scientific observations are consistent with their responses to item 21 of the TSEBQ. All the interviewed teachers with the exception of Mawonde were of the non-traditional view that scientific observations are subjective, theory-laden and necessarily selective. Two of the teachers Martin and Kundai explained.

> Martin: I think scientific observations are limited by theory. When we make observations we tend to ignore certain things and concentrate on others. They tend to be subjective.
>
> Kundai: Scientific observations tend to be subjective because when you do experiments you tend to overlook certain things. They [observations] are influenced by what you think, your theory.

The conception of subjective here appears to be associated with observations being necessarily selective. Zivanai gave a clearer answer:

> Zivanai: If you have a theory, observations maybe biased towards the theoretical background. There are instances were you can do away with that through experience.
>
> Interviewer: Are scientific observations objective?

> Zivanai: I think there are instances where they can be objective but we can't get rid of our beliefs when carrying out observations. There is a certain percentage of objectivity but there is always that subjectivity.

The idea that scientists' background could affect their observations and interpretation of evidence is also raised by the majority of the teachers in a study by Murcia and Schibecci (1999). Interesting is the observation that the teacher's professional and academic background does not appear to be a factor in the views of the nature of scientific observations. This is so given that three of the teachers were trained in Zimbabwe in the typical British tradition and the other three were trained in Cuba (Table 4.0).

Teacher Mawonde had a different view and saw observations as objective. His meaning of the term objective however appears to be the same as that for the term real.

> Mawonde: They [observations] are objective because ee […] what you observe and what actually happens is one and the same thing.
>
> Interviewer: Can different scientists make different observations on the same thing?
>
> Mawonde: They should see the same things if they all observe carefully.

The nature of the scientific process: the generation and validation of scientific knowledge

The six teachers views fall into three categories. There is Abongile and Martin whose views were inductivist and positivist and totally believed that scientific knowledge comes from experiments and observations.

> Abongile: At times you get reactions, but at times you get some result and you have to explain why you get those results. So by observing, they may be doing some experiment with a control of some sort and then they come to make a conclusion and say it's like this.
>
> Interviewer: What about just imagining?
>
> Abongile: Even dreaming, but all the same you have to back what you say by doing experiments. So really its experiments that matter.

Kundai also held the same view although he said imagination and creativity could also play very small parts in the generation of scientific knowledge. He linked experiments to proving that scientific knowledge is correct. The other two teachers (Mawonde and Zivanai) did not think that scientific knowledge was sourced from experiments alone but that it was also the product of human creativity and imagination. They agreed that dream could also play a part. Their view can be described as "anarchism". They appear to base their thinking on the belief that scientists use all kinds of sources of information (for example, dream and guessing) and various methods to produce (or discover) claims later accepted as valid scientific knowledge (Feyerabend, 1978). Fidel believed in the scientific method and was of the view that scientific knowledge was generated from following a scientific method. This view is categorized here as traditional. This is what he said:

> Fidel: Scientific knowledge is obtained through inquiry […] in fact that is the major characteristic of the scientist, the inquiry approach.
>
> Interviewer: What is the inquiry approach?
>
> Fidel: To me it's the methods, which are used to acquire scientific knowledge […] may be the research method in acquiring scientific knowledge.

Five of the six teachers however, believed that scientists settle disputes and validate scientific knowledge by repeating experiments. Zivanai did not think that way. He said:

> Zivanai: Usually its beliefs which are cultural for example the cold war between Soviets and Americans. When scientists work together, without cultural conflicts, consensus is usually arrived at. To a large extend our science in Africa is considered inferior. The chemicals we produce are not considered to be of scientific value.
>
> Interviewer: How do the scientists arrive at consensus?
>
> Zivanai: I think they sit down and talk and come to one point like Americans coming together with the Russians.

These response show quite sophisticated views of the NOS. They are however reminiscent of the argument peddled with much emotion by many scientists and politicians in developing countries, that there is hegemony in the dispensation of scientific knowledge.

The nature of scientific knowledge: Is it dynamic and culture free?

Teachers' views on two aspects of the NOS were investigated. These are whether scientific knowledge is dynamic or static and whether or not it is culture free (cultural contextuality). All the six teachers held the contemporary belief that, scientific knowledge changes, with the most popular reason for change being advances in technology bringing about a better understanding of nature and leading to abandonment of theories. This response corroborates teachers' responses to item 24 of the TSEBQ, "Currently accepted scientific knowledge maybe modified in the future". Martin explained:

> Martin: It [scientific knowledge] changes possibly because of technology things can be discovered and in the process you can see that what you believed in is not correct that is why certain hypotheses are being disputed.

Zivanai concurred:

> Zivanai: What we can call a theory can be untrue in future. Some theories can stand the test of time but in many areas there is a lot to learn for example the Periodic Table is one area in Chemistry where [...] We are still synthesizing elements maybe one day someone will rearrange the elements.

While the teachers were unanimous about scientific knowledge being dynamic, they differed on the issue of whether scientific knowledge is culture free. Martin, Abongile, Kundai and Fidel were of the opinion that scientific knowledge does not depend on culture. Zivanai and Mawonde thought it did.

> Mawonde: It [scientific knowledge] is based on culture and we have many Cultures [...] the knowledge becomes a problem because we have different cultures.
>
> Interviewer: How does it become a problem?
>
> Mawonde: We Africans believe lightning can be created. Its true knowledge to us but whites don't believe so you see it becomes a problem what is true or not.

4.5.4 Teachers' laboratory instructional practices

4.5.5 Responses to the tLPVI: Teachers' perceptions of their instruction

In this section teachers' instructional practices are described from the perspectives of the teachers themselves as indicated by their responses to the tLPVI. The teachers can be placed into categories according to how they perceived their instruction. Figure 4.2 shows the distribution of teachers' tLPVI scores.

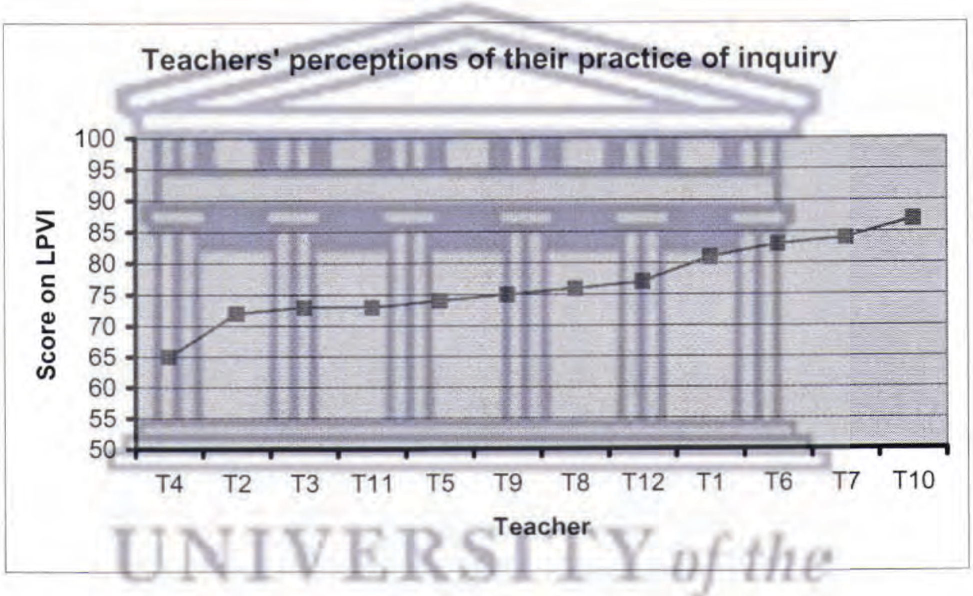

Figure 4.1: Teachers' perceptions of their practice of inquiry

Table 4.4 Nature of laboratory inquiry as perceived by the teacher (n =12)

tLPVI Score Range	Nature of inquiry	Teachers in score range
25-50	Very low inquiry	0
51-75	Low inquiry	T2*, T3*, T4*, T5*, T9, T11
76-100	Medium inquiry	T1*, T6*, T7, T8,T10,T12
101-125	Very high inquiry	0

***Interviewed teachers**

A teacher's score below the theoretical midpoint of 75 (maximum =125, minimum = 25) was taken to mean that the teacher perceived his/her laboratory practice as of low inquiry or very low inquiry (Table 4.4). Scores above 75 were taken to mean perception of laboratory practice as of medium or high inquiry. On the average, teachers can be said to perceive the nature of inquiry as somewhere between low and medium inquiry (inquiry taken to exist along a continuum see Chapter 2) (mean = 76.7, median = 75.5, s.d. = 6.1). On the continuum of the nature of laboratory instruction, Teacher 10's instructional practice is the most inquiry oriented (most positive towards theoretical maximum) and Teacher 4's instructional practice is the least inquiry oriented (Figure 4.2).

As was the case with teachers' SEBs, the small sample size did not allow meaningful statistical exploration of relationships between tLPVI scores and demographic variables. A crude item analysis identified those tLPVI items contributing to the explanation of at least 10 % of the variance. The teacher's score on an item was correlated against the total tLPVI score (Spearman r., 2-tailed test). The following items were seen to contribute significantly (at least 10 %) to the explanation of variability (r greater than 0.37) 2, 6, 11, 13, 14, 15, 16, 18, 21, and 23. Item 18 produced the largest significant correlation coefficient ($r = 0.89$, $p = 0.003$). It is interesting to note that most of these items appear to deal mainly with either how the problem of investigation is formulated or the nature of student-student and student-teacher communication. These are important peg marks in determining the "open-endedness" of inquiry.

For this sample of teachers, the commonest laboratory practices can be picked up from Table 4.5 below. On this table three categories of frequencies were formed by collapsing the often and almost always into one category of often, the almost never and seldom into one category of seldom and doing nothing to the sometimes category of the tLPVI. A practice is taken to be very common if there is a high frequency (at least 9 teachers in often category) of teachers indicating that they do what the item statement says often. The most common practices from Table 4.5 are that teachers:

- identify the problem to be investigated
- require students to solve problems (perform calculations) during laboratory work
- require students to answer specific questions during laboratory work
- are concerned with the correctness of data

Table 4.5: Frequency of laboratory instructional activities as perceived by teachers (n = 12)

Item No	Statement	Frequency (number of teachers)		
		Seldom	Sometimes	Often
1	My students follow step by step instructions in the laboratory guide or handout	1	3	8
2	My students interpret data in the laboratory reports	1	3	8
3	*I am concerned with the correctness of data	0	2	10
4	I allow my students to go beyond regular laboratory exercises and do experiments on their own	6	4	2
5	I use laboratory activities to develop concepts	2	3	7
6	I lecture to the whole class	3	5	4
7	I ask my students to design their own experiments	4	5	3
8	During practical work my students record information requested by me or the laboratory assistant	3	2	7
9	Laboratory sessions raise new problems or result in data that cannot be explained immediately	3	7	2
10	*I identify the problem to be investigated	2	1	9
11	*Laboratory activities require students to solve problems	1	1	10
12	*Laboratory reports require specific questions to be answered	1	0	11
13	The teacher or the laboratory assistant requires the student to explain why certain things happen	1	4	7
14	The laboratory is used to investigate a problem that comes in class	4	6	2
15	Laboratory experiments develop skills in techniques and procedures of Chemistry	1	4	7
16	I require students to write reports in which they use evidence to backup their conclusions.	4	2	6
17	Students discuss their data and conclusions with each other during the lab	4	6	2
18	I ask students to state alternative explanations for observed phenomena	2	4	6
19	During the laboratory my students record information they feel is important	2	2	8
20	Students propose their own explanations to observed phenomenon	1	4	7
21	Students identify problems to investigate	5	5	2
22	During the laboratory students check the correctness of their work with the teacher	2	4	6
23	In discussion with the teacher my students challenge assumptions and want conclusions justified	2	2	7
24	Students usually know the general outcome of an experiment before doing the experiment	4	5	3
25	I give information to individual students in small groups	2	6	4

** very common practices according to teachers*

It is also common (Table 4.5 frequency equal to 8 for often) for teachers to:

- allow students to record information they feel is important
- have students to follow step-by-step instructions of the lab manual
- ask students to interpret data during practical work

4.5.6 Teachers' laboratory instructional practices: Lesson observations and interviews results.

In this section results from the laboratory class observations and interviews are presented. The lesson observations were the primary source of data and teacher interview data is used as a secondary source performing mainly a corroborative function. About the interviews, the reader should be aware of the fact that in listening to the teachers, it was discovered that there was need to examine the role of external factors or beliefs (Martin, 1999) in order to get insights into the interaction between teachers' NOS beliefs and their instructional practices. These external factors were not included in the research questions at the outset. Each of the six teacher's practice is described. This is followed by a summary of the six teachers' practices.

Zivanai

Zivanai had been teaching A-level Chemistry for six years. His teaching load also included classes in O-level Physical Science and Mathematics. He said he would enjoy his teaching as he loves the profession, but the acute shortage of essential reagents and chemicals for the effective teaching of A-level Chemistry was increasingly frustrating him. As is the case in many of Zimbabwe's High Schools the country's teething economic problems are inevitably bearing on teachers' classroom practices. Zivanai succinctly captured the sad scenario:

> Zivanai: A hundred grammes of silver nitrate now cost the equivalent of my monthly salary. So you see, most of the time you really don't teach the way you want. Some practicals you simply avoid because they are unaffordable, especially for a school like this one. You do the best you can but hey […]

Zivanai believes that laboratory work should train students to become scientists in their own right. When asked: "What is the aim of school Chemistry laboratory work?" he replied:

> Zivanai: To boost the understanding of scientific concepts and also training them for life so that they are able to solve problems so that they can find solutions. They can actually solve problems of a scientific nature because they have learnt skills of a scientific nature.

His general strategy in teaching A-level laboratory work is that he starts by demonstrating the use of equipment including manipulations of apparatus. Students are then assigned to work on practical activities in small groups with the teacher moving from group to group giving assistance where it is required. After a few laboratory sessions and when he is satisfied that the requisite laboratory skills have been mastered by the students he gives the students individual practical work. He gave his rationale:

> Interviewer: What methods do you normally employ in teaching laboratory work?
>
> Zivanai: It depends on the stage for example when they are in Lower Sixth they need lots of assistance from the teacher. I demonstrate the use of equipment, they work in small groups and this is not for evaluative purposes [...] We change stages in Form 6 we gradually get to the individual. We expect them to be scientists in their own right. They must learn to have their own results.

For all four observed lessons, Zivanai's pattern of instruction was basically the same. Typically he would start by introducing the day's problem of investigation. Almost always the problem for investigation is sourced from past examination papers. During the pre-laboratory talk the students listen and write notes. The talk is mainly about going through the laboratory worksheet with the students with the teacher explaining the distribution of apparatus and reagents. Although the practical is to be done individually, the students are told that they are free to exchange information and discuss their results during the practical. Students ask questions pertaining to aspects of the practical as they read about it from the worksheet. Students start working on the practical. The laboratory assistant is present all the time and assists students with manipulations of apparatus. In one practical the lab assistant was seen to spend some time with a student who was struggling with using pipette filler.

Students work quietly at first but the laboratory becomes noisy as the practical period progresses. Meanwhile the teacher has disappeared to his office. The noise level rises. Occasionally the lab assistant shouts at the students "Hey guys too much noise". Students are seen to share ideas and ask each other questions. The girls generally appeared to be less talkative and more self-centered and individualistic than the boys. They also appeared to be less confident in following the procedures of the practical work. During one of observed laboratory sessions, students were seen checking on each other's titres. One student whose volume was much different from the others went back to repeat a titration. The teacher pops in from his office to check on students' progress. He moves around the class making stops here and there. Students are reminded that their laboratory reports should be handed in by the end of the following day. After collecting and marking the students reports the teacher would then discuss the practical during one of the theory lessons.

Fidel

Like Zivanai, Fidel is also a product of the Zimbabwe-Cuba programme. Fidel believes that the main purpose of laboratory work is to help students to understand theory and to elicit and correct students' misconceptions. He described his practice:

> Fidel: We do practicals, which relate to the syllabus only. In Form 5 we do some practicals from the manual by Manyuchi [Manual with A-level Chemistry practical exercises] after that we just concentrate on preparing for examinations.

Fidel believes that school Chemistry has the potential for productive inquiry (produce scientific knowledge like professional Chemistry), but its scientific character is destroyed by material, syllabus and examination constrains. He said:

> Fidel: Given appropriate equipment and not dealing with the syllabus the conditions will be conducive but you are tied down by the syllabus. Sometimes certain methods, we don't teach using certain methods because of constrains with the system. Exams are prohibitive.

In one of his typical lessons Fidel started off the lesson by reviewing the previous week's practical in which students were required to identify Copper (II) ions in a solution labeled FA6. They were also required to design an experiment to determine the solubility of copper (II) sulphate at room temperature. The teacher performed a demonstration for identifying Copper ions adding ammonia and then sodium hydroxide to solution FA6. Students were asked to compare the teacher's observations and inferences with what they had written in their worksheets. Reference was made to the examination-marking scheme, which the teacher had before him. Marks allocated for each correct observation and inference were given to the students, who in turn compared what the teacher said with the marking done on their worksheets. No effort was made to explain to the students how scientists made their observations. One student raised his hand and asked:

> Student: Sir, in determining solubility of Copper (II) sulphate, number f (i) how many steps are allowed for the design?
>
> Teacher: Usually the number of marks should tell you about how much you should write.

There was no attempt to refer to the process of science but rather an emphasis was placed on marking of students' work in preparation for the examination.

After revision of the previous practical, the teacher went on to introduce the day's laboratory work, titration of acetic acid with sodium hydroxide. The teacher handed out sheets (photocopies from a past examination paper) with the problem of the investigation: determining the concentration of a solution of acetic acid. Each student had his own set of apparatus. The laboratory assistant had already prepared the reagents for the practical. The teacher gave information about which reagents to share and how they were going to be shared. Students were given 10 minutes to read through the worksheet. The teacher then said, "You may begin your practical. I am giving you exactly one hour. I will be collecting the worksheets at the end of the practical". The students got busy working through the practical. The atmosphere was hush with occasional whispers. Students worked individually. The teacher was present all the time moving around but doing little to assist the students. No exchange of ideas between students was observed. The practical session was conducted like a typical examination. Some students showed difficulties with turning the burette tap as they performed the titration. The teacher noticed one of them and commented "My friend if by this time you still can't do a titration properly you are going to be in trouble" The other students stirred and then continued with their work as if nothing had happened. Towards the end of the hour the teacher realized some students were not going to finish the practical. He then announced: "Okay, I am giving you an extra ten minutes, but make sure next time you work on your speed". The session came to an end and the teacher collected the students' worksheets for assessment. He would certainly come back with the same procedure the following week.

Martin

Martin is one of the first graduates from the newly established Bindura University of Science Education. With only two years in the teaching profession he is one of the most inexperienced in his department. He believes that the main purpose of practical work is to help students understand theory. When asked "What is the purpose of practical work?" He answered:

> Martin: To marry information obtained from theory and to help them [students] to retain information. I think you can easily remember if you actively do something. Doing is remembering I think.

His teaching strategy is to give students the theory behind the practical first and then allowing the students to do the practical afterwards. In one of his typical laboratory sessions his students were going to determine the enthalpy of reaction (ΔH_r in Kilojoules per mole) for the decomposition of sodium hydrogen carbonate by experimentally measuring the enthalpies of reactions for the reaction between hydrochloric acid and sodium carbonate and the reaction between hydrochloric acid and sodium hydrogen carbonate. The reaction in question was:

$$2NaHCO_3\,(s) \longrightarrow Na_2CO_3\,(s) + H_2O\,(l) + CO_2\,(g)\ \Delta H_r = ?\ KJ\ mol^{-1}$$

Martin first discussed Hess's law of constant heat summation questioning students on their concepts from Physical Chemistry. He then went through the practical worksheet with the students explaining relevant theoretical concepts and ensuring that Hess's law was understood. As was the case with Fidel and Zivanai, the problems for the practicals are sourced from previous examination papers. The students were then asked to do the practical in pairs. Asked whether it was his normal practice to have students do the practical in pairs, Martin replied:

> Martin: I use the group work because for this particular practical we don't have enough resources. You see we only have eleven of these thermometers for the whole school that includes Physics and Biology so [...] Otherwise it's proper for them to work individually.
>
> Interviewer: But why is it that important for them to do it individually?
>
> Martin: Because we are preparing them for examinations. It's important that each student is able to work alone.

Students went on to do the laboratory exercise. They were seen discussing and sharing ideas. The teacher is present and moves around the class chatting with the students. Students frequently walk into the balance room where the laboratory assistant will assist them weigh samples of sodium carbonate and sodium hydrogen carbonate. At the end of the session students are asked to go and complete the calculations and ensure that they handed in their completed worksheets by the end of the week. Martin was asked whether he thought what he was doing with his class was in any way similar to how scientists practiced science. His reply was that in school Chemistry the practice of science was limited because of the syllabus and examination requirements. He explained:

> Martin: Okay, You see in really Chemistry you don't work with worksheets as the students are doing. Real chemists don't write exams. It's all about discovery. Here we want to verify things and show that what we talk about in theory is actually true.

Abongile

Abongile was a professional neophyte. She had just come out of university (1 year experience) and was handling her first A-level class. Abongile was interested in proving herself as an effective teacher. When asked what she thought was the main purpose of school Chemistry laboratory work, she earnestly replied that it was to prepare students for examinations. The development of students' understanding of the subject matter was only important if it aided the examination preparation goal. She is a strict disciplinarian. Her strictness is revealed by the manner in which she emphasizes accuracy of students' experimental results. During one of the observed laboratory sessions, a student raised a complain about the mark he had been given by the teacher for one of the answers to the post laboratory questions. Abongile had this to say to the student:

> Abongile: Robert [not the real name of the student in question], ee you are one of those who failed to follow instructions. Now if you don't read the instructions carefully you mess up. I always say first read and understand the instructions then go on to do the practical. It's mistakes like yours, which can lead to inaccurate results. By the way your question again.

In one of the observed laboratory sessions, the problem of investigation was the separation of magnesium and copper ions from a solution of FA7 using sodium hydroxide, sulphuric acid, distilled water, test tubes, filter funnel and filter paper. Students were required to design an experiment to achieve the separation and go on to identify the ions in the separated precipitates or solutions. Students were given a handout outlining the problem for investigation. The problem in question was a past examination question. Students were asked to do the practical individually. The teacher emphasized that it was to be individual work and no exchange of ideas or any form of unnecessary interaction was going to be tolerated. Each student was provided with a set of core reagents and apparatus and chemicals to be shared were made known to the students and their place of source indicated. The laboratory assistant was in attendance.

Students went on to do the laboratory. The teacher moved around the class whispering assistance to some students. When one of the students was making a serious error, the teacher stopped the class and boomed at the students:

> Abongile: Now you people, what did I say about adding reagents in qualitative analysis. I said little by little not a whole bucket at a time. If you don't follow instructions your results will always be inaccurate or wrong.

The students continued with the practical still with not much interaction going on among them. At the end of the session Abongile collected the completed worksheets. She was going to mark them putting a lot of emphasis on accuracy of observations. If the marking showed her that the students had problems with the practical she would come back the following session and start by performing a demonstration. She said she always wanted the students to do the practical first then she could follow it up with class discussions or demonstration or both.

When she had marked the students scripts, she came back in the following laboratory session and started by reviewing the students' answers. She reported that one quarter of the students had done well. Most had failed to follow instructions. The teacher went on to propose and demonstrate her own method for separating copper ions from magnesium ions. The students said the teacher's method for separation of ions was good. Abongile challenged students who thought their method was good to come forward and share it with the class. None of the students volunteered. Instructions for the day's practical were given and students went on to do the practical. This time it was strictly individual work. The problem had again been sourced from a past examination paper and no student-student cooperation was tolerated.

Mawonde

Mawonde is of the view that in addition to developing students' understanding of theory practicals also serve the purpose of developing students' abilities to manipulate apparatus and chemicals. He is of the opinion that school Chemistry laboratory work is not very different from the Chemistry practiced by the frontier scientists. The only difference according to him is that 'real chemists' do their practicals more accurately with greater precision and have plenty of chemicals and apparatus.

> Mawonde: I can say they are the same the difference lies in the accuracy, precision and purity of chemicals and also they [chemists] have more resources. Some procedures are the same.

His laboratory work teaching strategy is that when students are in Lower Sixth he organizes practical activities involving both individual and group work. This is also accompanied by occasional teacher demonstrations. He explained:

> Mawonde: I first make them know the apparatus and reagents and the manipulative skills. I also emphasize laboratory safety. I do some teacher demonstrations to illustrate the skills after that I allow the students to do it on their own correcting them. Then they work in groups then they work individually. I can say in Lower Sixth they work in groups but in Form 6 its mainly individual work.

> Interviewer: When they work in groups what exactly do you allow them to do

and not to do?

Mawonde: Interaction within the group and across the groups, discussing data, exchanging data, interpreting data. After that we can look at results as a class.

Interviewer: What is it you think students find difficult in laboratory work?

Mawonde: Designing experiments is most difficulty especially in reaction kinetics. They also have difficulties in making observations and completing [experiments] in time. Now in Upper Sixth they have to work under exam conditions and individually except when there is a shortage of apparatus.

When his Upper Sixth Chemistry class was observed he was seen to introduce the practical work by outlining the purpose and theory of the experiment. Like most of his contemporaries, the problems for the investigation are sourced from past examination papers. During the observed sessions, students started off quietly at first but went on to discuss and interact among themselves as the laboratory progressed. The teacher moved around and assisted students mainly with manipulations of apparatus. The teacher emphasized that the worksheets had to be completed and handed in at the end of the lesson. In one of the observed sessions students were standardizing a solution of hydrogen peroxide using potassium permanganate. The teacher first explained the reaction theory. Students were asked questions requiring recall of balancing redox reactions and the mole concept. The teacher then illustrated how they were going to calculate the concentration of hydrogen peroxide. Students went about doing the titration, working individually but exchanging ideas, results and showing each other their calculations. The teacher was moving around mainly checking on students' abilities to handle the burette and associated equipment (pipettes, pipette fillers, etc.). He would give limited assistance here and there. Most of the students were unable to complete the exercise in the time stipulated by the teacher. The teacher gave the students extra time. At the end of the session the teacher collected students' completed worksheets for assessment. When the teacher was asked why he had chosen this particular strategy, his reply was that he wanted students to work on their speed in performing titrations because there was danger that they might not be able to complete the three questions in the examination.

Kundai

> Kundai: Syllabus specifications will tell me what practicals to teach otherwise I would not try new things. If you try new things and things go wrong you might have difficulties explaining.
>
> Interviewer: What things might go wrong?
>
> Kundai: If students fail the exam they will say that teacher with his experiments. At this school its examination results that count. If students fail they say you can't teach even when the students are not that good.

The above conversation summarizes Kundai's attitude towards practical work. Strictly it is about preparing students for the examination, staring in Lower Sixth. Almost every practical session is a mock examination. Students go through three questions as in the examination. What he actually does is to take the past examination papers year by year and say "This week's practical is 1997 examination, next week its 2001" and so on. Students are told which examination practical they will be doing a week before the practical and asked to prepare and read around the subject matter. When the day of the practical comes they go to the laboratory to find the laboratory assistant having set up the reagents and other materials as in the examination. The teacher hands out the worksheets with questions and spaces for filling in the answers. Students are given necessary information pertaining to the organization of the practical. They are then started with the teacher keeping time strictly. Students work through the practical individually. Communication among the students is kept minimal. The teacher moves around the laboratory giving minimal assistance to the students. At the end of the session the teacher collects the mock-examination scripts for assessment. After marking the scripts the teacher goes through the answers with the students during one of the week's theory lessons. If there is an experiment which has been very badly done the teacher performs a demonstration. Students can ask questions and engage in discussion with the teacher but only at this stage. In the process of feedback the teacher has his marking scheme handy (actually the real marking scheme used that year for the examination in question). He tells students how the marks were allocated. He gives students hints on how to get the maximum marks from a practical examination. Students raise problems about calculations. The teacher goes through the calculations with the students. Emphasis is given to the fact that in the practical examination the most important thing is to make accurate observations and measurements. The A-level Chemistry syllabus stipulates that more marks are given for observations and accurate results.

4.5.7 Summary of teacher laboratory instructional practices from the lesson observations and interviews

The picture of each of the observed teacher's laboratory instructional practice emerging from the lesson observations and interviews is displayed below, Table 4.6. From the laboratory observations, it emerged (or it was discovered) that the degree of open-endedness or extend of inquiry was low in most of the observed sessions if we use the peg marks of: the latitude given to students (degrees of freedom) to make decisions concerning; the choice of the problem for investigation, how to carry out investigations and communicate findings (Tamir, 1991). This feature of the nature of inquiry (the nature of tasks and activities) appeared to be fixed or determined more by the nature of the curriculum and examination requirements than by the teacher. Differentiation of instructional practice as closed or open-ended was largely invested in the assessment of: the nature of student-student and teacher-student interactions and how strongly teachers emphasized verificationism and preparation for examinations.

As the summary table shows, teachers' instructional practices range from very low inquiry (Fidel, Abongile and Kundai), through low inquiry (Mawonde and Martin) to medium inquiry (Zivanai). The nomothetic categorization done here differs slightly from that done through teachers' perceptions of their instructions (tLPVI). This is not surprising. Disconnections between what teachers said they did, and what they were observed to be doing in classrooms were also found in a study of urban elementary science teachers by King et al. (2001). The lesson observations suggest that the level of inquiry in the teachers' laboratories is slightly lower than what some of the teachers' responses to the tLPVI suggest. Tsai (2003) has referred to these disconnections as epistemological gaps. For the categorization done in the present study, the placement is slightly different for 3 teachers (Fidel, Kundai and Abongile). It is different for Kundai who moves from medium inquiry to very low inquiry. Fidel and Abongile shift from low inquiry to very low inquiry. It should be emphasized that the decision to place a teacher into a category (see Table 4.6 below) is based on the criteria of level of student-student interaction, use of practical work for understanding theory, and frequent use of verificationism.

Table 4.6 Summary of observed teachers instructional practices

Teacher	Objective of labwork	Main Strategies	Level of interaction	Level of inquiry	Mentioned constraints
Zivanai	-Develop students' NOS images and understanding of theory -Examination preparation	-Practical then theory -group practicals -teacher demonstrations -problem solving	High student-student interaction	Medium inquiry	Examinations Syllabus content Resources
Fidel	-Correct misconceptions -Understanding of theory -Examination preparation	-practical to theory -teacher demonstrations -Individualized practicals -Guided discovery	Low student-student interaction	Very Low inquiry	Examination focus Inadequate materials Syllabus constraints
Martin	-Understanding theory -Examination preparation	-Verificationist -theory to practical -Individualized	High student-student interaction	Low inquiry	Examinations Materials/Resources
Abongile	-Examination preparation	-Verificationist -Guided discovery -practical to theory -Individualized	Low student-student interaction	Very Low inquiry	Syllabus content Examinations Resources
Mawonde	-Manipulative skills -Understanding theory	-Verificationist -Guided discovery theory to practical -Group work mainly individualized	High student-student interaction	Low inquiry	Examinations Resources Syllabus content
Kundai	-Examination preparation -Understanding theory	-Verificationist -Guided discovery -practical to theory -Individualized	Very low student student interaction	Very low inquiry	Examinations Syllabus content Resources

Table 4.6 shows that a high level of student-student interaction does not mean the teacher's instruction is of high inquiry. Student-student interaction can still be high but all the students will be discussing is verificationism. Students can exchange ideas without necessarily engaging in the kind of discourse described by Newton et al. (1999) as scientific argumentation; for example, arguing about the merits and demerits of procedures, conclusions, hypotheses etc. This was found to be mainly the case in Martin and Mawonde's laboratory classes. For example students in these classes would exchange such questions as "What is the average value for your titration?" They however would not engage in discourse about why their values could have been different. Such a discursive engagement is essential for students (Driver, Newton and Osborne, 2000) if laboratory inquiry is to be a cognitive apprenticeship into the practice of science (Sandoval and Reiser, 2004).

4.5.8 Teachers' science epistemological beliefs and laboratory instructional practice

In this section the interaction between teachers' science epistemological beliefs and instructional practice is considered. First a correlation was made between teachers' scores on the TSEBQ and the tLPVI. A Pearson correlation coefficient of 0.23, $p = 0.45$, for a 2-tailed test was obtained. According to Cohen et al.(2000), this value shows a limited slightly weak relationship. Only 4 % of the variance can be explained by the obtained correlation coefficient. This could point towards a weak interaction between teachers' science epistemological beliefs (SEBs) and their instructional practices. The categorization of teachers' instructional practices done by the tLPVI is not much different from that coming out of the lesson observations. If as Fraser (1998) suggested, teacher perceptions are a reliable indicator of the classroom practice then the interaction of teachers SEBs into practice can be taken as weak.

Secondly an analysis is made of the interaction between teachers' SEBs and laboratory instructional practices as determined by the interviews and lesson observations. This analysis shows an interesting pattern. The pattern can best be represented in table form as shown below, Table 4.7.

Table 4.7 Observed teachers' SEB and their laboratory instructional practices

Teacher	NOS beliefs category	Instructional practice (Level of inquiry)
Martin	Traditional	Low
Kundai	Traditional	Very low
Abongile	Traditional	Very low
Fidel	Fairly Traditional	Very Low
Mawonde	Fairly Non-Traditional	Low
Zivanai	Non-Traditional	Medium

Examination of Table 4.7 shows that the one teacher whose SEBs can be considered clearly non-traditional also shows instructional practice which can be described as of medium inquiry. One would be tempted to support Tsai (2002) and say there is a relationship between holding constructivist (non-traditional) SEBs and practicing more open-ended laboratory instruction. Such a generalization however is impossible given the sample size. It is more fruitful to examine the nature of the interaction at the individual level of the teacher. Meaning making and interpretation of the interaction can be done from the insights inherent in some of the teachers' interview responses and the observed lessons.

Zivanai appears to hold strong beliefs about science as progressing through consensus and that scientists are creative. That belief however only feebly attenuates into (interacts with) instructional decision-making and eventual instructional practice. He identifies a constraint responsible for the nature of attenuation:

> Zivanai: We repeat experiments whose results are known rarely do we ask students to be creative. Our education system is examination oriented there is little room for students to be creative.

In his practice however, Zivanai is seen to struggle against an "un-friendly" instructional environment and still make decisions and do practices he believes can bring about students' understanding of science and how it is practiced. He is observed to organize group activities and encourage students to engage in scientific discourse (Driver, Newton and Osborne, 2000; Duschl, 2000; Duschl and Osborne, 2002; Newton et al., 1999). Some of his beliefs taper into (however small the amplitude), his instructional decision-making and eventual instructional practice. Evidence of this feeble attenuation also comes from the practices and responses of Mawonde.

Mawonde believes that science is inquiry and students should be taught the skills and practices inherent in the scientific method. In his instructional practice he attempts to concentrate on manipulative skills development but the extent to which he does so appears to be limited by factors in the instructional environment; the syllabus content, lack of resources and examinations. When asked whether the way he was teaching laboratory work made students understand scientific inquiry as he understood it he replied:

> Mawonde: You don't always teach the way you want science to be like because of these examinations, and also sometimes you don't have resources. It's' not always about what you believe, not in our system.

This is also observed with Teacher Fidel who also raises the same issues. In a quotation given above Fiedel says: "you are tied down by the syllabus... we don't teach using certain methods". This is irrespective of the fact that Fiedel believes that "the major characteristic of a scientist" is "the inquiry approach". Fidel also says given the appropriate conditions the practice of inquiry would flourish in the classroom. In his practice he is seen to be trying to give students a feel of inquiry, as he understands it when students are in Lower Sixth. At least then he makes them explore some practical activities from the book by Manyuchi. In Form 6 he moves into examination gear. His practice might be viewed as an effort to balance examination demands and his convictions about inquiry.

As Table 4.6 shows all the interviewed teachers raise inhibiting environmental factors (resources, examinations, educational system, the syllabus demands). That some environmental constraints sort of "inhibit" the translation of teacher beliefs into practice is not surprising. This supports assertions (Abd-El-Khalick, Boujaoude, Duschl et al., 2004; Abd-El- Khalick and Lederman, 2000; Lederman, 1992) that the translation of teachers NOS beliefs into instructional practices is difficult because of these intervening variables or barriers. According to Martin (1999) these constraints, which she calls *external beliefs*, have an influence on teacher decision-making and instructional practice. What appears to be the case with the teachers in the current study is that the extent to which the teacher's SEBs filter onto the laboratory instructional practice is reduced by the "external beliefs". The effect of the external belief or constraint appears to be to make teachers not to teach science "the way you want" or not always to teach, "what you believe". As the teachers' instructional practices and the interview transcripts suggest the teacher instructional practices appear to be a balance between their own SEBs and external beliefs/contextual factors/barriers or constraints. Some of the teachers' beliefs appear to filter onto the practice.

Because they are factors in the instructional environment, which sort of inhibit or intervene or interfere with the translation of teachers' SEBs into instructional decision-making and eventual practice this author will call them *attenuating factors* (could be called competing factors). They interfere with the interaction between (translation of) teachers' science epistemological beliefs and (into) instructional practices. The apparent influence of these instructional environment factors on the attenuation shall be coined here, *in vitro attenuation.*

The translation of a teacher's SEBs into instructional decision-making and practice also appears to suffer from some other influence within the teacher's conceptual ecology. An interesting observation is the apparent association between teacher beliefs about (conception of) inquiry and teacher instructional practice. When asked to explain what she understood by laboratory inquiry Abongile had this to say:

> Abongile: I think eee [...] it is how scientists gather information or can I say discover things. Its how scientists show that or obtain new knowledge and showing by experiments that that knowledge is actually true.
>
> Interviewer: You are talking about what scientists do but what about here in your laboratory with your students?
>
> Abongile: Here we want students to learn by doing experiments so that they pass the examination.

There is an apparent link between believing that scientific inquiry is about scientists "showing by experiments that knowledge is actually true", that school laboratory inquiry helps students "to learn by doing experiments" and Abongile's practice of instruction which is mainly verificationistic (as witnessed during the laboratory lesson observations). Beliefs about the purpose of experiments in professional science appear to be linked to the teacher's beliefs about the purpose of experiments in school Chemistry. This is not surprising, since teachers' epistemological beliefs have been shown to be related to teachers' beliefs about teaching (Aldrigde et al., 1997; Tsai, 2002). Beliefs have also been known to be interrelated (Hofer and Pintrich, 1997; Pajares, 1992). Three of the teachers (Kundai, Abongile and Fidel) who believe that scientists do experiments to verify theory also appear to be the ones who strongly believe that school Chemistry experiments serve the purposes of verifying concepts, learning how to observe, and developing student understanding of theory in preparation for examinations. This appears to have some influence on the way they organize their laboratory instruction; individualistic and low student-student interaction. Zivanai and Mawonde with instrumentalist beliefs about the purpose of laboratory inquiry in science appear to be the ones whose beliefs about examinations as the purpose of school Chemistry are not very strong. They are also seen to organize laboratory activities in which student-student interaction is relatively high. It would appear that teachers' beliefs about the purpose of experiments in professional science also interact with their beliefs about the objectives of school Chemistry laboratory work and with their instructional practices. Beliefs about teaching and the objectives of school Chemistry are part of what Martin (1999) categorized as *internal beliefs*. These internal beliefs appear to interact with teachers' science epistemological beliefs (SEBs) and also strengthen the attenuation of the SEBs into instructional practice.

A belief about teaching such as about the purpose of laboratory work in Chemistry, that is embedded within the teachers' conceptual ecology, and which also appears to influence or interact with the translation of teachers' SEBs into practice is an attenuating factor. Because such factors are embedded within the individual, this author will call them *in vivo attenuating factors*.

It appears that the interaction between teachers' SEBs and their instructional practices suffers from both *in vitro* and *in vivo attenuation.*

4.6 Discussion

This study used an adaptation of Abraham's 1982 instrument to assess teachers' perceptions of their laboratory instruction. The categorization of teachers' levels of classroom inquiry done using the instrument has shown reasonably little variation from the categorization done using lesson observation and interview data. As far as the author can ascertain, this is the first time that Abraham's instrument has been used in this way. The results emanating from the use of the instrument though with a small sample size appear to be encouraging. It is reasonable to suggest that Abraham's instrument can be used to assess teachers' perceptions of the nature of inquiry in science laboratories (Physics, Chemistry, Biology). Research to further develop this instrument for this purpose is recommended.

In their review of studies of teachers' understandings of the NOS, Abd-El-Khalick and Lederman (2000) and Lederman (1992), have suggested that the translation of teachers conceptions of the NOS into classroom practices is constrained by such variables as pressure to cover content, resources, examinations and motivational requirements. Their argument is based on the pre-supposition that such a translation must necessarily result in teacher practices that promote desirable students' NOS conceptions (non-traditional or contemporary understandings). The existence of constraints or intervening variables does not in itself constitute evidence for lack of interaction between teachers SEBs and their instructional practices. In fact as is evident in some of the teachers' in the present study (Abongile, Kundai), so-called constraining variables can actually foster attenuation of verificationistic SEBs into laboratory practices. An examination-focused curriculum can actually promote translation of teachers' traditional NOS conceptions into practice. In this case it is not a constraint. The influence of instructional environment factors is not always necessarily to negate attenuation. It is safer to replace the idea of constraints with attenuation factors. An attenuation hypothesis is safer because it does not pre-suppose translation to mean teacher practices that promote desirable students' NOS understandings.

Previous studies (Newton et al., 1999; Tsai, 2002) have pointed towards teachers' habouring of non-traditional (constructivist) beliefs as meaning engaging in teaching practices that are also constructivist or open-inquiry oriented. The results of this study fail to fully support that view. Teachers' beliefs have been said to be the most important factors in governing teachers' instructional decisions (Haney, Lumpe, Czerniak and Egan, 2002; Pajares, 1992) and action agendas. They are said to ultimately determine the nature of instruction the teacher will put into practice (Duschl and Wright, 1989; Schraw and Olafson, 2002). Cronin-Jones (1991) concluded that teachers significantly altered the implementation of their curricula to be in congruency with their own teaching contexts and beliefs systems. This study gives support to that conclusion. It shows that teachers' beliefs (at least NOS beliefs) only feebly attenuate into (or influence) their instructional practice. The translation of teachers' beliefs into practice appears to be governed by the state of equilibrium between *in vivo* and *in vitro* factors. In deciding the nature of his/her practice the teacher appears to strike a balance between those convictions embedded within his/her conceptual ecology and factors obtaining in the environment in which he/she is supposed to operate as a teacher. The part of the teacher's belief system that eventually filters onto the practice is only but a trickle from the interplay of that balance. This could explain the observed weak correlation between teachers' SEBs and their perceptions of instructional practice. Teachers practice what they believe, but only to a limited attenuated extent.

4.7 Implications for curriculum and instruction

Overall, the observed and interviewed teachers have raised issues about the "examination focusedness" of the A-level Chemistry curriculum as an impediment to their practice of inquiry. The fact that some of the interviewed teachers appear to practice more inquiry oriented instruction in Lower Sixth and tune into an examination mode in Upper Sixth demonstrates what the cloud of examinations hanging over the laboratories can do to the nature of teacher instructional practice. If it is accepted that teachers' use of inquiry oriented instruction can promote the development of desirable NOS conceptions among the students, then there is need to think about reforming the nature of practical work assessment in Zimbabwe's A-level Chemistry. The teachers observed in this study tend to concentrate only on those activities they know will be assessed in the final examination. Different practical work assessment models could be tried. Bennet and Kennedy (2001) have reported the use of teacher based assessments and visiting examiner as possible alternatives to the end of year examination. This is not to say these alternatives don't have their own weaknesses. Whereas in the United Kingdom various A-level Chemistry practical work assessment models have been tried and are in use, Zimbabwe appears to be still clinging on to that one assessment model courtesy of the colonial legacy.

Additionally, in line with trends in contemporary science education, the A-level Chemistry curriculum needs to be re-examined with the objective of making the NOS an explicit curriculum goal. This necessitates a reform of the curriculum content. As Abd-El-Khalick and Lederman (2000) have recommended, making the teaching of the NOS an explicit curriculum goal can result in improvements of students' NOS conceptions. Such a reform will have implications for Zimbabwean science teacher education.

4.8 Conclusions

The major findings of this study are:

(i) The sampled teachers hold fairly non-traditional and traditional beliefs of the selected aspects of the NOS.

(ii) The level of inquiry in laboratory work instruction for the sampled schools is generally low.

(iii) The interaction between teachers' SEBs and laboratory instructional practices is weak.

(iv) The interaction between teachers' SEBs and laboratory instructional practice appears to suffer from attenuation.

This study has examined teachers' beliefs in the framework of traditional non-traditional conceptions of the NOS. No attempt was made to explore the SEBs and their interaction with practice within the realm of products and processes of science dimensions of the NOS construct. This can be a subject for further research. It could also be interesting to find out how the A-level teachers conduct their theory lessons and what effect this might have on students' NOS understandings.

CHAPTER FIVE

Paper two

High School Chemistry students' images of the nature of science and perceptions of laboratory instructional practice

5.0 Introduction

For over a hundred years, school science laboratory instruction has been linked to the development of students' knowledge or images of the Nature of Science (NOS) (Jenkins, 1998; Nott, 1997). The nature of laboratory instruction has been assumed to be related to students' images of the NOS (Abd-El-Khalick, Bell, and Lederman, 1998; Edmundson and Novak, 1993; Hodson, 1996a; Hogan, 2000; Lederman, 1992; Rudolph, 2003; Lederman and O'Malley, 1990; Newton, Driver and Osborne, 1999; Ryder and Leach, 1999, 2000; Tsai, 2002, 2003). In their study of the relationships among science epistemological beliefs, gender, approaches to learning and implementation of instruction in Chemistry laboratory, Saunders, Cavallo and Abraham (1999), found that college students' science epistemological beliefs or images of the NOS were not related to the type of laboratory instruction (inquiry or non-inquiry) employed by the teacher. In contrast, studies by Tsai (1998, 1999, 2003) with Taiwanese eighth grade (14 year-olds) and tenth grade (16 year olds) students showed that students' science epistemological views (images or beliefs about the NOS) were related to both the nature of laboratory instruction and students' perceptions of the instruction.

These contradicting findings could mean that the students' age level is a factor in determining association between images of the NOS and perceptions of the nature of instruction/ laboratory inquiry. Other than the studies by Tsai, the interaction between students' images of the NOS and their perceptions of secondary school science laboratory instruction remains largely unexplored. It would be interesting to explore the nature of this relationship within the context of an African High School/ Advanced level (A-level) school Chemistry laboratory. To this author's knowledge, no study examining students' images of NOS and their perceptions of laboratory instruction has been done with High School Chemistry students in Zimbabwe.

Students' perceptions of instruction have been used to describe, determine, explore or characterize the nature of teaching and learning activities (instructional practices) in school science laboratories (Abraham, 1982; Fraser, Giddings and McRobbie, 1995; McRobbie, Lucas and Roth, 1997; Tsai, 1998,1999, 2003; Soyibo and Figueroa, 1998). The perceptions can be taken as reliable indicators or determinants of actual classroom practices. Fraser (1998) alludes to the use of teachers' and students' perceptions to assess the classroom learning environment as being more reliable than the independent observer.

Gathering data on students' perceptions of their classroom environment can be done quantitatively through the use of closed questionnaires or qualitatively through interpretive interviews or through a combination of both strategies. In this study student' perceptions of their laboratory environment, specifically the instructional practice were obtained through a quantitative questionnaire and interviews. Images of the NOS were similarly determined.

Knowledge of students' images of NOS and their perceptions of laboratory instruction can inform both curriculum development and inquiry-oriented constructivist pedagogy in Chemistry education. Constructivistic pedagogy entails understanding and responding to students' curiosity, prior knowledge and experience, and adapting curricula to students' interests and views (Campbell, 2001; Yore, 2001). For laboratory instruction, inquiry is an essential ingredient of constructivist-oriented practice (Abd-El-Khalick, Boujaoude, Duschl et al., 2004; Domin, 1999; Shiland, 1999). What students think about science and how they experience its teaching and learning (instructional practice) in the laboratory is of interest to those engaged in the processes of curriculum change and innovation for both school Chemistry and Chemistry teacher education.

It is against this background that this study sought to investigate the students' images of the NOS, their perceptions of laboratory instruction and the possible interactions between students' images of the NOS and perceptions of laboratory instructional practices. The following research questions guided the research.

1.What images of the NOS do A-level Chemistry students hold?

2. How do the students perceive A-level Chemistry laboratory instructional practice?

3. What is the nature of the relationship (if any) between the students' images of the NOS and perceptions of laboratory instructional practice?

5.1 Theoretical Framework

This study is informed by what the literature reveals about students' images of the NOS and perceptions of laboratory work instruction. The literature related to this study is reviewed under two sub-headings of (i) studies of students' images of the NOS and (ii) studies linking students' NOS images and laboratory instruction. Before briefly examining this literature it is important to give an understanding of images of the NOS.

5.1.1 Images of the nature of science

The ideas an individual holds or displays about the nature of scientific knowledge and the processes of its development and validation have been described as images of science (Driver, Leach, Millar and Scott, 1996). Leach, Millar, Ryder, et al. (1998, p.8) describe images of science as: the profile of ideas about "the epistemology and sociology of science used by individuals in specific contexts for specific purposes". According to a theory of mental representations by Johnson-Laird (1983), individuals can have mental and perceptual pictures of a scientist, a scientist's laboratory, or the nature of scientific knowledge. These pictures or models can be physical (physical entities such as laboratory, scientist, etc) or conceptual (mental constructs of concepts, e.g. atom, ion, etc) or both. An expression of views or beliefs or conceptions or understandings about such pictures constitutes an image of the NOS.

The phrase "images of the nature of science" (INOS) can be taken broadly to mean the views, beliefs, perceptions, conceptions and ideas about scientific knowledge and the process of its development that are held, expressed or displayed by an individual. This includes ideas about scientists and the nature of the scientific enterprise.

5.1.2 Studies of students' images of the NOS

According to Lederman (1992), studies of secondary school students' understandings, beliefs, views, images, and conceptions of the NOS started in the 1954 with a study by Wilson who measured High School students' attitudes towards science. Another study by Klopfer and Cooley followed in 1961. Early NOS studies were quantitative paper-and-pencil tests, for example the Test of Understanding of Science (TOUS) developed by Klopfer and Cooley in 1961. During the late 1960's and the 1970's, more quantitative studies were done utilizing the instruments developed by such people as Kimball, Aikenhead and Ryan and Rubba and Anderson. Generally, the results of the tests with these mainly Likert-type instruments almost invariably showed that most High School students held inadequate understandings of the nature of science.

By understandings being inadequate it is meant that the students were shown to hold beliefs about science, which were invariant with contemporary understandings of the NOS (Rudolph, 2003; Tao, 2003; Alters, 1997). Such beliefs or understandings have also been described as "traditional" (Pemeroy, 1993). As an example, students were found to believe that scientific knowledge is absolute and that the objective of science is to uncover the laws of nature (Wilson, 1954). Other studies also showed that students did not understand the role of creativity in science, the amoral nature of scientific knowledge, the tentative nature of science, the theory ladenness of scientific observations, the role of experiment in science and the interrelationships and interdependence of the various branches of science (Lederman, 1992).

Following these disappointing results, reasons were sought to explain students' poor understandings of the NOS. Science curricula were accused of suffering from content and other deficiencies and constrains (Lederman, 1992; Abd-El-Khalick and Lederman, 2000), which made the realization of students' adequate NOS conceptions difficult. These accusations continue to this day (Abd-El-Khalick, Boujaoude, Duschl et al., 2004). The hands-on inquiry oriented curricula of the 1960s and 1970s was partly a result of the conviction that by "doing science" students would come to understand the NOS (Abd-El-Khalick et al., 1998; Abd-El-Khalick, Boujaoude, Duschl et al., 2004). Hodson (1996a) attacks the legitimacy of this thinking, arguing that these curricula distorted and confused the NOS. Teachers' own NOS inadequacies (Abd-El-Khalick and Lederman, 2000; Lederman, 1992) and inappropriateness of science pedagogy (Hodson, 1996a) were also apportioned blame. As Lederman (1992) reports much research energy was focused on improving science education curricula, teacher NOS conceptions and methods of teaching science as a way of getting round the problem of inadequate student understanding of the NOS.

It dawned on others however that the quantitative instruments which were used to nomothetically classify students and place them on a normative map of NOS understanding ranging from realism to constructivism, or traditional to non-traditional were in themselves inadequate and misleading measures of the NOS (Abd-El-Khalick and Lederman, 2000; Bezzi, 1999; Chan, 1999; Hogan, 2000; Lederman, 1992). *Qualitative methods* gained popularity.

Some writers on the subject of students' understandings of the nature of science (Abd-El-Khalick and BouJaoude, 1997; Moss, Abrahams and Robb, 2001) have argued that the criteria which has been used to judge students' NOS conceptions as adequate or inadequate have been too complex and really relevant for judgement of philosophers of science, science educators or sociologists of science but irrelevant to the needs of school science teaching and learning. Moss, Abrahams and Robb (2001) proposed a model of NOS understanding they say is suitable for secondary school science. They proposed that the nature of the scientific enterprise should include (rephrased by the author):

- Science is only one of the ways of knowing about the universe. The universe can be known through scientific exploration.
- Scientific exploration attempts to explain and predict phenomenon, compare theories, check on previous results and generate new questions.
- Logic, imagination, *dream*, curiosity, serendipity and even *stupidity contribute to generating scientific knowledge.*
- Science is a social activity influenced by personal, cultural, *historical economic, political, and religious factors.*
- The scientific endeavour is characterized by, questioning, data collection, drawing conclusions, and communication. Scientific research makes use of both experimentation and naturalistic observation.

Scientific knowledge is characterized by the following:

- Scientific knowledge demands evidence and is testable through the scientific enterprise.
- Science cannot provide answers to all questions.
- Scientific knowledge is tentative and developmental.

Under the light of these NOS criteria, Moss et al. (2001) *qualitatively examined* NOS conceptions of pre-college students and found that students held fully informed views about the tentative and developmental nature of scientific knowledge but were unsure about the nature of the scientific enterprise. This result supports the notion that secondary school students habour informed views on some NOS aspects and inadequate views on others. Another study giving credence to this notion is by Haidar and Balifakih (1999) who found that the majority of the sampled students believed that scientists could make different observations of the same thing (a modern view of scientific observations). The same students also said scientists reported only what they see; a traditional and ill-informed view. This partly supports the finding of BouJaoude (1996) who concluded that the majority of High School students held traditional views of the nature of scientific observations.

As was the case with the shift to qualitative methodology, the redefinition of criteria for assessing students' NOS conceptions did not result in studies showing a change in the status of students' understandings of the NOS (despite the findings by Moss et al., 2001). Research continues to show that many students from primary school up to university, have inadequate NOS understandings (Abd-El-Khalick and Lederman, 2000; Sandoval and Reiser, 2004; Sere, Leach, Neidderer et al., 1998). McComas (1996) has produced a set of ten misconceptions about the NOS, which he says are common among secondary school and university students throughout the world. Some of the common inadequate conceptions (misconceptions) about the NOS listed by McComas include the beliefs that: scientific observations are theory free, there is one method of science, and scientific knowledge can be proved through carrying out experiments. In the "Pemeroy sense" these views of the NOS can be described as traditional.

A recent study by Tao (2003) showed that junior secondary school students believed that scientific theories could be proved by experiments, scientific knowledge is absolutely true and that the purpose of experiments in science is to discover knowledge. This study showed that the students generally held empiricist views of science. It is also interesting to note that following the criticisms of the mainly nomothetic and quantitative NOS studies (Bezzi, 1999) of the 1960s and 1970s, some researchers (Haidar and Balifakih, 1999; Tao, 2003; Tsai, 1998,1999) have methodologically made ideographic probes of students' NOS understandings but have used the data to normatively place students along continua of positivism/constructivism, traditional/non-traditional etc.

In Taiwan, Tsai (1999) found that some secondary school students whom he called constructivist believed that: scientific knowledge was imaginative, problematic (gave no clear correct answers), dynamic and tentative, and that science was just another human activity done by people who did not rely on a certain method or a prescribed set of procedures. On the other hand, empiricist students had the views that science was a collection of accurate and valid knowledge, and the building of scientific theory as emanated from gathering evidence. Haidar and Balifakih (1999) produced similar results and described students as positivist or constructivist. Positivistic students for example saw observations as theory-free. In another study Tsai (1998), found that constructivist students valued the importance of conceptual understanding, and preferred learning environments, which made learning meaningful by promoting the use of their prior knowledge. Empiricist students on the other hand believed that they could learn best if teachers presented them with information for remembering. It was concluded that students' science epistemological beliefs were related to their learning orientations. This contradicts the findings of Saunders, Cavallo and Abraham (1999) who did not find any relationship between beliefs about science and learning orientation.

According to Lederman (1992), the literature on studies of students' images of the NOS is not conclusive about the relationship between student gender and science epistemological beliefs (views of the nature of science). However, a study of college students taking an introductory Chemistry course by Saunders, Cavallo and Abraham (1999), found that student' epistemological beliefs were related to gender. In their study of NOS conceptions of Aboriginal students, Sutherland and Dennick (2002) found that the students' culture and language affect understandings of the nature of science. Song and Kim (1999) found that students' images of a scientist were related to the mental age of the student, with older students seeing themselves as different from real scientists compared to the younger students. These observations make the exploration of relationships among such variables as age, gender, culture, and learning orientations and the images of science held by students an interesting research venture. While this may be so, such a foray was not a major concern in the current study. This exploration was therefore limited to only two variables; gender and the type of school (boarding or day) attended by the student.

5.1.3 Studies linking students' images of science and laboratory work

Over the past ten years a number of studies have examined students' images of the NOS within the context of laboratory or practical work (Lucas and Roth, 1996; Martin, 1999; Ryder and Leach, 1999, 2000; Sere et al., 1998; Sere, Fernandez, Leach et al., 2001; Tomkins and Tunnicliffe, 2001; Tsai, 2003, 1999). The bundle of research papers from the Labwork in Science Education research programme[3], investigated the ways in which students' notions of science (images of the nature of science) influenced their learning and actions during laboratory work. This research focused on secondary school and university students, and covered the three major disciplines of science (Biology, Chemistry and Physics). One finding recurring in these studies is that students view knowledge claims as emerging directly from experimental data (Ryder and Leach, 1999, 2000; Sere at al., 1998; 2001). Students were seen to believe that scientific theories emerged directly from data analysis and did not see scientific theories as helping scientists to evaluate and interpret data. They were also found to habour the notion that experimental data was a description of the real world (Sere et al., 2001) and the relativist view that different scientists could interpret and explain data differently (Ryder and Leach, 2000; Sere et al., 1998).

While students' activities during laboratory work might be influenced by other variables (guidance, motivation, materials, learning orientation, nature of instruction, etc.), the results of these studies make it increasingly plausible that students' views about the NOS could be a critical factor in guiding students' actions during laboratory work. Students' decisions on how to carry out investigations, what observations to make, which experiments to repeat, what counts as a conclusion and when to repeat experiments might as well depend on their notions of scientific knowledge and the nature of scientific inquiry.

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[3] The Labwork in Science Education Project was a European Commission funded project (February 1996 to April 1998) involving several European countries. The students who took part in the study were in upper secondary school and first two years of university. The science subjects covered in this project include Biology, Chemistry and Physics.

As pointed out, links between students' views of the NOS and their laboratory learning have been demonstrated (Tiberghien, Veillard and Le Marechal et al., 2002; Tsai, 1999). To a very large extend, students' experiences and actions during laboratory work are influenced by the instructional setting (Gibson and Chase, 2002; Hodson, 1993; Tiberghien et al., 2002). The laboratory instructional setting or laboratory learning environment is largely determined by the manner in which the teacher organizes and implements instruction. This in turn is assumed to have a direct bearing on students' views of the NOS (Tiberghien et al., 2002) and their perceptions of instruction (Tsai, 2003) and their laboratory experiences.

It has been mentioned that in his studies with Taiwanese Junior High School students, Tsai (1999, 2003) came to the conclusion that, students' science epistemological views were related to their learning during laboratory work and possibly influenced their perceptions of laboratory instruction. Tsai (1998, 1999, 2003) used selected items from the questionnaire of Pemeroy (1993) and follow up interviews of selected students to determine the students' science epistemological views. Students' responses to the questionnaire and interviews were used to classify the students as holding either empiricist (traditional) or constructivist (non-traditional) views of the NOS. To assess students' perceptions of their laboratory-learning environment, Tsai used the actual and preferred forms of the Science Laboratory Environment Inventory (SLEI) developed by Fraser, Giddings and McRobbie (1995). Interviewing of selected students was also done as a secondary source of data.

Tsai (1999) found out that constructivist students tended to perceive their laboratory learning environments as less open-ended and less integrated than those who were empiricist. They also viewed their laboratories as helping them to understand theory compared to empiricists who saw their laboratories as helpful in their memorization of ideas. To the constructivist student, laboratory work was the same as doing science. Compared to empiricist students, constructivists showed a preference for laboratory classes that gave them opportunities to engage in student-student interaction. Empiricists valued laboratories, which had greater material support and emphasized accuracy of experimental rules and procedures. The study also confirmed that within class students could have different perceptions of their learning environment as found out by McRobbie, Roth and Lucas (1997).

The exploration constituting the present investigation is different from the study by Tsai in two ways. First, the current study uses a completely different

5.2.0 Assessing students' images of the nature of science

5.2.1 Students' images of the nature of science (SINOS) instrument

This instrument (found in Appendix A) was in two parts. For both parts students indicated their responses by ticking in appropriate boxes. The first part (PART A) asked for information about three demographic variables, gender, the subjects the student was doing at A-level and the type of school (Boarding or Day School). Exploration of linkage of students' conceptions of the NOS to similar demographic variables is reported in some studies of students' NOS conceptions (Lederman, 1992; Tsai, 1999) and was seen as of interest in this study. Part B of the questionnaire solicited students' views on selected aspects of the NOS. Students were asked to indicate their views on a five point Likert scale ranging from strongly agree to strongly disagree (Pemeroy, 1993).

Items for the SINOS questionnaire (see Appendix A) were drawn from the instruments of Pemeroy (1993) and Aldridge et al. (1997). Selection of items from an instrument for studying students' science epistemological views has been done successfully by Tsai (1999), who selected seventeen items from the Pemeroy instrument in his study of eighth grade Taiwanese students. For the current study, thirty-one (31) items were selected from both Pemeroy's and Aldridge et al's instruments. The items were chosen to represent both the product and process dimensions of the NOS. Minor changes were made to the wording of the items to suit the Chemistry laboratory context. For example the word "science" was replaced with "chemistry" and scientist with "chemists". For purposes of illustration, the statement: "scientific knowledge is absolutely true because it is based on observations" (from Pemeroy, 1993, p. 274) became "Chemistry knowledge is absolutely true because it is based on observations".

Pemeroy's instrument categorizes items into traditional and non-traditional. The instrument by Aldridge et al. (1997) categorizes items into two groups of process of scientific inquiry (for example, scientific/chemistry knowledge starts from observation of nature) and certainty of scientific knowledge (for example, currently accepted chemistry/scientific knowledge will be changed in the future). Within the context of the dimensions of the NOS defined in this thesis, the certainty of scientific knowledge category falls under the dimension of the product of science and the process of scientific inquiry under the dimension process of science. As can be seen from the examples of statements, categorization of items for both instruments can be done in either way, that is traditional /non-traditional and/or process of inquiry/ certainty of knowledge (product of science). In the version of the instrument used in the current study, this categorization was not shown on the instrument itself, as is the case with the instrument of Aldridge et al. The statements were presented as mixed and the separation into categories only done at the stage of analysis.

Scoring was done as follows: *strongly agree* = 1, *agree* = 2, *not decided* = 3, *disagree* = 4 and *strongly disagree* = 5 (Tsai, 1999). Items representing the non-traditional conception of science were scored in reverse. These items are: 2, 3, 4, 6, 8, 9, 16, 17, 22, 24, 25, 28, 29, and 31 (see Appendix A). A low total (minimum score = 31) score meant agreement with traditional views of science and a high total score (maximum score = 155) meant views that were more non-traditional or constructivist. Tsai (1999, 2002) has used a similar scoring technique.

Before the instrument could be used on the sampled students, its validity and reliability were ascertained. The researcher was not sure about whether or not the A-level students who were going to be the population of the study would not have problems with the meanings of some of the words contained in the selected items. This doubt was largely based on the knowledge that for the targeted student population English is only a second language after either Shona or Ndebele, the two major indigenous languages in Zimbabwe.

A version of the instrument was therefore administered to ten Lower Sixth Chemistry at a High School (the school was not part of the sample for the study) in Bindura, where the researcher was based. After completing the instrument the students were asked as a group and individually about whether or not they had difficulties with understanding the meanings of any of the words in the questionnaire. When none of the students indicated lack of understanding, the researcher went on to ask the students individually (in the absence of the other students and also ensuring that the students did not mix to share answers) to explain the meanings of some words chosen from the questionnaire. The words, intuition, myth, and inference were chosen because the researcher thought they could cause problems for the respondents. All the students gave satisfactory meanings of the words, although some of them did so in vernacular. The researcher's fear about the language level of the items was allayed. As the researcher later found out, a course in General Paper (mainly use of English) which is compulsory for all A level students does a lot to improve the English Language proficiency of the students.

The ten students were also asked to comment on what they thought the instrument was designed to measure. It came out that the students understood that the questionnaire sought to elicit their views on what science is, based on what they did during Chemistry laboratory work. On the same issue their class teacher concurred. The instrument was taken to have face validity. Without making any changes to the instrument, three colleagues one of them an experienced science education researcher were asked to make judgements about the content and construct validity of the questionnaire items. It was generally agreed that the instrument had content and construct validity.

The internal consistency of the items chosen for this study was determined using the Cronbach alpha. This was done with the 72 questionnaires administered to the students. Determination of alpha was done after reverse scoring. A Cronbach alpha of 0.59 was obtained. This appears to be a very low value but is actually consistent with determinations of alpha made by Pemeroy and Aldridge et al. In her study Pemeroy (1993) reported internal consistencies (Cronbach alpha) of 0.59 and 0.69 for the traditional and non-traditional items respectively. For an early version of their questionnaire, Aldridge et al (1999) determined Cronbach alpha reliability coefficients ranging from 0.51 to 0.71. It could be argued that the alpha values quoted for Pemeroy and Aldridge et al were from results of studies with teachers. But, Tsai (1999) reports more or less the same range of alpha values (0.59, 0.65) with Taiwanese eight grade students. Although the alpha value obtained here is consistent with determinations by Pemeroy and Aldridge et al., it is low enough to point towards relatively high homogeneity of the sampled students in terms of the trait under consideration. Reliability is said to be lowered by greater homogeneity of the sampled group (Ary et al., 1996).

5.2.2 Student Interviews

Semi-structured interviewing of 18 selected students was done for the purposes of getting a deeper understanding of students' views of the nature of science as well as corroborate open-ended and Likert instrument (SINOS) responses. Interviewing was done around a set of five core questions. The structuring of the core questions was informed by the literature (Hogan, 2000; Leach et al, 1998; Ryder et al, 1998; Ryder and Leach, 1999; Saunders et al, 1999). Questions were "adapted" from the literature with their relevance to laboratory work in mind. The five questions formed the basis for the student probing and other questions were also asked as a way of following up to get clarifications or to get a deeper understanding. Additional questions such as: "How do scientists settle disputes?" were asked as part of the probing. For example this question was asked as a follow up to question 5 below. Questioning was not done in the same sequence for all the interviewed students. The five questions are:

1. Why do scientists do experiments?
2. Does the knowledge known in Chemistry change with time?
3. From what you do in Chemistry practical work, what can you say about scientific observations?
4. What can you say about the data you collect during practical work in Chemistry?
5. Where does scientific knowledge come from?

5.2.3. Assessing students' perceptions of laboratory instruction

5.2.4 Student Laboratory Programs Variables Inventory (sLPVI).

The instrument of Abraham (1982) (found in Appendix C) was adapted for use in this study. To determine the nature of inquiry in students' laboratory classes, Abraham (1982) asked Chemistry students to rank a group of 25 statements describing the educational setting in their laboratory. Examples of the statements are:

1. Students follow the step-by-step instructions in the laboratory guide.

10. The instructor or laboratory guide identifies the problem to be investigated.

21. Students identify the problem to be investigated.

The rankings given to the statements by a class are used to categorize the type of laboratory they experience into verificationist, guided inquiry or open-ended inquiry. As an example students exposed to more open–ended laboratory work would be expected to rank statement 21, above very highly and those in low inquiry laboratories to rank statement 10 very highly. There are various ways in which the rankings could be analyzed (Abraham, 1982). One way is to use the rank of each statement. Stepwise discriminant analysis of the rankings can be done. Another way is to convert the individual rankings into scores and use the scores to determine the nature of the laboratory setting. This is the approach used in this study.

In adapting Abraham's instrument for the study some slight changes were made to the instrument and method of scoring. First changes were made to the wording of the statements to suit the A-level classroom situation. For example statement 10, above was changed to read: "Our teacher identifies the problem to be investigated". In this instance teacher replaces the word instructor. Some other examples of statements on the instrument are as follows (with the statement number in square brackets), [7] "Our teacher allows us to go beyond regular laboratory exercises and do experiments on our own"; [21] "Students identify problems to be investigated"; [1] "Students follow the step by step instructions of the laboratory guide or handout given by the teacher" and [24] "Students generally know the outcome of an experiment before doing the experiment".

Second, students were asked to indicate how often a given activity occurred in their laboratory classes by responding to each of the 25 statements on a bipolar Likert-scale ranging from; (1) *almost never*, (2) *seldom*, (3) *sometimes*, (4) *often*, to (5) *almost always*. In scoring each item response is allocated 1, 2, 3, 4 or 5 from *almost never* to *almost always* respectively. Scoring is done in reverse for those statements representing non-inquiry or closed inquiry laboratory. Examples of such items are, 1and 24 above. A high class average score (maximum = 125) is taken to mean that the nature of instruction in that laboratory is generally open-inquiry and a low score (minimum = 25) means laboratory work is verificationist or closed inquiry. Reverse scoring was done for the following items: 1, 3, 4, 5, 9, 10, 12, 22, 24, and 25. The scores were used to place instructional practice (or students' perceptions of that practice) along a continuum ranging from verificationist/ expository to open-ended inquiry.

While the validity of the instrument items was ascertained (Abraham, 1982), there was need to corroborate the content and construct validity of the instrument especially given the age of the instrument. Abd-El-Khalick and Lederman (2000), have strongly criticized researchers who use instruments developed more than three decades ago, arguing that the time lapse is a critical enough variable to influence relevance and hence validity. Perhaps there is need for a reminder from the annals of the history of science, that many ideas were retrieved from the archives, only for them to be pivotal in the development of scientific knowledge (Asimov, 1972). Mendel's work is a case in point. That aside, three colleagues who in their own right are experts on the issue of laboratory work studies corroborated the content and construct validity of the adapted version of Abraham's instrument.

The actual questionnaire responses used in the study produced a Cronbach alpha of 0.71 for the whole test and Cronbach alpha values of 0.69 and 0.68 for the open-ended inquiry items and the verificationist items respectively.

5.2.5 Student Interviews

Students were asked to give their opinions about how their Chemistry practical work was organized and conducted. Probing for purposes of clarification and getting more information about students' perceptions was done around the student's description of the laboratory instruction. One of the questions asked students to compare what they did in their Chemistry laboratory work with what they did in Physics or Biology laboratory work in terms of the pictures of science depicted by the laboratory in the respective subjects. Students' responses to questions on the images of the NOS were also used to get insights into the perceptions of instructional practice.

5.2.6 The Sample

The 72 students (24 females and 48 males) who participated in this study were randomly selected from Chemistry classes at twelve A-level schools (coded A to L). The schools were randomly sampled from a total of 30 A-level schools in three of Zimbabwe's nine schools administrative provinces. Of the 72 students 55 (76 %) were in boarding school and the rest in day school. Six students were selected from each Lower Sixth Chemistry class at each of the twelve schools. All the 72 students completed the SINOS and the LPVI. Six of the twelve schools were selected (on basis of proximity) for student semi-structured interviews. For each school, three students were purposefully selected (ensuring gender balance) for participation in the interviews. Of the 18 students interviewed, seven were females and eleven were males.

5.3 Results

5.3.1 Students' images of the nature of Science

5.3.1.1 Results from the SINOS questionnaire

Analysis of responses to the SINOS instrument reveals that as a group the students can be said to habour views of the NOS ranging from "fairly traditional" to "fairly non-traditional" or "fairly constructivist". Low scores mean traditional views and high scores non-traditional. Table 5.1 below shows the number of students falling into each category along a normative scale ranging from traditional to non-traditional. On this scale, scores below the theoretical midpoint (93) are taken to show traditional views and scores above the theoretical mid point to indicate non-traditional views. Within the traditional views category students can fall into the traditional (very low score below 62) and fairly traditional (range from 63-93). The table shows a similar categorization for non-traditional. The majority of the students (72 %) held fairly traditional views of the NOS.

Table 5.1 Placement of students along a normative map based on students' total score on responses to the SINOS (n = 72).

Score Range	Number of students	Frequency as a percentage	Categorization of students
31-62	0	0	Traditional
63-93	52	72	Fairly Traditional
94-124	20	28	Fairly non-traditional
125-155	0	0	Non-traditional
Totals	72	100	------

Table 5.2 Descriptive statistics showing the variability for students' scores on the SINOS

Statistic	*Value*
Mean	84.3
Median	83.5
Mode	80
Standard Deviation	9.3
Range	49
Minimum	67
Maximum	116
Count	72
Theoretical Minimum	31
Midpoint	93
Theoretical Maximum	155

The SINOS scores also show that there was little variation in the views of the students on moving from one school to the next. Although the sample sizes per school were small, the average scores from school to school generally show little variation. This variation is shown on Figure 5.1 below. School K is extreme on the image scale as all students gave answers above the median (83.5). Otherwise the students in the twelve schools were reasonably homogeneous with respect to the image of the NOS. Students at School K were the most positively positioned (towards theoretical maximum of 155) on the traditional to non-traditional scale (mean score = 91.2, s.d. = 4.6). Students at School I are relatively the most fairly traditional (mean score = 78.5, s.d. = 11.2).

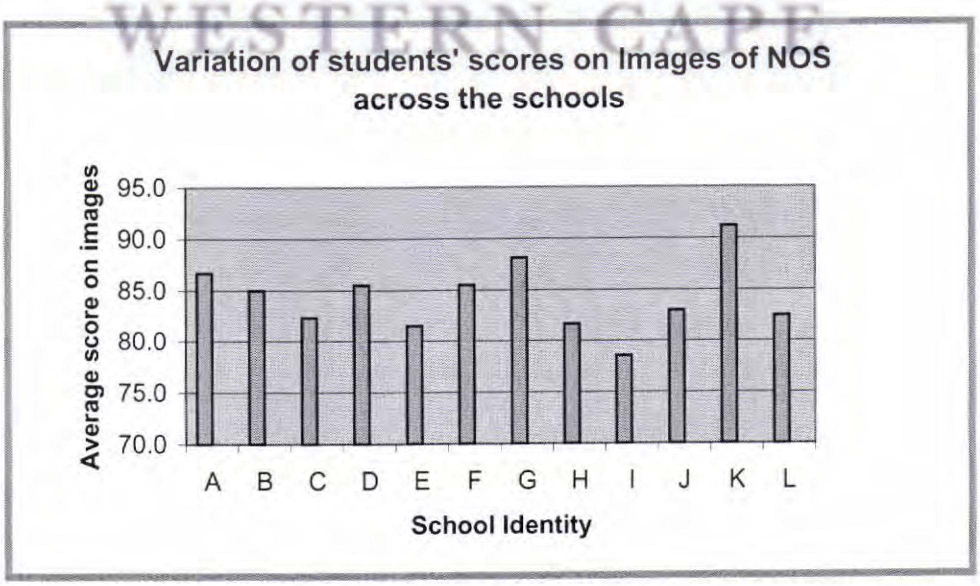

Figure 5.1: Variation of students' scores on images of the NOS across the schools

No difference was found between males and females in the responses to the SINOS. The Kruskal Wallis test was performed to determine differences between the males and females' median scores with alpha set at .05 for a 2-tailed test. The test showed that males and females perceived the NOS in the same manner ($H = 0.17$, $p = 0.68$) when the total score on the SINOS instrument was considered. No differences were also found in the males and females views on traditional items on the SINOS ($H = 1.68$, $p = 0.20$), and on non-traditional items ($H = 0.13$, $p = 0.71$). Being in boarding or day school was not found to be related to the student's total score on the SINOS instrument (Spearman r.) ($r = 0.003$, $p = 0.48$, for a 2-tailed test). Students' (as a group) responses to non-traditional items were not related (Spearman r.) to their total score on the SINOS ($r = -0.05$, $p = 0.65$ for 2-tailed test). Responses to traditional items were however found to be related to students' total score ($r = 0.73$, $p = 0.001$ for 2–tailed test). Most of the strong positive correlations were between the traditional score and the total score. Of the 17 traditional items there was more than 60 % agreement (percentage of students saying agree or strongly agree) for eleven of the items. Some notable statements getting high approval (with the cumulative percentage of students strongly agreeing and agreeing in brackets) from the students are:

- Chemistry knowledge is absolutely true because it is based on observations (83 %)
- When making observations Chemists do not make use of their beliefs and values (75 %)
- Chemistry knowledge can be proven in the laboratory (91 %)
- What you observe in the lab depends on the material being observed and not what you like (94 %)

Students also showed strong non-traditional views on some items. Some examples (with cumulative percentages of students strongly agreeing and agreeing in brackets) include:

- Current Chemistry knowledge will be changed in future (60 %)
- When making inferences from observations we rely on theory (75 %)

5.3.1.2 Interview Results

The transcribed responses for the 18 students were analyzed by combining the methods of sequential analysis (Harwell, 2000), analytic induction (Murcia and Schibecci, 1999) and interpretive analysis (Borg et al., 1996). The data analysis sequence roughly followed the one adopted from Harwell (2000) (Chapter 3). Table 5.3 below gives a summary of the students' views of the NOS.

Explorations were done for students' views on:

- the purpose of experiments in science
- the generation and validation of scientific knowledge (the nature of the scientific process)
- the nature of scientific observations
- the nature of scientific knowledge (static or dynamic) and
- the nature of experimental data.

Data presentation is done here under these issues of the NOS construct. Responses were read and re-read and coding and recoding done of the ideas (phrases and sentences), which were common and frequently mentioned. For the finally agreed-on categories (coding done together with a colleague studying at the same university with the researcher) words or phrases capturing the main idea presented by the student were written. Frequencies were counted for each idea raised by the students, with the idea being counted only once for each student (Leach et al., 1998). Students raised more than one coded issue within one statement. For example in one statement the student would say that the purpose of experiments is "to produce knowledge" and also say, "to prove theories". The total frequencies count is therefore more than the number of students (18) in some instances. The formed categories are not necessarily mutually exclusive. It is important to point out that for each of the explored NOS issues the categories emerged from the ideas raised by the students rather than from the prior ideas of the researchers. The data analysis was done together with a colleague.

Table 5.3: Summary of students' views on the NOS from interview responses (18 students)

NOS Issue	Response category (Code)	Frequency	Statement summarizing students views	Classification T or NT
Purpose of experiments	(a) produce knowledge	4	By doing experiments scientists or Chemists came to understand nature better and produce knowledge	T
	(b) prove theories	5	Experiments enabled Chemists or scientists to show that Chemistry or science theory is correct e.g. textbook knowledge	T
	(c) solve man's problems	4	To solve human beings' problems of needs and wants e.g. make drugs for diseases	NT
	(d) improve technology or environment	3	To improve technology and the environment for better human life	NT
	(e) control nature	2	By doing experiments scientists can control the laws of nature	T
Nature of scientific knowledge	(f) dynamic	15	Current Chemistry knowledge can change when new experiments are done to produce new knowledge or is approve existing theory	NT
	(g) Static	3	What is known in Chemistry will not change because it has been proved by experiment	T
Nature of scientific observations	(h) confirm theory	6	Observations show that what is described by Chemistry theory is reality or is true	T
	(i) were objective	6	Scientists make objective observations of reality	T
	(j) not always true and accurate	4	Chemistry observations were not always accurately and truthfully done	NT
	(k) build knowledge	5	Observations are used to build knowledge in Chemistry	T
	(l) theory-laden	5	The observations made by Chemists depended on their theoretical understandings	NT
Nature of scientific process	(m) from observations and experiments	13	Scientists build knowledge after carrying out experiments and observing phenomena	T
	(n) human imagination and creativity	6	Chance, intuition, creativity and imagination played a part in building scientific knowledge	NT
	(o) from many sources	3	Scientific knowledge came from many sources including observations and the human mind	NT
Nature of Experiment Data	(p) if procedure	8	Chemists always obtain accurate data if they follow procedures and use the right apparatus and reagents	T
	(q) fit theory	6	Data collected during laboratory work should always fit known theory	T
	(r) repeat experiment	4	Chemists repeat experiments if they have made mistakes and also to solve disputes	T

*** T = Traditional View; NT = Non-Traditional View**

Each categorized statement or phrase was also interpreted and classified as expressing a traditional or a non-traditional view or image of the NOS. The quotations given below taken from students' interview answers illustrate traditional and non-traditional NOS images respectively.

> IS50: Experiments are usually done to prove certain reactions that they are feasible or not [...] in Chemistry [...] but experiments as a whole are done to prove certain theories, hypotheses, or any scientific material their existence or non-existence through observations and deductions made.

> HS43: Scientific knowledge comes from practical experience and we come to certain conclusions, from experiments, from many sources [...] imagination and creativity also play a part like Kekule and the benzene ring.

5.3.1.3 Some issues about validity: student interpretation of questions

Students' interview responses were also analyzed with the aim of corroborating the students' responses to some of the SINOS items and *checking the validity* of students' responses to the probes. In this section the major validity issue tackled is how the students interpreted the probe questions.

For each student, the responses to each of the explored NOS issues were examined to determine whether there was congruency between what the student said and his/her agreement or disagreement or not decided response to related items in the SINOS. As an example, in the interview responses student KS65 said, "experiments are done to prove certain theories or laws". The corresponding/related item in the SINOS was item 10, "Chemistry knowledge can be proven in the laboratory". Student KS65 indicated agreement with item 10 of the SINOS.

While for many students there was congruency between the views they expressed in the interview and their responses to related items in the SINOS, some students gave contradictory responses. A typical example was student HS44 who said:

> HS44: The best way to get scientific knowledge is by making observations and doing experiments.

In his responses to the SINOS student HS44 disagreed with statement 1, "In Chemistry knowledge is obtained from observations." It could be that the student interpreted "obtained from observations" as having a different meaning from "to get scientific knowledge by making observations." By "get scientific knowledge" the student appears to have been referring to the process of building scientific knowledge. Some students might also have interpreted item 1 to mean that observations are the source/origin of scientific knowledge. For example student GS37 who agreed with item 1 of the SINOS also referred to scientific observations (in interviews) as the source of scientific knowledge i.e. "comes from observations". The students probably interpreted item 1 of the SINOS ambiguously. Another question which also appears to have been interpreted ambiguously was the interview question, "Where does scientific knowledge come from?" Students appeared to have interpreted this question in two ways. Some students thought of "Where does scientific knowledge come from?" in terms of the "source of the knowledge" (source here means origin for example, from senses or from the mind or dream, etc.) whereas others thought of it in terms of "the scientific process". By scientific process it is meant the method of getting knowledge and showing that that knowledge is valid.

Another interesting methodological challenge was to try and ascertain whether the student was reflecting on his/her Chemistry laboratory experiences or was thinking about science laboratories in general or drawing his answers from some other source when giving responses to both some of the SINOS and the interview questions. In other words what was the context in which the student was giving his or her response? Sandoval and Reiser (2004) are of the view that students' NOS conceptions may not be stable but contradictory and inconsistent across contexts. The issues in question were: "Did students base their answers only on their Chemistry knowledge and Chemistry laboratory experiences?" that is the context in which the student was giving his response and, "How did the student interpret the question?" To a very large extend the context in which we give responses to questions is guided by our interpretation of questions. Wickman (2004) argues that the only way to know about what a person is thinking (or should we say state of mind or mode of thinking) is through observing his behaviour and/or hearing what he/she is saying. From observation of behaviour and listening to answers to questions reasonable inferences can be made about the mental mode of the individual. One does not need an axe to open the human head in order to understand how a person is "thinking".

It was interesting to observe that most of the interviewed students were of the opinion that the picture of science they got from their Chemistry laboratory work was different from the image of science they got from either Physics or Biology. The most popular reasons were "because in Chemistry we worry about chemicals and in Physics about objects", Biology was "more scientific because it dealt with living organisms" and because in Physics "we do our own experiments". The nature of instruction and/or the curriculum were also pointed at:

> LS67: When you do Biology practicals you need a lot of analysis […] in Chemistry you can foretell the results […]
>
> GS38:Physics is more scientific because..[…] In Physics we solve problems by doing our own experiments […] in Chemistry we sort of confirm what is known […]

The few students who thought the picture of science from laboratory work for all the subjects (Chemistry, Biology or Physics) was the same gave the reason that in all the subjects experiments were done following a "method of science".

It could be argued that in both the above cases students reflected on the "scientific nature" of their Chemistry laboratory compared to the Physics or Biology laboratory experiences. Could it be that the students really reflected on their Chemistry experiences in answering SINOS and interview probes as the instructions asked them to do? One way of checking on this was to examine some of the students' responses to the interview probes and compare their answers with how they had responded to both the SINOS and the probe requiring them to compare the "scientific nature" of their Chemistry and Biology or Physics laboratories (laboratory work).

One of the interview questions was: "Where does scientific knowledge come from?" In responding to this item some students appeared to reflect on their Chemistry laboratory experiences. Student GS37 responded:

> GS37: […] when we are asked to find ions in FA something we will say for example FA7 has lead (II) ions because it gives a positive result with say potassium iodide. So they [scientists] experiment and if the result is positive they [conclude]

This student appears to directly draw upon his experiences in A-level Chemistry qualitative analysis. The response given here is in tandem with the student's agreement to the SINOS items 10 and 13 which said respectively: "Chemistry knowledge can be proven in the laboratory" and "Chemistry is based on experiments which any other competent scientist should be able to repeat at will". The same student said Physics was more scientific than Chemistry because in "Chemistry you don't plan your own experiments" but "in Physics you plan and design" experiments. It is probable that student GS37 reflected on and drew upon her Chemistry laboratory experiences in responding to the two SINOS items and the probe in question.

In contrast student IS50 said his Chemistry and Biology laboratory experiences gave him different pictures of science but at the same time agreed to SINOS statements 10 and 13. His response to the question "Where does scientific knowledge come from?" appears to show that he was not necessarily thinking about his Chemistry laboratory experiences only in giving his answer. He could have been thinking about science laboratories in general. Probably his experiences in the Biology laboratory also came in. This is part of his response:

> IS50: Usually scientific knowledge comes from theoretical and experimental aspects [...] by deductions of results, method and observations scientists [get knowledge]

This response does not show that the student was drawing on his Chemistry laboratory experiences only.

By examining the students' responses in this way it became apparent that students could have been drawing upon their Chemistry laboratory experiences but most of their responses to probes were also under the influence of some other experiences and knowledge e.g. from the Biology/Physics laboratory and from theory lessons. This appeared to be the case irrespective of whether the probe question was in the direct context of their Chemistry laboratory experience or not. For example, the students' responses to the question "From what you do in Chemistry practical work, what can you say about scientific observations?" also revealed this phenomenon.

It would appear that although the students were aware of the differences in the scientific nature of their Chemistry laboratories compared to Physics or Biology and were also aware of the requirement to base their responses on their Chemistry laboratory experiences only, they still drew upon other "experiences" in answering probes. Alternatively their responses were also under the influence of other "experiences". Some responses suggest the possibility that some of the students could have interpreted the probes with the idea of satisfying the instruction of "you should base your answers on what happens during your Chemistry laboratory work" while at the same time failing to ignore the influences of their beliefs about "professional science". These observations and the apparent ambiguous interpretations by students of some of the probes made the extraction of students' NOS images a very challenging task.

The analyses and interpretations producing the summarized NOS images given in Table 5.3 above were done with an awareness of the issues raised in this section.

5.3.1.4 Interview results: Triangulation of SINOS findings

Other than the issue of student interpretation of questions discussed above, the other methodological challenge was the corroboration or triangulation of SINOS and interview findings. To Ratcliff (1995) triangulation is also a tool for demonstration of validity. In order to triangulate findings from the SINOS a matrix with subheadings (and example) as shown in Table 5.4 below was drawn to facilitate the search for congruency between a student's normative placement done with the SINOS instrument and his/her interview responses. This analysis also revealed that some students hold fairly traditional views on some NOS aspects and fairly non-traditional views on others.

Table 5.4 An illustration of the matrix used to aid the search for congruency between SINOS and interview responses. (18 students)

School ID	Student ID	Student Score SINOS	Category of student Traditional or Non-Traditional SINOS	Interview Purpose of Experiment	Interview Scientific Observation	Interview Nature of scientific process	Interview Nature of scientific knowledge	Interview Experimental data
G	GS37	75	T	Understand theory	Confirm theory	From experiment	Static	Always Correct
	GS38	94	NT	Solve problems	Build knowledge	From experiment	Dynamic	Not always True
	GS39	101	NT	Improve environment	Always true	Many sources	Static	Not always True

Roughly, the matrix analysis confirmed the nomothetic categorization done by the SINOS, strengthening the validity of the SINOS instrument. What this means is that students classified as traditional by the SINOS were seen to generally, display a *traditional NOS outlook (TNOSO)* in the interview. A general traditional NOS outlook here means that the student expressed non-contemporary views in the Pemeroy sense for example, scientific knowledge is absolute; on at least three of the explored NOS issues/aspects shown in Table 5.4. Of the 13 students (out of the 18 interviewed) classified by the SINOS as falling into the traditional/fairly traditional category eleven were confirmed to habour a TNOSO by the matrix. Three of the five students classified as non-traditional/fairly non-traditional by the SINOS were also categorized in the same way using the matrix.

The researcher and a colleague first independently did the nomothetic placement of each student for each of the explored NOS issues. Each student's reference to an issue in all the probes was examined and interpreted. The placements were then compared and through discussion consensus was sought on the final placement of each student on each of the issues. In the decision-making the traditional or non-traditional orientation of the student on a NOS issue was aided by considering the consistency with which the student expressed his/her ideas on the issue throughout the interview. Discussions were guided by the question "On this issue is the student's overall outlook traditional or non-traditional?" This was a challenge since in some instances students expressed both traditional and non-traditional views in responding to an issue.

5.3.2 Students' perceptions of the laboratory instruction

In this section results are considered for students perceptions of laboratory instruction. The major findings from the sLPVI are summarized in the Tables 5.5, 5.6 and 5.7, and Figure 5.2 below. This is followed by presentation of results from interviews.

5.3.2.1 Quantitative data: Results from the student LPVI questionnaire

Table 5.5 Categorization of students according to their perceptions of laboratory inquiry (n = 72).

Score Range	Number of students	Frequency as a percentage	Nature of inquiry
25 – 50	3	4	Very low inquiry
51 –75	62	86	Low inquiry
76 – 100	7	10	High inquiry
101 – 125	0	0	Very high inquiry
Totals	72	100	------

Table 5.6 Descriptive statistics showing the variability of students' scores on the sLPVI

Statistic	Value
Mean	64.4
Median	65.0
Standard Deviation	7.9
Range	37.0
Minimum	43.0
Maximum	80.0
Count	72
Theoretical Minimum	25
Midpoint	75
Theoretical Maximum	125

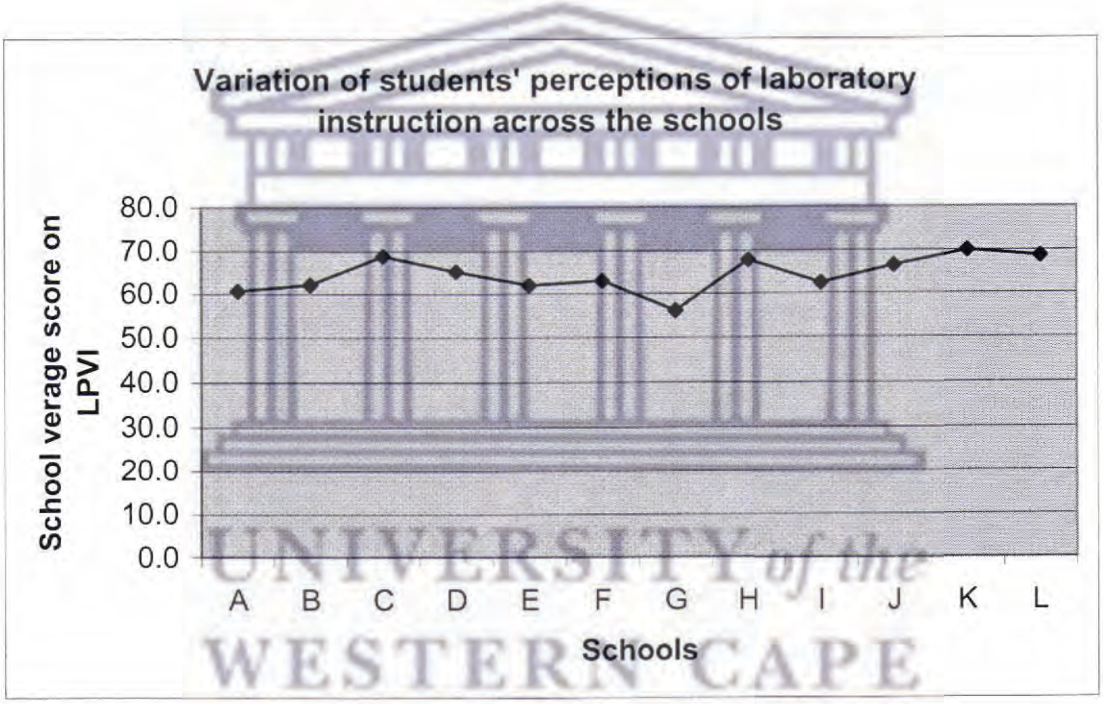

Figure 5.2: Variation of students' perceptions of laboratory instruction across the schools.

School G was extreme (mean = 56.2, s.d. = 6.2) on the perception of laboratory instruction scale as all the students gave answers below the median (65). School K although not extreme had the highest average score (mean = 70.0, s.d. = 4.8) on the perception scale. Relatively, the sampled students at School G perceive their laboratory instruction as of lower inquiry orientation and those at School K as of higher inquiry orientation. The binomial distribution of students scoring above and below the median at each school shows that the twelve schools were reasonably homogeneous with respect to perceptions of laboratory instruction. While some individual students within the sample (7 or 10 %) view the level of inquiry in their schools as high and a small fraction as very low (3 or 4 %) (Table 5.6), the school averages could mean that the level of inquiry in the schools is generally low and more or less to the same extend.

Students' total scores on the sLPVI did not differ with gender as determined by the Kruskal Wallis test (H = 0.45, p = 0.50). No difference was found between the males and females' perceptions of sLPVI inquiry oriented items (H = 0.21, p = 0.65). Males and females also perceived non-inquiry oriented items in the same way (H = 1.37, p = 0.24). The students' total score on the sLPVI did not show a relationship (Spearman r, for 2-tailed test, with alpha set at .05) to the type of school Boarding or Day School) (r = 0.02, p = 0.84). Some weak positive correlations (Pearson r.) were however found between students' perceptions for the following:

- their laboratory as requiring them to solve problems and teacher's identification of the problem for investigation (r =0.35, p = .002)
- teacher use of the lab to help students understand theory and investigations of problems that come up in class (r = 0.32, p = .006)
- teacher requiring students to give alternative explanations to observations and teacher use of the laboratory to investigate problems that come up in class (r = 0.49, p =. 001) and
- teacher requiring students to provide alternative explanations to observations and teacher requirement for students to explain why certain things happened (r= 0.46, p = .00).

From the percentages of students saying what the sLPVI statement stated occurred often or almost always, students perceive their laboratories to be dominated by (with cumulative percentage of often and almost always in brackets):

- Following step by step instructions in handout or manual (72 %)
- Emphasis on correctness of results (80 %)
- Teacher lecturing to the whole class (89 %)
- No room for doing own experiments (72 %)
- Emphasis on developing skills and techniques (86 %)
- Little room for student-student discussion (70 %)

- Interpretation of data (63 %)
- Teacher identification of problem for investigation (63 %)

5.3.2.2 Summary of interview responses

Students' views about instruction in their laboratories were analyzed in the same manner as responses to the images of the NOS responses. The categories of students' perceptions of instruction that emerged from the analysis and descriptions of what they represent are summarized in Table 5.7 below.

Table 5.7 The nature of laboratory instruction as perceived by students (students = 18).

Category	Frequency	Descriptive Statements
Examination Focused	11	Laboratory teaching seen as preparation of the students for the practical examination. There is emphasis on doing things properly and getting accurate results to prepare for examinations. Most of the problems they investigate in class are from past examination papers.
Individualistic	10	Teachers organize practical activities done individually by students for them to be able to read instructions and acquire knowledge and skills required for examinations. Teachers discourage student cooperation during laboratory work. Teacher assistance of students during labs is inadequate.
Co-operative	5	Cooperative laboratory work is organized for mainly to cater for shortages of apparatus, reagents and other materials.
Confirmistic	6	Laboratory activities are organized and done to show students that what they learn in theory is true. Most of qualitative analysis practical activities are confirmatory.
Developmental	4	Teachers organize practical activities during which students design their own experiments so that students can acquire the methods and habits of scientists or chemists.

The examination focus and individualistic nature of the instruction as perceived by students is illustrated by the quotation given below which is taken from students' interview scripts.

> IS 49: Of course problems [the problem for investigation] come from the teacher mainly past examination papers. I mean we get little help from the teacher when doing practical work. Maybe he just wants us to do things on our own for the exam but sometimes we don't get things right. I expect the teacher to help me with the skills.

5.3.3 Students images of science and perceptions of laboratory instruction

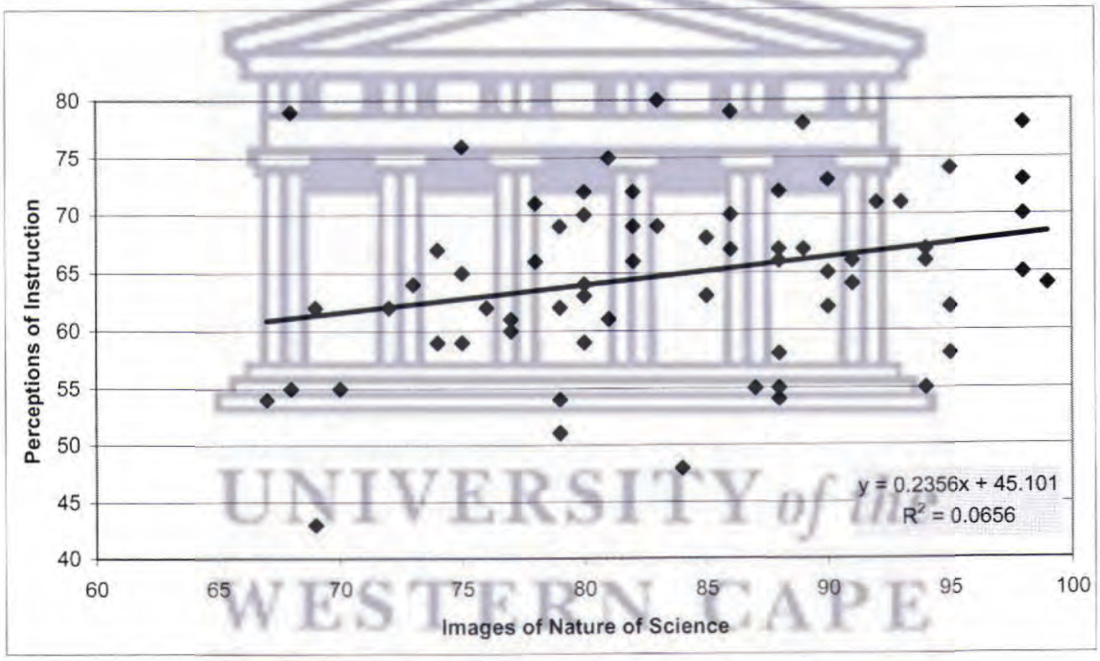

Figure 5.3: Scatter plot showing the very weak relationship between students' images of science and their perceptions of laboratory instruction (n = 70).

From Figure 5.3 and the calculated correlation coefficient (Pearson correlation coefficient = 0.26; two-tailed p-Value = 0.03) only a very weak relationship exists between students' perceptions of instruction and their images of the NOS. After removing two observations from the 72, the correlation strengthened from approximately 0.11 to 0.26 (which is the value with r-squared shown on Figure 5.3). These two observations were removed due to unusual large values on the "image of science scale". This makes it possible to explain the changes in the values of "image of science" by "perception" of lab instruction'' to an extent of 6 %.

Habouring fairly non-traditional views of the NOS does not necessarily mean perceiving laboratory instruction as highly inquiry oriented. The converse is also true in this instance. As the calculated square of the correlation coefficient shows, the changes in the "values of images of science" by "perception of laboratory instruction" can only be explained to an extent of 6 %. This being so, it is interesting to note that School K with the highest mean score (91.2) on image of the NOS scale also has the highest mean score on the perception scale (70.0). School G with the lowest score (56.2) on the perception scale has a relatively fairly high score on the image scale (88.2).

To get insights into the images of science perception of laboratory work interaction, students' responses to interview questions were analyzed. Of the 18 students, 13 were classified from the SINOS as holding fairly traditional images of the NOS and five as fairly non-traditional. Eleven students (5 fairly non-traditional and 6 fairly traditional) (Table 5.7) perceived the laboratory instruction as 'examination focused'. Seeing instruction as examination focused does not appear to be related to the image of the NOS. The idea of instruction being designed to help students acquire the methods and habits of science (developmental) was mentioned only by the fairly non-traditional students. These same students are also the ones who said the purpose of experiments in Chemistry is either to solve man's problem or to improve technology. This could be suggestive of students' views of the purpose of experiments in science being related to perceiving instruction as developmental. No patterns were found linking students' images of the NOS to perceiving instruction as confirmistic and as individualistic. This is corroborative of the very weak relationship found between images and perceptions of instruction from the SINOS and the sLPVI.

An interesting finding is that students failed to link use of group practical activities to the idea that science is a cooperative activity. Instead they saw group activity as an instructional expediency by the teacher to overcome the problem of shortage of resources. It could also be that students are aware of the constraints and traditions in the school context. If students are aware of how the examination constraints the teacher's decision-making, it might make them interpret laboratory activities not as similar to what chemists do but simply as "school science". Some of the students' responses were suggestive of student awareness of constraining effects of the curriculum, availability of resources and examinations on their practice of "genuine scientific inquiry." One of the students had this to say:

> IS51: We are restricted by time, small-scale apparatus or chemicals. Some of the experiments done by scientists we cannot do in our lab.

Students perceptions of the scientific value of practical activities organized by the teacher appear to be impaired and distracted by individualistic and examination focused laboratory instructional practice. When asked whether it was important in science for students to discuss ideas with their friends during practical work, student GS 37 expressed the sentiments of many of the students when she answered:

> GS37: No! No! No! that is not allowed. We share apparatus and chemicals but each one must produce his or her own results and after the teacher has marked we discuss in class only then do we discuss and share results. You see during the exam you will be on your own so its important to make sure you can do things on your own.

This impairment and distraction could have a negative attenuating effect on the interaction between students' images of the NOS and their perception of instruction. By this it is meant that the nature of instruction itself is a possible factor responsible for the weakness of the images-perception interaction. A much deeper insight into the nature of instruction as an attenuating factor is apparent in student KS63's description of instruction and the nature of Chemistry. He said:

> KS63: We don't do things from our own ideas. We are asked to design our own experiments but given apparatus and lines along which to come up with ideas. In real Chemistry you take time to design your own experiment using your own apparatus. Eventually you come up with a theory.

Here perceptions of instruction as "design our own experiments" and image of the nature of Chemistry as "chemists designing their own experiments" appear to be in concordance. This could result from the student's experiences involving Chemistry practical work in qualitative analysis in which students are asked to design their own experiments. Because students have gone through experiences or activities during which they are asked to "design experiments" with apparatus provided, they might develop notions that in "real Chemistry you take time to design your own experiments using your own apparatus". Such concordance could be symptomatic of instruction positively attenuating the interaction between images of NOS and perception of instruction.

It is hypothesized that the nature of instruction is a factor, which can negatively or positively attenuate the interaction between a student's image of the NOS and perception of laboratory instruction.

5.4 Discussion

This study has found that for the sampled students the majority held NOS views that are fairly traditional (72 %) and the minority (28 %) held views, which are more non-traditional than traditional. This finding is consistent with the majority of the studies reported in the literature. Studies of students' views, images or understandings of the NOS that have been reported over the past 15 years (Abd-El-Khalick and Lederman, 2000; Boujaoude, 1996; Haidar and Balifakih, 1999; Lederman, 1992; McComas, 1996; Saunders et al., 1999; Sere et al., 1998; Tsai, 1998) have shown that in many parts of the world, the majority of secondary school and even university students show inadequate or traditional NOS understandings. BouJaoude (1996) for example found that the majority of High School students hold traditional views of the nature of scientific observations. Students in this study have displayed such traditional images of the nature of science as scientific knowledge comes from observation, experimental data leads directly to theory, scientific knowledge can be proven and that human values and beliefs do not influence the scientific endeavour. McComas (1996) describes such images as NOS misconceptions. The idea that experimental data leads directly to theory development has been reported in studies with High School Chemistry students in Europe (Leach et al., 1998). It is also consistent with studies done elsewhere (Haidar and Balifakih, 1999; Tsai, 1998, 1999) that some secondary school students should habour non-traditional or constructivist images of science. As the results of this study show a reasonable proportion (28 %) of the sampled students hold such acceptable NOS images as: observations are theory-laden, creativity imagination, dream and serendipity play roles in the generation of scientific knowledge, the instrumentalist view that the purpose of science is to solve man's problems of needs and wants, and that scientific knowledge is tentative. In this regard then, this study confirms existing knowledge.

The lack of association between gender and students' images of the NOS contradicts the finding of Saunders et al. (1999) whose study although with College Chemistry students showed that epistemological beliefs were correlated with gender. It is consistent with the findings of the studies reported by Lederman (1992), which show no such a relationship. In Zimbabwe, Boarding Schools are known to have more laboratory instructional resources than Day Schools (Vhurumuku, 1992). Laboratory resources are assumed to be an important factor in determining the nature of instruction. The fact that the type of school (boarding or day) was not related to instructional practice might point towards instruction being similar in both types of schools.

Results from the sLPVI show that the majority of the sampled students perceive the level of inquiry in their laboratories to be low. The interview responses reveal that to many of the students, laboratory inquiry is intended to help students understand Chemistry content and acquire requisite skills as part of preparation for examinations.

> LS72: Scientists discover whereas in our laboratory we are there to prove what is already available information. It is just a way of trying to make us understand [nature].

Abd-El-Khalick (in Abd-El-Khalick, Boujaoude, Duschl et al., 2004) has called this perception of the nature of inquiry, *inquiry in science* or inquiry as a means to acquiring or understanding scientific knowledge. This is different from *inquiry about science* during which students not only learn to do science (learn knowledge and acquire skills for example, identifying problems, hypothesizing, etc.) but also come to develop understandings about the NOS. Only a very small fraction of the sampled students appear to perceive their laboratory experiences as inquiry about science. Most of the students appear to habour the notion that their own laboratory experiences are far divorced from the real nature of science as practiced by the professional chemist. The message inherent in the students' interview responses appears to be that the practice of scientific inquiry is being hindered by plethora of factors amongst them: the nature of the curriculum, availability of resources, constraints placed on teachers and too much emphasis on examinations. This is sad for science education especially as science educators from around the world are producing reports pointing towards this scenario being a global feature. As Duschl (in Abd-El-Khalick, Boujaoude, Duschl et al., 2004) has observed this could result from lack of a clearly formulated policy about the form of scientific inquiry to be given emphasis in the classroom. Perhaps there is need to re-examine Zimbabwe's A-level Chemistry curriculum and pedagogical practices with this in mind.

The results of this study does not fully support the idea that students' science epistemological views are linked to their perceptions of laboratory instruction. This is in contradiction to the findings of Tsai (1998, 1999, 2003) who found that constructivist (non-traditional) students tend to see their laboratory work as doing science compared to empiricists (tradional conceptions). Although the two classes K and G from schools K and G respectively produce quantitative results which would support Tsai's findings, the analysis of students' interview scripts fail to fully support the images perception linkage. Moreover correlations from the other schools indicate otherwise. There is also the possibility that the results of the current study are influenced by the small samples of students taken from each school at least for the quantitative data. There is need for more studies in examining this relationship with larger sample sizes.

Students' responses to interview questions suggest that the interaction between perceptions of laboratory instruction and images of the NOS is not a straight forward affair but a complex entity whose magnitude could be positively or negatively attenuated by another factor or other factors. The nature of laboratory instruction (which in this case is the object of perception) is one such a factor.

5.5 Implications for A-level Chemistry curriculum and pedagogy

The unveiled students' perceptions of the nature of laboratory instruction generally point towards the A-level Chemistry laboratory instruction being of low inquiry orientation. Newton et al. (1999) and Driver, Newton and Osborne (2000) have suggested that organizing instruction during which students can engage in discourse can result in students developing positive images of the nature of science. The perceptions of laboratory instruction revealed by students in this study carry messages for A-level Chemistry teachers' consideration. If A-level Chemistry laboratory work is to have a positive impact on students' NOS images then there is probably a need for the teachers to move away from individualistic and examination focused instruction. This obviously has implications for teacher practices and the nature of assessment in A-level Chemistry in Zimbabwe. Students are complaining that teachers are not giving them enough assistance to acquire requisite practical skills and not providing enough room for students' engagement in scientific argumentation. This could seriously jeopardize the desirable outcome of students' understanding of the NOS. Perhaps it is time that Zimbabwe's A-level Chemistry curriculum be re-examined with a shift away from examination centeredness in mind.

5.6 Conclusion

This study has examined A-level Chemistry students' images of the nature of science and perceptions of laboratory work. The major findings are that:

(i) Most of the sampled A-level Chemistry students (72 %) hold fairly traditional images of the nature of science

(ii) Some students (28 %) hold fairly sophisticated understandings of the NOS

(iii) The sampled A-level Chemistry students perceive their laboratory instruction to be of low inquiry, individualistic and examination focused.

(iv) A-level Chemistry students' images of the NOS are only very weakly related to their perceptions of laboratory instruction.

As a way of explaining the weak relationship between student images and perceptions of instruction the author has proposed the hypothesis of negative and positive attenuation. The interaction between students' perceptions of laboratory work and their images of science appears to suffer from attenuation.

CHAPTER SIX

Paper Three[4]

An investigation of Zimbabwe A-level Chemistry Students' Laboratory Work Based Images of the Nature of Science

6.0 Introduction

Laboratory work has been central to science instruction for over a hundred years (Jenkins, 1998; Nott, 1997). School science laboratory work has been linked to students' views, images, beliefs and understandings of the Nature of Science (NOS) (Hodson, 1996a; Hofstein and Lunnetta, 2004; Sere, Leach, Niedderer, et al., 1998). For decades, school science laboratory work has been thought of as the best way of building and articulating the students' images of the NOS (Jenkins, 1998; Nott, 1997). In recent times the development of students' NOS understanding has emerged as one of the important goals of laboratory work (Hofstein and Lunetta, 2004; Rudolph, 2003). The underlying assumption has been that by being involved in laboratory work, students would come to develop and assimilate the implicit images of the NOS inherent in or conveyed by laboratory work activities and experiences (Hodson, 1996a; Rudolph, 2003). According to Rudolph (2003), the school science laboratory is the best place for nurturing students' images of the NOS. This is particularly so for curricula such as the Zimbabwe A-level Chemistry one in which instruction about the NOS is not made explicit. Science curricula are said to be explicit about the NOS when the curriculum content, the instruction and student assessment deliberately aim to develop students' NOS conceptions. Students are taught about the NOS. Their understanding of the NOS is formally assessed. This is in contrast to the implicit approach where students' NOS understandings are assumed to develop as a secondary product of instruction. There is no deliberate effort to teach about the NOS.

It has been argued that students' understanding of the NOS is an important dimension in the development of a scientifically literate citizenry (Deboer, 2000;

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[4] A shortened version of this paper was presented at the Southern African Association of Research in Mathematics, Science and Technology Education (SAARMSTE) 12th Annual Conference held at the University of Cape town from 13 to 17 January 2004.
Another version of this paper has been re-submitted for review (first submission September 2003, resubmission, May 2004) to the *Journal of Research in Science Teaching* for publication.

Laugksch, 2000; Laugksch and Spargo, 1996). Understanding the NOS is considered to be a constitutive dimension of scientific literacy (Laugksch, 2000; Songer, Lee and MacDonald, 2003). As citizens within communities and as decision-making adults, students are expected to know how scientific knowledge is generated and about the processes of science in general. According to Kolsto (2001) it is necessary for citizens to have some understanding of the NOS in order for them to meaningfully debate controversial socio-scientific issues. Developing students into scientifically literate citizens is at the core of many science education reform agendas throughout the world (Deboer, 2000, 2002; Matthews, 1998a). The development of students' NOS understandings is therefore a major science education curriculum goal.

While these assumptions, arguments and aspirations have been perennial features in science education, little effort has gone into finding out the images of the NOS students develop from their participation in laboratory work. This paper describes an investigation of the images of the NOS Zimbabwe High School (Advanced level or A-level) students develop from their participation in A-level Chemistry laboratory work. The study being reported here is an effort to identify some of the ideas students implicitly develop from their A-level Chemistry laboratory work experiences and activities. In this study, the term *laboratory work based images of the NOS* (LABINOS) is used to describe students' NOS ideas that have an umbilical cord to their participation in laboratory work.

Lederman (1998) has described the NOS as epistemological and sociological values and beliefs held by an individual about scientific knowledge and the processes of its development and validation. The ideas an individual holds or displays about the nature of scientific knowledge and the processes of its development and validation have been described as images of the NOS (Driver, Leach, Millar and Scott, 1996). Leach, Millar, Ryder et al. (1998, p.8) describe images of science as 'the representations of the epistemology and sociology of science used by individuals in specific contexts for specific purposes'. According to a theory of mental representations by Johnson-Laird (1983), individuals can have mental and perceptual pictures of a scientist, a scientist's laboratory, or the nature of scientific knowledge. An expression of such views or beliefs or understandings constitutes an image of the NOS.

There are complexities associated with the concept of labwork-based images of the NOS (LABINOS). For example: How does one locate with precision the source of an image? How does one account for the confounding effects on students' ideas of laboratory experiences and influences from lectures, television, reading, radio, museums and other out of school experiences? In the case of A-level Chemistry students in this study, how does one decide that a displayed image is not sourced from other A-level practical activities (for example, Biology and Physics) in which the student is involved? It is the conviction of the author that the impact and the real value of laboratory work in developing students' understanding of the NOS can only be fully understood if science educators begin to tackle these issues. For too long the assumption has been that laboratory work conveys to students certain ideas about the NOS (Hodson, 1996a; Nott, 1997). The issue of what images of the NOS students actually build from their participation in laboratory work has received little attention from the science education research community. This study casts a ray, however faint on the issue. It is hoped that this ray will contribute to the illumination and elucidation of the issue.

Furthermore, it is the view of this author that the location of the source of a student's ideas about the NOS is a methodological challenge. The contribution of this thesis is to demonstrate how students' LABINOS can be identified and extracted through an analysis of students' responses to written and oral interview questions about their laboratory work. It is argued that given some background understanding of the context and nature of student participation in laboratory work, it is possible to make reasonable inferences about the source of students' ideas about the NOS.

According to Hogan (2000) knowledge, understandings, beliefs, views, ideas or images of the NOS can be delineated into two categories, either proximal or distal. Proximal knowledge of the NOS is about students' own notions or ideas about the science they learn (school science) and their own knowledge building. It constitutes the personal understandings, epistemological commitments and beliefs held by students about the scientific knowledge they learn and their learning process. An individual's knowledge and beliefs about knowledge and how he/she learns has been described as meta-cognition (Hogan, 1999; Tsai, 2001). Proximal knowledge has both meta-cognitive and epistemological characteristics. Students are assumed to develop ideas about the science they learn and their building of scientific knowledge from their participation in laboratory work. In this study the term *students' labwork-based proximal images* is used to describe such student ideas. Hogan (2000) describes distal knowledge of the NOS as the explicit views students express about the protocols, practices and products of professional science. Distal knowledge of the NOS is the knowledge students express about the nature of professional science and the process of its development and validation as well as the epistemological commitments of scientists. Professional science is science as practiced by the professional scientific community; the frontier scientists. In this study, the term *students' laboratory work-based distal images of the NOS* is used to describe the views of the nature of professional science students develop from of their participation in laboratory work.

Proximal and distal understandings of the NOS are thought to interact although there is no consensus about the nature of the interaction (Hogan, 2000). Students' proximal understandings and beliefs are thought to build into and develop their distal understandings and beliefs. The reverse is also said to hold i.e. students' images of professional science influence their thinking about the science they learn and how they learn (Hogan, 2000; Sere et al., 2001). Saunders et al. (1999) however, report a study by Edmondson in 1989 as having shown that proximal and distal understandings of the NOS are completely separate and parallel. While students' proximal and distal images of science have been known to influence their participation and learning during laboratory work (Ryder, Leach and Driver, 1998; Sere et al., 1998; Tiberghien et al., 2002), little is known about how students laboratory experiences and teacher instructional practices develop students' images of the NOS. There is also nothing known about how students' laboratory experiences and the nature of laboratory instruction interplay with the interaction between proximal and distal understandings of the NOS.

The present study investigates the proximal and distal images of the NOS Zimbabwe students develop from their participation in A-level Chemistry laboratory work. Additionally, by analysing and interpreting students' responses to written and oral interview questions about their laboratory work, the present study provides some insights into the interactions among students' laboratory experiences and their proximal and distal understandings of the NOS.

Understanding the proximal and distal images of the NOS and how they interact could be a valuable starting point in crafting constructivist instruction for A-level Chemistry and the design of explicit NOS curricula. Constructivist instruction and curricula start from a consideration of students' naïve epistemologies, prior knowledge, alternative conceptions (misconceptions) (Coll and Taylor, 2001; Domin, 1999; Hodson, 1996a; Shiland, 1999) and students' NOS images. Research on students' LABINOS is of value to both the theory and practice of Chemistry education.

6.1 The Research Questions

This study aimed to answer the following questions:

(1) What proximal images of the nature of science do A-level Chemistry students hold as a result of their participation in laboratory work?

(2) What distal images of the nature of science do A-level Chemistry students hold as a result of their participation in laboratory work?

(3) What is the nature of the interactions (if any) among students' proximal images, distal images and laboratory instruction?

6.2 The Research Methodology

6.2.1 Eliciting Students' LABINOS: methodological issues and challenges.

Either a nomothetic or ideographic methodological approach can be used in probing images of the NOS (Bezzi, 1999; Leach et al., 1998). In the nomothetic approach questionnaire items are written around a normative 'map' of the NOS. As an example, students can be asked to respond (in true or false or Likert fashion) to such statements as: 'scientific observations are free from human pre-conceptions' and 'scientific knowledge is based on experiment and observation only'. Statements such as these can be used to position individuals along an axis labelled 'Relativism/Positivism' (Leach et al., 1998). When an ideographic methodological approach is used, respondents are asked survey questions, which do not directly lean on any one philosophical position (Bezzi, 1999; Leach et al., 1998). With this methodology such questions as: " From what you have been doing during Chemistry laboratory work, what can you say about how scientists arrive at conclusions when building scientific knowledge?" "What can you say about the data you collect during Chemistry laboratory work?" are asked. According to Leach et al. (1998) and Bezzi (1999), respondents can answer these questions from a wide range of perspectives.

Respondents have a relatively, wider latitude for expressing their own views. Leach et al. (1998) and Ryder et al. (1998) are of the view that images of science are drawn from a variety of experiences and contexts and it is important for researchers to know about the context in which respondents will be giving answers. As an example how would the researcher know exactly that the student's image has been drawn upon from experiences in the Chemistry laboratory and not from the Physics or Biology laboratory or from other sources, cinema, television newspapers, etc.? One way of placing respondents' images within the appropriate context is to (through interviewing) probe the respondent's answers through open-ended questioning. The study reported here combined open-ended paper and pencil responses with interviewing of respondents to understand and profile proximal and distal images of science A-level Chemistry students develop from their participation in laboratory work. Insights and inferences drawn from students' responses are used to build hypotheses about the interplay between students' images and laboratory experiences and instruction.

Several techniques can be used by researchers in framing questions for eliciting students' images of the NOS (Hogan, 2000; Leach et al., 1998). Irrespective of the methodological approach being nomothetic or ideographic, probes can be designed to be contextualized or de-contextualized (Leach et al., 1998). When contextualized questioning is employed, students can be asked to respond to situations based on their own laboratory experiences or some other typical laboratory situation, comment on public statements about science or compare aspects of school science with professional science. In these cases, students mentally reflect on specific contexts, episodes, situations, experiences and events in answering questions. Bezzi (1999) and Leach et al. (1998) have pointed out that this kind of ideographic exploration is not completely free from the problems associated with the researcher's interpretation of responses. Language and the students' cultural background can still be impediments to the valid elicitation of students' views (Sutherland and Dennick, 2002). De-contextualized probing asks questions, which do not call on students to strictly, reflect on any one specific situation, event or episode.

In their review of literature on approaches to contextualized questioning, Leach et al. (1998), have identified at least three techniques that can be used in eliciting students' views. One way is to ask students to respond to questions based on investigations they would have carried out in class. A variation of this technique is to ask students to comment on a typical laboratory situation. As an example, students can be given data from a typical school laboratory experiment that is shown to be in disagreement with known theoretical facts. They are then asked to give their views on what they would do when they find such a situation. Contextualized questioning can also be done by asking students to give their views on why given public statements about science should be taken as reliable. Another way is to ask students to compare school science to professional science. A typical question, which is also used in this study, is, "Do you think what you do in your Chemistry laboratory is similar to what scientists do in their laboratories?" In answering this question students can reflect on their own laboratory work as well as their notions of professional science. Students' responses to such questions can be analyzed for proximal and distal NOS views.

Writing on eliciting students' proximal and distal understandings of the NOS, Hogan (2000), is of the opinion that different questioning frameworks should be used for proximal and distal understandings. To Hogan (2000), questions such as, "What is science?" and "How do scientists arrive at conclusions?" tap students' knowledge about professional science (distal knowledge of the NOS). On the other hand questions such as, "What can you say about the data you collect during your practical work?" and "What influence does discussion of your results with a friend have on your thinking?" are said to elicit proximal understandings of NOS.

It would appear that, eliciting students' proximal images or views could best be done through contextualized questioning while distal understandings can be done through de-contextualized questioning. The position taken by the author of this paper is that both types of questioning can still elicit proximal and distal understandings.

Consider the following question. "From what you do during Chemistry practical work, what do you think about scientific observations?" In answering this question the student reflects not only on his/her Chemistry practical work experiences but could also think about the nature of scientific observations in general. The question can therefore elicit both proximal and distal NOS understandings. As Larochelle and Desaultels (1991) noted, the challenge is to examine students' responses to interview questions and be able to make a distinction between those ideas belonging to conceptions or representations of professional science (distal images) and those belonging to school science (proximal images). Saunders et al. (1999) observed that even when students were given verbal and written instructions to reflect their answers on immediate laboratory experiences they still drew upon lectures, examinations and textbooks in giving answers to questions about the NOS. This could be so when laboratory experiences do not provide enough influence for students to shake off epistemological assumptions held prior to the laboratory experiences. In this study, contextualized and de-contextualized questions were asked to elicit students' proximal and distal understandings.

Consider the following de-contextualized question "How do scientists arrive at conclusions?" In answering this question, the student can draw upon a variety of sources: the cinema, television, reading, the laboratory, lectures, etc. If one has some background knowledge about the information, experiences and activities students are exposed to or participate in as a result of the lectures, cinema, television, reading, etc., it is possible for one to analyze and interpret students' responses to this question and be able to make reasonable inferences about the source of the student's displayed notion of the NOS. It is akin to a parent saying about her child "I think John is getting these ideas from this new church." The parent would have some background knowledge about what is done in and preached in the new church. Her examination of John's statements makes it possible for her to make reasonable inferences about the source of John's ideas. Alternatively the utterances of John can be informative about the source of his ideas.

By the same token, analyzing students' responses to the question "How do scientists arrive at conclusions?" should make it possible not only to identify and extract proximal and distal NOS images but also to make reasonable inferences about the source of those images. The author appreciates what Saunders et al. (1999) found out; that even when students were given verbal and written instructions to reflect only on their laboratory experiences they still drew upon examinations, lectures and textbooks in giving answers to questions about the NOS and their laboratory work. Furthermore, it is possible that in responding to probe questions, students might fail to give answers, which directly relate to the NOS. The challenge in this thesis was to examine students' responses to questions and identify and extract those aspects of their responses, which could be classified as proximal or distal understandings of the NOS. This examination also enabled the drawing of reasoned inferences about the possible sources of students' images or understandings. The data analysis was partly guided by the questions "Is the image displayed proximal or distal?" and "Where could this understanding have come from?"

6.2.2 Sampling

For this study, twelve schools were randomly sampled from a total of 30 schools (N=30), offering A-level Chemistry in three of Zimbabwe's nine schools' administrative provinces. The provinces were chosen because of their proximity to the researcher. The 30 schools had a total of 496 students doing Upper Sixth Chemistry. At each of the twelve schools, six students were randomly selected from the Upper Sixth Chemistry class giving a total of 72 students (n = 72). Of the 72 students, 48 were males (67 %) and 24 were female (33 %). The sampled students were also studying, Mathematics and Physics, Biology or Geography in addition to Chemistry. The average age of the students was 18 years (age range 17 to 19 years). The 72 students completed an open-ended questionnaire (see next section), which elicited their views on the nature of science.

For the interviews, six of the twelve schools were selected. The selection was on the basis of proximity. From each school three students who had completed the open-ended questionnaire were purposefully selected (ensuring gender balance) to take part in the semi-structured interviews, giving a total of 18 students. Of the interviewed students, seven were females and eleven were males. The interviews also elicited students' views of their laboratory learning and laboratory work experiences in A-level Chemistry.

6.2.3 Open-ended Questionnaire

The open-ended questionnaire consisted of five questions. Questions were asked to elicit students' views on the issues: the role of the laboratory in generating scientific knowledge (purpose of experiments), the nature of scientific knowledge from laboratories (truthfulness), the nature of scientific observations, the generation and validation of scientific knowledge (nature of the scientific process) and on the data they collected during practical work. These issues were selected because of their relevance to laboratory work. The questionnaire specifically asked the students to base their answers on the laboratory work they were doing in A-level Chemistry. Studies done on eliciting students' views of the NOS (Ryder et al., 1998; Saunders et al., 1999), as well as the work by Hogan (2000) were invaluable in the framing and adaptation of the questions. Responses to the open-ended questions were also used for getting insights into the nature of students' experiences during laboratory work. The content and construct validity of the questions was ascertained through consensual agreement with three science education researchers.

6.2.4 Student Interviews

Semi-structured interviews were done to corroborate student responses from the open-ended questionnaire as well as to further elicit students' images of the NOS and their interplay with laboratory experiences and instruction. The questions were fashioned to get students' views on: the purpose of experiments, the nature of scientific knowledge (dynamic or static), the nature of observations, the development and validation of scientific knowledge (nature of scientific process) and the nature of data collected during laboratory work. Some questions also sought students' views on their laboratory experiences and the nature of laboratory instruction. A set of seven core questions one on each of these areas formed the basis of the interviewing. The questions were structured and synthesized from literature (Leach et al., 1998; Ryder et al., 1998; Saunders et al., 1999). The following questions guided the semi-structured interviewing:

1. Why do scientists do experiments?
2. Does the knowledge known in Chemistry change with time?
3. From what you do in Chemistry practical work, what can you say about scientific observations?
4. What can you say about the data you collect during practical work in Chemistry?
5. Where does scientific /Chemistry knowledge come from?
6. Do you think what you do during Chemistry practical work is the same as what scientists do in their laboratories?
7. What do you think about the way laboratory work is done by your class?

All interviews were audio taped and transcribed verbatim into Microsoft Word. On the average each interview took 25 to 30 minutes. The transcribed data for each student was given a school and a student code matching that of the student's open-ended questionnaire.

6.2.5 Data Analysis

Data for both the open-ended responses and interview transcripts was analyzed using a combination of analytic induction (Murcia and Schibecci, 1999), sequential analysis (Harwell, 2000) and interpretational analysis (Gall. Borg and Gall, 1996). The sequence used in data analysis roughly followed the one used by Harwell (2000) in her analysis of middle level schoolgirls' perceptions of school science and science learning. To improve the validity of the analysis the researcher and a colleague first independently analyzed the data following the Harwell sequence (Chapter 3). The analyses were then compared and the final categorization and interpretation of responses arrived at through consensus.

All student responses to each question were considered question by question. Repeated readings of the students' responses revealed those statements, which were frequently mentioned by the students. From the common patterns that emerged, clusters of common ideas were used to form categories and sub-categories. The categories were developed from the students' responses and not the prior ideas of the researcher. In placing a student's statement into a category, care had to be taken about the researcher's assignment of the statement as belonging to a cluster of common ideas. Lederman et al. (2000), have warned of the threats to validity associated with researchers misinterpreting respondents' statements when doing this kind of categorization. They further point out that in inferring meanings from respondents' statements researchers should take care to ensure such inferences are supported by interview data. Elby and Hammer (2001) point out that researcher's failure to consider "contextual nuances" can result in misleading diagnosis of students' epistemologies. In developing the categories, statements were coded and re-coded and categories formed and re-formed. The finally agreed upon categories were given codes. For each category a statement was written to capture the common ideas expressed by the students' responses. Each coded response was counted as a frequency. Since each student could raise more than one coded issue in each statement, the total number of frequencies on an issue in some cases exceeded the student sample size. An issue was counted only once for each student for both the open-ended questions and interviews (e.g. a student could raise an issue twice in response to one question or several times as he/she responded to other questions).

The coding was based on the open-ended responses with the interview responses used for corroboration and getting deeper insights.

As a way of triangulating student open-ended responses, congruency was searched for in each student's answers to the open-ended questionnaire and answers to similar questions in the interview scripts. The aim was to determine whether or not for a given issue the student gave the same or a similar response in both the open-ended response and the interview. For most students, congruency between open-ended and an interview response was established on the issues: the nature of scientific observations, the nature of data collected during laboratory work and the development and validation of scientific knowledge. This was interpreted as corroborating the responses from the open-ended questionnaire.

6.3 Results and Discussion

Student open-ended responses clustered around three major categories of traditional, non-traditional and limitationist (laboratory had limitations). Students' proximal and distal NOS understandings were located within these categories. The issues around which the clustering was formed were: the purpose of experiments, the nature of scientific knowledge from laboratories (truthfulness), the nature of observations, the development and validation of scientific knowledge (nature of scientific process) and the nature of data collected during laboratory work. A different clustering of students' views emerged when perceptions of instruction were considered. Students' perceptions of laboratory instruction differentiated into five categories of individualistic, examination focused, confirmist, cooperative and developmental. The clusters of ideas forming from the consideration of students' perceptions of instruction were seen to spread across the traditional, non-traditional and limitationist categories. Categorization of students' perceptions of instruction was largely based on the interview data. Table 6.1 below summarizes the categories of students' labwork-based NOS images giving the frequencies shown by each of the major categories. Table 6.2 shows the spread of students' perceptions of laboratory work across the epistemological categories. Only the interview data was used to produce this table. Tables 6.3, 6.4 and 6.5 show the sub-categories formed by each of; traditional, non-traditional and limitationist categories. These tables combine data from both open-ended responses and interviews. For each sub-category a statement encapsulating the sentiments of the students is given. As can be seen from these tables there was not much difference among the three groups in terms of their perceptions of instruction.

Table 6.1: Categories of students' images of the nature of science (n= 72).

NOS Issue	Frequencies of categories (% Frequency)		
	Traditional	Non-traditional	Limitationist
The purpose of experiments in Chemistry/science	53 (74 %)	10 (14 %)	9 (12 %)
Nature of knowledge from laboratories	36 (50 %)	5 (7 %)	34 (47 %)
Nature of scientific observations	40 (55 %)	10 (14 %)	22 (31 %)
Nature of the scientific process	49 (68 %)	22 (31 %)	4 (6 %)
Nature of experimental data	47 (65 %)	10 (14 %)	12 (16 %)

Table 6.2: Students' NOS images and their perceptions of laboratory instruction (n=18)

Perception of instruction category	Instruction Descriptive statement	NOS Images Frequencies		
		Traditional	Non-traditional	Limitationists
Examination focused	Instruction is mainly aimed at preparing students for examinations	11	5	2
Individualistic	Students do laboratory work individually with little help from the teacher in order to prepare students for examination. Teachers discourage student-student cooperation	9	5	2
Confirmist	Most of laboratory activities are designed to verify Chemistry theory	6	4	0
Cooperative	Cooperative laboratory work is designed mainly to cater for shortages of apparatus and chemicals	0	4	0
Developmental	Teacher organize practical activities during which students design experiments to develop students' skills and habits of science	0	2	0

Table 6.3: Students' traditional proximal and distal NOS images (n= 72).

NOS Issue	Sub-category	Image Displayed	Frequency (number of students)	Frequency (%)
Purpose of Experiments	verificationism	Experiments can be done in the laboratory to verify or prove that Chemistry knowledge is true	28	39
	learner verificationism	The laboratory helps the student to learn and understand theory by demonstrating, verifying or proving school Chemistry theory	25	35
Nature of knowledge from labs	Empirical validity	Knowledge from laboratories is true because experiments and observations can prove the knowledge	36	50
Nature of observations	objectivist	Scientific observations were objective and real	16	22
	inductive learner	Observations help students to understand theory	10	14
	inferiorists	Real scientists or chemists always make correct observations	2	3
	skill deficiency	Observations in qualitative analysis and titrations were difficulty to make e.g. those involving colour changes	12	16
Nature of scientific process	positivists	Scientific knowledge is built from observation and experiments.	30	42
	logical empiricists	Scientists repeat experiments to validate knowledge	11	15
	Baconianists	Scientific knowledge was built from research following the scientific method	8	11
Nature of laboratory data	verificationism	Data collected was used to prove that theory was correct	21	29
	learner verificationism	Data collected was important for students to understand theory as it verified knowledge	12	16
	realists	Data collected was a true or correct picture of reality	14	19

Table 6.4: Students' non-traditional proximal and distal NOS images (n = 72).

NOS Issue	Sub-category	Descriptive Statement	Frequency (Number of students)	Frequency (%)
Purpose of Experiments	instrumentalist	To solve man's problems	4	6
	instructional aid only	School laboratory was only a place for learning ready made science but not generation of scientific knowledge	6	8
Nature of knowledge from labs	subjectivists	Knowledge from laboratories could be true or false depending on circumstances	5	7
Nature of observations	relativist	Different students could make different observations	8	11
	theory-laden	Observations made by scientists depended on theory	2	3
	debatists	Some observations made by scientists were debatable	4	6
Nature of scientific process	anarchism	Scientific knowledge came from many sources including dream, serendipity, chance, creativity and imagination	22	31
Nature of laboratory data	theory-laden	The data collected during laboratory work depends on the theory in the mind of the scientists before the experiment	10	14

Table 6.5: Limitationists proximal and distal NOS images (n= 72).

NOS Issues	Sub-category	Descriptive Statement	Frequency (number of students)	Frequency (%)
Purpose of Experiments	limited inquirists	School science or Chemistry experimentation cannot generate scientific knowledge because it is limited by apparatus shortage, inadequate materials, time, curriculum and examination constraints, and lack of sophisticated equipment	9	12
Nature of knowledge from labs	traditional apologists	Knowledge obtained from the laboratory only fails to be true if students or scientists fail to follow procedures, use faulty apparatus, contaminated reagents, don't make accurate observations, lack accuracy or laboratory conditions are not favourable.	34	47
Nature of observations	observation apologists	School laboratory observations were not accurate because of poor state of apparatus and contaminated laboratory reagents	22	31
Nature of scientific process	Inferiorists	Students cannot generate scientific knowledge because their knowledge is limited compared to that of real scientists	4	6
Nature of laboratory data	data apologists	Scientists collect inaccurate laboratory data when they failed to follow procedures, used inappropriate apparatus or worked with contaminated reagents	12	16

6.3.1 Proximal images of the NOS

The proximal images of the NOS students appear to develop from their participation in laboratory work can be extracted from the summary tables given above. Many students revealed views about Chemistry laboratory work and their learning process that can be described as traditional. They subscribe to realist ontology and think that the observations they make and the knowledge they verify in their laboratories are true pictures of reality. Some of these students believe that the experiments they do, the observations and the data they collect (Table 6.3) in A-level Chemistry laboratory work helps them to acquire knowledge or understand theory as it demonstrates and verifies theoretical knowledge (textbook knowledge). It appears however that the students equate being able to remember with understanding. Students GS42 and KS62 gave representative statements:

> GS42: You start with experiments and you see what exactly happens as in the observations one thus acquires knowledge. Having made the observations when compounds are mixed an acid and a base it is quite definite that the individual will come to know and will always remember that salt and water are formed.
>
> KS62: They [observations] help the student to get the deeper knowledge of the theory behind the particular Chemistry under study.

They viewed the school Chemistry laboratory not as a place where they could construct their own knowledge but one in which learning could occur through some form of "inductive-verificationism". These traditionally oriented, inductive-verificationist learners IVLs, viewed observation and experimentation as facilitating learning through some form of "gestalt connection" (GS42) between theory and practical work, something similar to what Novak (1977) referred to as the confluence of word, perception and action.

According to the IVLs, A-level Chemistry laboratory work learning activities (mainly in qualitative analysis and titrations) involving observation of colour changes were difficult. One of the students had this to say:

> LS72: We have lots of problems with the observations especially the colour changes [...] Like difference between blue and pale green.

These difficulties could explain why some students are "inferiorists" and viewed themselves as not capable of making observations as accurately as done by the professional scientist. This could be symptomatic of teachers not doing enough to develop students' observational skills. Some of the students have the notion that observation is the same as "seeing". Johnstone and Al-Shuaili (2001) have proposed that scientific observations are more than just seeing but a purposeful psychological activity requiring students' use of previous theoretical knowledge and the perceptual ability of being able to select relevant data from a myriad of stimuli of varying magnitude and intensity. They suggest that scientific observational ability can be developed through teacher training of students. Johnstone and Al-Shuaili also propose that students understand practical work better if they know the theory behind the practical. Student KS63 appears to concur:

> KS63: Some observations we don't understand but if you know the theory you see what […] you should observe.

A few students who can be described as non-traditional and relativist expressed the view that different students can make different observations. Student IS52 was one of them:

> IS52: People observe differently during experiments. They can get different results or mess up the work by forgetting one important step. Some colours are not clear to you hence you cannot deduce.

This finding supports Haidar and Balifakih (1999) who found the same notion of laboratory observations among 59 % of the sampled secondary school students in the United Arab Emirates. Some of the non-traditionalists looked at the knowledge they got in their laboratory work with skepticism. Student DS19 pointed out:

> DS19: Sometimes we cannot be too sure, the knowledge seems to contradict itself. Also […] sometimes we use indirect method and then make assumptions from the data we get from experiments.

Some students hid their traditionalism behind the material inadequacies of their school Chemistry laboratories. These students were coined "limitationists" although they should actually be described as "traditional apologists". They appear to believe that the school laboratory is a place where scientific knowledge can be generated (their perception of generation appears to be verificationism not them constructing school Chemistry knowledge), where observations can be done and students actually practice "professional science". They however say that this cannot happen because in the school Chemistry laboratory they use poor apparatus and contaminated reagents, and that they don't have state of the art equipment found in real scientists' laboratories and as a result the laboratory is limited for both learning and the kind of inquiry done by frontier scientists. Curriculum constraints are also cited. This is what one of them said:

> IS50: The scientists have all the time in the world to carry out their

> experiments and do so accurately whereas we students have limited time and we end up rushing things when we carry out experiments. Scientists have more access to apparatus and chemicals than we students have in our laboratory.

6.3.2 Distal images of the NOS

Most of the distal images of science shown by the students do not appear to be entirely based on their school Chemistry laboratory experiences. Some students give the impression that they are drawing understandings about professional science from a variety of sources. This non-traditional and "anarchist" answer from student GS38 is indicative of exposure to the history of science having an influence on students' ideas of how professional scientific knowledge is generated.

> GS38: By carrying out experiments by observing nature and also from books you get scientific knowledge so from many sources scientists can come up to conclusions about knowledge. I think imagination also. I am not sure whether it was Newton or Galileo who started from an apple from a tree.

Another non-traditional response from student LS63 however, appears to link the understanding of how scientific knowledge is generated to the qualitative analysis practical activities done by the student.

> Interviewer: How exactly does new knowledge come about?
>
> LS63: Here at school we design experiments. We are given room in qualitative analysis to design experiments and improve experiments to improve the one that is already there so it helps us to improve ideas in that sense we discover new ideas. It needs a creative mind to come up with new ideas […] Being a scientist means being flexible in thinking so that when you carry out an experiment you don't want to base your deductions only on what the books say… you can actually raise conflicts by [your] conclusions and deductions.

This fairly sophisticated image of the nature of the scientific process appears to be linked to laboratory experiences and instruction that encourages inquiry. The experiences and instruction could positively attenuate the interaction between school science laboratory work perceptions (proximal understandings) and distal understandings of the NOS. In this situation the implicit messages carried by the nature of the practical activity or laboratory instruction technique employed appears to be perceived by the student in such a way as to translate itself into an understanding of the nature of professional science, something akin to Hodson and Hodson's (1996) enculturation or the cognitive apprenticeship of Sandoval and Reiser (2004).

The idea that professional scientists solve disputes by repeating experiments could be linked to the fact that during their own laboratory work students repeat experiments when they get wrong results or observations which are found to be out of tandem with theoretical expectations. This exchange between the researcher and student JS60 illustrates this point:

> Interviewer: Do you always expect something from your observations in Chemistry laboratory work?
>
> JS60: Yes the titrations are mainly to do with the colour changes. We expect the colour of the solution to change so that we see something is happening.
>
> Interviewer: What if there is no colour change?
>
> JS60: We repeat the experiment or procedure. It means something wrong [...] not following instructions.
>
> Interviewer: How do scientists solve disagreements among themselves?
>
> JS60: They repeat their experiments over and over again until one is disapproved. One will see that his experiment is wrong.

Although this student shows a traditional understanding of the NOS the laboratory experience of repeating experiments appears to be linked to and to foster the students' image of how scientific knowledge is validated.

6.3.3 The interaction of proximal and distal images of the NOS

The examples of students' responses given in the previous section point towards the nature of laboratory experiences or indirectly the nature of the instruction (the activities organized by the teacher) being a factor in the interaction between proximal and distal NOS understandings. This has been called positive attenuation. The nature of instruction as perceived by the students can also weaken the proximal-distal NOS understanding interaction as exemplified by the following exchanges:

> Interviewer: Why do scientists do experiments?
>
> GS37: To discover and confirm what they are assuming to discover and to investigate.

Interviewer: Why do you do experiments yourself in the Chemistry lab?

GS37: To prepare for the final examination and to make us prove things …to understand theory but no no eee […] I think mainly to prepare for the examinations.

Interviewer: Why exactly do you say that?

GS37: Because you see […] I think the teacher is only worried about us passing the examination. Most of our practicals are from past exam papers.

The student appears to make a weak link between the purpose of school laboratory work as "to understand theory or prove things" and the purpose of experiments in professional scientific inquiry as "to discover and to investigate". Because the student perceives preparation for examinations as the more important objective of his Chemistry laboratory work, he might fail to appreciate the NOS messages inherent in laboratory activities. It could be argued that in the case of the above student because the instruction is examination focused, it does not provide students opportunities to move from an awareness of their own learning (proximal understanding) to more generalized notions about the NOS (distal understanding). The student does say something about her own laboratory work promoting understanding of theory but that appears to be masked or clouded by the examination focus of the instruction. This apparent effect of the nature of instruction on students' perceptions of the NOS also appears evident in Table 6.2 above which shows that for most of the interviewed students, the major purpose of laboratory work is preparation for examinations and verifying knowledge and not development of scientific habits. In terms of the implicit transference of NOS understandings (from laboratory experiences onto the student), the nature of the instruction (or accurately the perception of instruction, for example, Student GS37) appears to weaken the interaction between proximal and distal understandings. This is *negative attenuation*.

There appears to be a link between students' ideas about how they obtain accurate data during their Chemistry practical work and their image of how scientists validate scientific knowledge. In explaining how scientists arrive at conclusions student JS59 said:

> JS59. They take many experiments to find out if their observations are really true and also they take eemm one or two scientists do the same experiment and compare the results [...] If the results agree they conclude.
>
> Interviewer: Why are you saying that?
>
> JS59: Its like even here in our practicals when [...] I mean we have to like do several titrations before we can say this is the true value required. If our values are wrong we repeat the titration with the teacher and he shows us the correct result.

In this conversation, the image that in school Chemistry laboratory work several readings have to be taken or experiments have to be repeated before conclusions about the data can be made appears to translate into or reinforce the idea that professional scientists build knowledge by repeating experiments and observations. If repeated observations and experiments give the same result then they make conclusions about the knowledge being true. The student's proximal image about the nature of school Chemistry appears to interact into his distal image of the nature of professional science. The school laboratory experience (or the nature of instruction) of repeating experiments and observations appear to be the one encouraging the interaction. In this instance it can be called *positive attenuation* of proximal images into distal images.

It would appear that the proximal/distal NOS interaction might be weakened or strengthened by the nature of instruction or if not the instruction itself then the perception of instruction. The author posits that *in vitro* attenuating factors can have a negative or a positive effect on the proximal-distal NOS interaction. If that is the case as appears to be evident here then there is reason to suspect that *in vivo* attenuators can also operate on a similar principle.

6.4 Theoretical Implications

According to Hogan (2000) proximal understandings are more meta-cognitive than epistemic. Meta-cognition (cognitive monitoring) is an individual's knowledge about his/her understanding of the subject matter and his/ her own strategies for acquisition of knowledge and skills (Tsai, 2002). Both proximal and distal understandings however are embedded within the individual's conceptual ecology. The conceptual ecology consists of the whole system of personal theories, cognitive and meta-conceptual entities, epistemological beliefs, and belief structures and sub-structures, etc.; all forming an interrelated system (Hofer and Pintrich, 1997; Pajares, 1992). Proximal and distal understandings not only interact between themselves but also with these other aspects within the conceptual ecology.

In a previous paper (Chapter 5) this author proposed the hypothesis of attenuation to explain interactions between variables embedded in an individual's conceptual ecology (for example, teacher beliefs about teaching and instructional decision making). The influence of factors originating from outside the individual was referred to as *in vitro attenuation* and the effect of factors embedded within the individual's conceptual ecology was called *in vivo attenuation.* Teacher instructional practice here is an *in vitro attenuation factor*. The attenuation hypothesis is extended here to saying that both *in vitro* and *in vivo* attenuation can be either positive or negative.

6.5 Conclusions

This study set out to investigate the images of the NOS students develop from their participation in laboratory work. It became apparent that students' proximal NOS images are much more located within their laboratories than distal understandings. Naturally the laboratory appears to have much greater influence on students' views of the Chemistry they learn and how they learn than on their images of the practices of professional science. It was also evident that using interview responses to locate the source of students' distal understandings is quite complex and could only be made by inference. The data analysis revealed that the nature of instruction is a possible factor in fostering the attenuation of students' laboratory experiences into desirable images of the NOS. Students in this study have spoken in very strong language, that they have difficulties in making observations in qualitative analysis. Additionally they see their instruction as too examination centered.

It also appears that the interaction between students' proximal and distal images of science is under the governance of the *in vitro* and *in vivo* factors. Proximal images appear to taper into students' distal images but only to a very small extent. The translation of laboratory experiences into notions about the NOS appears to suffer from some form of attenuation.

CHAPTER SEVEN

Paper four

High School Chemistry Teachers' Laboratory work Instructional Practices and Students' Images of the Nature of Science

7.0 Introduction

The full picture of the interaction between teacher instructional practices and students' images of science is far from being understood. This study contributes to the illumination and elucidation of that picture. In essence, the study explores the nature of Zimbabwe A-level Chemistry teachers' laboratory work instructional practices and their students' images of the nature of science (NOS). Instructional practice is located within the paradigm of the nature of inquiry; or specifically the use of inquiry-oriented-pedagogy. The study seeks to enlighten the question: Does the manner in which teachers organize and implement Chemistry practical work activities influence students' ideas about the nature of scientific knowledge and the process of its development and validation?

7.1 The Objectives of Laboratory work

Laboratory work has been central to science instruction for over a century. The teaching of science through laboratory work is said to have actually started with Chemistry (Jenkins, 1998; Nott, 1997). Ever since the introduction of laboratory work into the school curriculum in the middle of the nineteenth century, a variety of reasons or rationales for involving students in laboratory work have been put forward. For decades, debate has surrounded the purpose of school science laboratory work. There appears to be no consensus as to what it is that laboratory work should aim to achieve and can achieve in secondary school science instruction (Vhurumuku, 2001). The inclusion of laboratory work in science instruction has been seen by some as an imposition by professional and academic scientists to protect their own status and massage their professional feelings rather than an appropriate strategy to benefit science teaching and learning (Hodson, 1996b; Nott, 1997). Research evidence has failed to fully support many of the peddled aims and objectives of laboratory work (Hodson, 1996b; Tamir, 1991). The legitimacy of the purpose of school science laboratory work is increasingly being questioned. It has been argued that much of what laboratory work claims to achieve can be pursued at a much lower cost in non-laboratory settings (Wilkinson and Ward, 1997), especially given the poverty haunting many developing countries.

The purposes, aims or objectives of school science and/or Chemistry practical work or laboratory work, have been enumerated by several authors (Bennet and Kennedy, 2001; DeBoer, 1991; Garnett and Garnett, 1995; Gunning and Johnstone, 1976; Hodson, 1996b; Hofstein and Lunetta, 2004; Johnstone and Al-Shuaili, 2001; Nott and Wellington, 1996; Vhurumuku, 1992, 2001; White, 1996; Woolnough, 1991). Generally, the literature on the purposes of school science laboratory work distills (irrespective of the discipline: Physics, Chemistry or Biology) the following as the major goals of laboratory work:

- teaching students laboratory or practical skills, which are manipulative, observational, interpretational, planning, reporting, etc.
- to help students acquire and develop conceptual understanding of the subject matter
- to help students learn about science i.e. develop an understanding of the NOS
- develop students' interest in science (motivation); this includes so-called affective outcomes e.g. attitudes to science

7.2 Laboratory work and the nature of science

Historically, the major aims of laboratory work have encapsulated the conviction that by being involved in laboratory work, students would not only learn science (understand scientific knowledge) and practice science (do science as it is done by the frontier scientist and develop practical skills) but also learn about the nature of scientific knowledge and the processes of its development and validation

(Hodson, 1996a, 1996b; Hodson and Hodson, 1998). As Rudolph (2003) observes, the school laboratory is seen as a place where the image of science can be articulated and given life. Rudolph further argues that the articulation of the image of science through instruction has roots in the philosophies of Schwab, Dewey and Polanyi. Dewey emphasized the importance of instruction in scientific thinking (the method of science). The assumption is that by making students think like scientists, they would come to epistemologically understand and appreciate the process of scientific inquiry. To Schwab, science is inquiry and students need to learn about science to appreciate its nature. Polanyi was of the opinion that science was craft knowledge that could only be pursued by apprenticeship; learning science and learning about science by doing science. Central to these philosophies is their view of science as a form of inquiry.

While this might be so, questions have been raised (Hodson, 1996a; Roth and Roychoudhury, 1993) about the assumption that certain types of laboratory activities or approaches can result in students developing sophisticated or desirable images or pictures of the NOS. As Roth and Roychoudhury (1993) found out, the involvement of students in laboratory exercises based on promotion of constructivist learning (mainly open-ended inquiry) did not necessarily lead to students becoming more aware of the tentative and interpretive nature of science. A study by Saunders et al. (1999) investigated relationships among the type of school Chemistry laboratory instruction (less inquiry or more inquiry), approaches to learning, gender and students' epistemological beliefs and concluded that the type of laboratory instruction did not influence students' epistemological beliefs as measured by a Science Knowledge Questionnaire (SKQ). Lederman (1992) cites a number of studies that showed that involving students in more traditional laboratory activities (illustrative and verificationistic) compared to discovery oriented ones did not influence students' understanding of the NOS. The lack of relationship between teacher practices and students' images of science is given support by Lederman (1992) and Abd-El-Khalick and Lederman (2000) who argue that there are too many intervening variables (time, examinations, availability of resources, etc.) mitigating against the 'influence' of teacher instructional practices on students' NOS understandings. The position of this author is that more research on these issues is required before anybody can claim the absence of "influence" with finality.

The teacher is a key factor in the realisation of the anticipated outcomes of laboratory work (Tamir, 1991). It is apt to postulate that the manner in which the teacher plans, organizes and implements laboratory instruction can make significant contributions to nurturing students' conceptions of the NOS. Along this strand of thinking, teacher instructional practice can be seen as opening windows through which students' laboratory experiences, exercises and investigations can implicitly or explicitly form conduits to the students' images of the NOS. The tenability of this hypothesis rests on the strengths of two observations.

Firstly, there is some research evidence linking teacher laboratory instructional practice to such laboratory work outcomes as students' conceptual understanding (Arce and Betancourt, 1997; Johnstone and Al-Shuaili, 2001; White, 1996; Wilknison and Ward, 1997a), interest in the subject (Arce and Betancourt, 1997; Gibson and Chase, 2002), and acquisition of practical skills (Yager, 1991). A study by Gibson and Chase (2002) for example, showed that when science is taught through an inquiry based approach students remain interested and become motivated. Yager's study shows that the percentage of middle school students who could demonstrate science process skills (hypothesizing, predicting, inferring, observing, etc.) was higher for students who were taught through Science-Technology-Society (STS) methodology (largely inquiry oriented) compared to those taught using traditional methodology (verificationistic). By way of inductive logic, it makes sense to suggest that if instructional practice is linked to most of the laboratory work objectives, it must also be linked to student conception of the NOS.

Secondly, some laboratory activities have been shown to positively develop students' images of the NOS (promote sophisticated or non-traditional NOS understandings) (Newton et al., 1999; Ryder and Leach, 1999). These studies point towards student engagement in practical work activities which are investigative and open-inquiry-oriented being effective in promoting students' awareness of the nature of scientific knowledge and inquiry. Students' laboratory experiences (exercises, investigations and other activities) are determined by teacher instructional practices. It has been asserted that, High School science teachers communicate implicit epistemological messages (messages about the NOS) through their design and implementation of laboratory activities (Ryder and Leach, 1999; Saunders et al., 1999; Sere et al., 1998).

In the next section common uses and types of A-level Chemistry laboratory work are briefly examined.

7.3 Laboratory work instructional practices in A-level Chemistry

7.3.1 Types of laboratory activities

The various ways in which A-level Chemistry laboratory work can be organized and executed by teachers can be structured from the literature on High School Chemistry laboratory work (Domin, 1999; Garnett and Garnett, 1995; Schraw and Olafson, 1995; Shiland, 1999; Wilkinson and Ward, 1997b). Gannert and Gannert (1995) have given five types of activities normally undertaken in Chemistry laboratory work. Their description, although done with the Australian High School students covers the range of activities common in A-level Chemistry in Zimbabwe and in the United Kingdom. The Zimbabwe A-level Chemistry practical syllabus content of practical activities falls within the categorization done by Gannert and Gannert (1995). Laboratory activities are classified as:

- *Activities that facilitate conceptual understanding.* These are usually highly structured and aimed at leading students to make observations and derive conclusions. Examples of such activities include; examination of the effect of pH on the chromate/dichromate equilibrium, illustrating hybridisation in molecules using organic molecular models and showing ligand displacement using solutions of copper (II) sulphate, aqueous ammonia and disodium EDTA (disodium salt of ethylene diammine tetra-acetic acid).

- *Activities that develop practical skills and techniques.* Skills and techniques are required for doing such acts as use a burette, use a pipette, filtrate, distillate, and use a balance. According to Vhurmuku (1992), the mastery of practical skills comes as a result of repetition of frequent practical tasks. Frequent practical tasks are those activities, which students have to do in order to successfully complete experiments or other practical work exercises. Examples of frequent practical tasks are: turning a burette tap, controlling a

Bunsen burner flame, transferring small quantities of liquids or solids and estimating quantities of reagents. The tasks are both manipulative (use of hands) and cognitive (assessment and evaluation involved) (Lock and Ferriman, 1987). Vhurumuku (1992) is of the view that mastery of practical skills is a pre-requisite to achievement of the objectives of practical work.

- *Activities that examine relationships between variables.* These are usually investigative or problem solving. Some examples are: studying the kinetics of the iodine propanone reaction, investigating the effect of temperature and concentration on the rate of decomposition of hydrogen peroxide and investigating the rusting of iron.

- *Activities involving chemical synthesis.* Examples are making gases such as carbon dioxide and hydrogen sulphide, making salts, making organic molecules and separation of cations by precipitation. These activities require application of knowledge such as solubility equilibria.

- *Activities involving quantitative and qualitative analysis.* Qualitative analysis normally involves identification of unknown chemicals (cations and anions or identifying functional groups of organic molecules) and distinguishing between various chemicals. Quantitative analysis includes such determinations as water of crystallization of a salt, volumetric titrations (acid-base and redox titrations). The success of the analysis might depend on the student's pre-requisite knowledge.

There are various ways in which these activities can be organized so as to maximize learning of Chemistry as well as promote inquiry and develop student understandings of the NOS. Shiland (1999) has suggested five ways in which Chemistry laboratory work can be modified to suit constructivist pedagogy. This author is of the opinion that the sort of activities described by Shiland can promote both the practice of inquiry and develop student NOS conceptions in A-level Chemistry laboratories. These ways are summarized below.

1. Modification of laboratories to increase the cognitive activity of the learner.

This can be done through allowing students to: identify relevant variables (e.g. controlled and uncontrolled), design procedures or reduce the procedure to essential parts, design the data table, use a standardized lab design worksheet i.e. a standard format with problem statement, hypothesis, variables, constants, data tables, summary and conclusions, and have students suggest sources of error and how they can be eliminated. It is suggested that this activities require mental activity and can therefore raise the cognitive level of the laboratory activity.

2. Designing laboratories for students to learn what they see.

Laboratories can be moved to the beginning of the Chapter to give the teacher the chance to diagnose students' misconceptions. Students can also be asked to make predictions and explain them before the lab and come up with alternative hypotheses. This is something similar to the POE model (Predict, Observe and Explain) developed by Klopfer and Anderson (Rickey and Stacy, 2000) in which students make predictions, and then go on to observe a demonstration or do an experiment to test their predictions. From their observations they reflect on and explain their hypotheses. This is said to have a motivating effect since students will have their predictions challenged.

3. Designing labs, which challenge students' present knowledge.

The teacher changes his role to that of problem poser and facilitator. Typical laboratory investigation problems can be rewritten so that the problem solution ceases to be obvious. Learners are made to be dissatisfied with their current knowledge creating perturbations, which increase their willingness to learn.

4. Designing labs, which include group and whole class discussions.

Students should be given opportunities to discuss their predictions, procedures, data tables and explanations before investigations as well as share and discuss results during and after the laboratory. Newton et al. (1999) have demonstrated that students would come to understand science better ad appreciate the nature of its practice if they are allowed to engage in discourse during the lab. Learning has a social component.

5. Design labs for students to demonstrate applications of acquired knowledge and skills.

Students should be given opportunities to demonstrate their knowledge and skills after the lab. Ideas obtained should be used in a wide range of contexts. This can have the effect of storing information in long-term memory.

7.3.2 Instructional Planning

Given the range of activities above, the teacher has to make decisions about how the laboratory work is to be organized and executed. Basically, in planning for instruction, the teacher must balance a wide array of concerns as well make appropriate choices of style and techniques from a large repertoire of available methods of teaching in laboratory work (Vhurumuku, 2002). Effective instructional planning should give careful consideration to such concerns as: availability of curriculum materials (reagents, apparatus, laboratory manuals, textbooks, laboratory space, etc.), syllabus aims and objectives, differentiation, multiculturalism in education, national educational goals, administrative requirements, constraints of time, student abilities, examination requirements, cost of the instruction and student motivation. The resultant instructional plan should be a product of such a balance of concerns as to maximize students' educational benefits. Decisions such as use of individual or group practical, going on a field trip, extend of laboratory assistance and the nature of student assessment are largely influenced by an effort to balance these concerns. In making decisions, the teacher also employs his content (subject matter) knowledge and pedagogical knowledge (knowledge about teaching methods, teaching skills) (King et al., 2001). For laboratory work the array of methods or models include: teacher demonstration, student demonstration, guided discovery, problem solving, open-ended inquiry and constructivism. The list of laboratory instruction styles is endless and what is given here represents only the most common. These methods are discussed in the next section. It should be borne in mind that there is no consensus on the merits and demerits of each of these methods (Domin, 1999).

In Zimbabwe A-level Chemistry teachers are required to produce a scheme of work outlining the objectives, content and instructional activities to be covered on a weekly basis. In most schools, a scheme of work for the whole term is produced. Some schools require very detailed schemes showing the content break down for each lesson, for each week and for the term. Other schools do not expect very detailed schemes. For such schools content break down is shown by the week and not lesson by lesson. Teachers are not required to produce a written daily lesson plan. As part of their evaluation, teachers complete records of work section on the scheme of work evaluating and summarizing the content coverage and student learning. In almost all the schools, teachers are given the leeway to structure the content according to how they see it fit, but adhere to syllabus requirements.

While teachers work with instructional plans (schemes of work, unit plans, lesson plans, etc.) it should be realized that gaps always exist between what the teacher intends the students to do and what the students actually experience and learn (King et al., 2001; Sere et al., 1998; Tiberghien et al., 2002; Tsai, 2003). A study by King et al. (2001) showed that there was a disconnection between teachers' instructional plans and what they were actually seen to do when their lessons were observed. This could point towards assessment of teacher instructional plans not being reliable in determining the nature of instructional practice. In the current study, teacher perceptions of their instruction, students' perceptions of instruction and lesson observations were used to determine the nature of instructional practice.

7.3.3 Styles in laboratory instruction

Demonstrations

This method has been in use in science instruction since the mid-nineteenth century (DeBoer, 1991; Nott and Wellington, 1996). Demonstrations can be done by the teacher on his own, by a student or students, or by the teacher and the students. Normally, demonstrations are done by the teacher when the handling or manipulations of apparatus and/or chemicals is too complex for the students, the teacher wants to illustrate some manipulations or theoretical phenomena, there is need to save on time or reagents, there is shortage of apparatus and as part of teacher correction of student misconceptions pertaining to practical skills or theoretical concepts. During demonstrations, teachers need to provide students opportunities to think critically by asking questions that encourage thought and use of prior knowledge (Hanson and Wolfskill, 2000) as well as maintain student interest and motivation. When done by the students, the activities are mainly illustrative or verificationstic and designed to help students' conceptualization. As Novak (1977) put it, conceptual understanding is said to occur at the confluence of word, act and perception. Indeed, in England much of the laboratory teaching during the early years of school Chemistry was through demonstrations. Nott (1997) reports that during those years university professors would regularly visit schools and perform experiments for students and teachers to watch. A study by Vhurumuku (1992) showed that for the sampled Zimbabwe A-level schools teacher demonstration was used less frequently compared to group practical work in Chemistry teaching. The more than ten years which have lapsed since this study was done might have produced a shift in this position, especially given the current economic situation in Zimbabwe. Most science teacher education pedagogics courses discuss the merits and demerits of using demonstrations. The consensus view appears to be that most demonstrations lack inquiry (Hodson, 1996a; Nott, 1997) and are not useful in translating onto the students, conceptions of the NOS.

Guided discovery

In guided discovery, also called guided-inquiry, students are led to an understanding of Chemistry concepts by performing experiments or exercises whose outcomes are already known to the teacher (Domin, 1999). The teacher formulates the problem for the investigation (or problem is taken from a laboratory manual or handout) and gives students the procedure to follow, and what observations to make and record. In many cases a table for recording data is provided. Through post-laboratory discussions or questions answered following the practical activity, students are led to "discover knowledge or new concepts". Student mastery of frequent practical tasks and practical skills is pre-requisite to successful completion of guided-discovery learning activities. Guided discovery can be organized for students to work individually or collaboratively in groups. A study by Hass (2000) shows that students' active engagement in cooperative laboratory work did not promote students' understanding of Chemistry compared to individual practical work. It was however seen to be effective in promoting student motivation. This contradicts the conclusion of a meta-analysis of studies involving almost 3500 High School and University students done by Bowen (2000), which shows that cooperative laboratory learning has a positive effect on academic achievement.

In essence discovery learning's major aim is student mastery of scientific knowledge. This was recognized as early as 1903 by Armstrong who advocated for students to perform experiments in order to discover information that others could only learn by rote memorization (Bodner, Hunter and Lamba, 1998) As a teaching approach, discovery gained prominence in the 1960's (Hodson, 1996a) following the Soviet Union's launch of the Sputnik in 1957 and outcries in the United States about American science education lagging behind (DeBoer, 2000). In the United Kingdom, the Nuffield curriculum projects of the 1960s went a long way to entrench the use of discovery approaches. In the United States inquiry oriented reform began in the 1950s with the National Science Foundations sponsored programmes (DeBoer, 2002). Piaget and Bruner's theories were utilized to support the notion that children are naturally scientists and should be allowed to discover knowledge for themselves (become scientists for the day). It made sense to suggest that since science was unraveling the secrets of nature through inquiry and discovery, it could be taught and learnt best that way. The assumption was that by engaging in discovery, students would come to implicitly understand the nature of the process of science (Chinn and Malhotra, 2002). This kind of instruction was seen as child-centered and emancipating. The effectiveness of guided discovery in implicitly developing students' NOS images has come under attack (Hodson, 1996a, Woolnough, 1991). It has been pointed out that it is presumptuous to expect students to discover during a forty-minute lesson ideas that took great minds (Mendel, Currie, Newton, etc.) many years to build. Hodson (1996a) thinks of discovery as distorting and confusing the real manner through which scientific knowledge develops arguing that, science does not proceed through the kind of discovery represented by school science teaching. Others (Haury, 1993; White, 1996) are convinced that use of discovery approaches can promote students' understanding of how scientific knowledge is developed. Guided discovery still dominates A-level Chemistry laboratories in many parts of the world.

Problem solving

Problem solving in Chemistry teaching has been described by a number of authors (Bodner et al., 1998; Domin, 1999; Gabel, 1999; Johnstone, 1997). Of these descriptions the one by Domin (1999) is adopted for this study mainly because of its conceptual clarity. In problem solving laboratory instruction, students investigate a question either individually or in groups. The students will be responsible for, designing and planning experiments, formulating the data collection procedures, making and recording observations, analyzing data, interpreting data, drawing conclusions and communicating the results. In more open-ended investigations, students even formulate the problem for investigation. As an example, students can device real world problems such as studying water pollution in their environment. The problem in most teaching situations, however comes from the teacher or laboratory manual. For example in a typical laboratory session, the teacher can ask students to investigate factors influencing the rate of decomposition of hydrogen peroxide given a set of apparatus and reagents (glassware, thermometers, enzyme catalase, etc.). The Zimbabwe A-level Chemistry syllabus has a section in which students are required to design and plan an experiment for separating cations by precipitation. Students are expected to use their understanding of solubility of salts to plan and execute the separation. A typical example taken from an A-level examination worksheet at one of the schools used in this study goes:

> You are provided with the reagents NaOH (aq), NH_3 (aq) and H_2SO_4 (aq) and distilled water, together with test tubes, a filter paper and filter funnel. Devise and carry out a sequence of steps using only these materials to separate the two cations in the provided solution FA7. Show that each cation is present in the separated precipitate.

To Domin (1999), problem solving differs from discovery in that in problem solving students make use of the knowledge they have acquired whereas in discovery students acquire knowledge. While the discovery approaches have student acquisition of scientific knowledge as the main focus, problem solving has the development of skills as its main agenda. During problem solving, teacher assistance to the students is kept minimal. In most laboratory situations, the teacher already knows the solution to the problem. For the more open-ended investigations (see open-ended inquiry below) both the teacher and the students might not know the problem solution prior to the investigation.

As a method of instruction in science, problem solving gained prominence in the 1970s and early 1980s (DeBoer, 2000; Hodson, 1996a). Problem solving naturally came to be associated with the process skills movement of the 1970s. The laboratory was seen as a place where students could learn the scientific processes of problem solving, observation, hypothesizing, manipulation, interpretation, etc. (DeBoer, 1991, Hodson, 1996a). Students were seen as scientific inquirers who could get generic and transferable skills from the laboratory. The skills were said to be independent of the science content (Hodson, 1996a).

According to Johnstone (1997) problem solving is unlikely to be successful if the memory of the students is overloaded. It is argued that the laboratory places too many demands on the students. Students are expected to perform and learn practical skills, learn theoretical concepts as well as develop attitudes and values characteristic of the practice of science all in one practical. This is said to overload the student's working memory reducing the effectiveness of practical work in achievement of desirable objectives. Hodson (1996b) is of the opinion that practical work sessions should be organized for specific outcomes. What this means is that teachers should organize practical activities whose aim might be say acquisition of manipulative skills and others in which the objective would be student understanding of theory or motivation or understanding of the nature of scientific observations. This can reduce data overload and increase the effectiveness of laboratory work.

Open-ended inquiry

Bodner, Hunter and Lamba (1998) have described an inquiry-oriented (open-ended inquiry) laboratory as having both different potential procedures and different learning outcomes. Haury (1993) comments that inquiry oriented instruction has been associated with guided-discovery approach and the development of process skills. He goes on to say that although these concepts are associated with inquiry they are not synonymous with inquiry. To Haury inquiry is about students' engagement in the investigative nature of science. This process is said to be activity and skills based and motivating. Its aim is to quench curiosity. Constructivist teaching is also described as a form of inquiry as it stimulates curiosity and provokes wonder as students try to make meaning out of their experiences. These understandings of inquiry overlap into problem solving. The distinction between inquiry instruction and problem solving instruction is made very clear by Domin (1999). Whereas in problem solving the outcome of the experiment or exercise is normally predetermined that outcome is undetermined for open-ended inquiry. For both methods however the procedure for carrying out the experiment is determined by the students. Additionally, the approach to open-ended inquiry is inductive (from specifics to general) whereas problem solving is deductive (from the general to the specific). In inquiry the problem of investigation almost always comes from the students. Both methods however can be described in terms of, the extent of inquiry, the degree of open-endedness of the investigations done by students (Tamir, 1991). This is shown by the degree to which students are allowed to formulate problems, decide procedures and make their own conclusions. Inquiry instruction can achieve both acquisition of manipulative skills and Chemistry content knowledge.

Songer et al. (2003) have pointed out that the practice of classroom or laboratory inquiry is limited by a variety of factors. Some of these factors are: pressure of examinations, shortage of material resources (apparatus, chemicals, laboratory space, etc.), class sizes, and constraints placed upon teachers and time. Teachers own pedagogical and content knowledge deficiencies can be impediments to the practice of laboratory inquiry (King et al., 2001). It was earlier on mentioned that the sort of inquiry practiced in school science laboratories should not be equated to the inquiry practiced by professional scientists (Chinn and Malhotra, 2002). Garnett and Gannert (1995) report that school students generally demonstrate poor skills relating problem analysis and planning, carrying out controlled experiments, identifying variables, interpreting data, drawing conclusions from data and detecting methodological limitations. However, Roth and Roychoudhury (1993) (with 11 and 12-year olds) and Toh (1991) (with 13 year olds) have shown that open-ended inquiry laboratory classes resulted in students' improvements on performance of these skills irrespective of whether the instruction was implicit (students receive no instruction on skills before investigations) or explicit (students receive instruction and then practice the skills). According to Johnstone (1997), inquiry oriented laboratories present too many cognitive demands on the students requiring them to simultaneously think about the subject matter and perform manipulations. Students might therefore fail to see the connection between what they do in the laboratory and the practice of science and the scientific enterprise (Tamir, 1991). Hodson (1996a) has accused the current practices in school laboratories as failing to portray the image of science as practiced by scientists.

To Hofstein and Lunetta (2004) scientific inquiry refers to the various ways of studying the natural world, proposing ideas and collecting evidence to justify assertions and explanations. They view school science inquiry as similar to the inquiry done by professional scientists by asserting that learners also investigate the world, propose ideas and justify explanations based on collected evidence. Chinn and Malhotra (2002), argue that school based inquiry is cognitively and epistemologically different from authentic scientific inquiry (research done by scientists). They point out that the cognitive tasks needed for authentic science are more demanding than what is required for school science. Authentic scientific inquiry is a complex activity employing expensive equipment, elaborate procedures and theories requiring highly specialized expertise for data analysis. Schools lack both the resources and time to engage in authentic science. Epistemologically, school science is simple inquiry aimed at uncovering simple observable regularities whereas authentic science aims at uncovering new theoretical models and revising existing ones. When examining inquiry in the context of school science therefore, it should always be borne in mind that this inquiry is within the cognitive and epistemological boundaries of school science. School science does not operate at the frontiers of scientific knowledge.

In the Chemistry laboratory inquiry instruction might take the form of students investigative projects done individually or in groups. Students can formulate problems around the syllabus content. Discussion of designs, plans, procedures, results and conclusions reached with other students is encouraged. The whole class as a group can also do investigations. Irrespective of the way in which it is done, the teacher takes the role of an advisor.

Constructivism in Chemistry laboratory instruction

Constructivism is a learning theory, a teaching approach, an epistemology of science, and a science education reform agenda whose origins can be traced to the philosopher Immanuel Kant (Cheek, 1992). Kant asserted that human beings are not passive recipients of knowledge but actively connect it to past experiences. Modern constructivism (and there are numerous forms of it) has two major strands. These strands are; cognitive constructivism associated with cognitive psychology of Piaget whose major tenets revolve around the belief that learning is an active experience between the learner and the environment strongly influenced by prior knowledge (Fosnot, 1996) and social constructivism. To social constructivists, learning occurs through social interactions and knowledge is the result of consensual agreement between cognitive patterns of different individuals (Heylighein, 1997). Social constructivists also value the importance of the learner's prior knowledge in instruction.

Some studies have examined laboratory inquiry through the lens of social constructivism (Newton et al., 1999; Songer et al., 2003). In this view the laboratory inquiry is seen as a process during which students find plausible explanations for phenomena, work collaboratively among themselves and with the teachers and negotiate meaning. Those more aligned to cognitive constructivism (Tsai, 2002) see constructivist laboratory instruction as interested in helping students to construct personal knowledge. This construction is said to start from the student's prior knowledge. It is however, reasonable to say that laboratory inquiry is both individual and social. Both cognitive and social constructivism are relevant to inquiry. According to Naiz (in Abd-El-Khalick, Boujaoude and Duschl et al., 2004) inquiry, constructivism and students' understanding of the NOS are all interrelated.

The constructivist approach for teaching Chemistry suggested by Shiland (1999) (outlined in previous section) has the ingredients of both problem solving and open-ended inquiry. Students are engaged in both constructivist learning and inquiry. For this reason this author has proposed the term *constiquiry* to cater for these two conditions. The term is used here to refer to the teaching of Chemistry through the organization of practical work activities during which students participate actively in formulating problems challenging their prior knowledge, planning and designing investigations, suggesting and carrying out procedures, collecting data and discussion and communication results.

7.4 Purpose of the study

This study aimed to explore the relationship between teachers' laboratory work instructional practices and their students' images of the NOS. Instructional practice was defined as what the teacher does during Chemistry laboratory sessions in organizing and implementing laboratory activities so as to give students opportunities to actively engage in inquiry. The nature of teachers' laboratory instructional practices was determined in paper one, of this thesis. In this study, the NOS understandings of the six students sampled from each of the six observed teacher's class are examined.

Their linkage or non- linkage to the nature of instruction practiced by their teacher is explored.

7.5 Research questions

To achieve the above purpose the following research questions were formulated:

1. Do A-level Chemistry students and teachers perceive the nature of instruction in their laboratories in the same manner?
2. What is the nature of students' images of science in laboratory classes where teachers' instructional practices are of very low inquiry, low inquiry and medium inquiry?
3. What is the nature of the interaction between students' laboratory experiences and their images of the NOS?

7.6 Research methodology

The teachers and students who participated in this study were from six schools selected from three of Zimbabwe's nine schools administrative provinces. School selection was done on the basis of proximity (distance) to the researcher. At each of the six schools, a Lower Sixth Chemistry class teacher and six of his/her students participated in the study. The six students were randomly sampled. This study commenced during the last term of Lower Sixth (Form 5) towards the end of 2002 and continued into early 2003 when the students were now in Upper Sixth (Form 6).

To determine the nature of teacher instructional practice, each teacher was observed conducting a laboratory session four times. One laboratory session was observed with the students in Form 5 and three sessions with the same students now in Form 6. Each teacher also completed a 25-item Likert type Laboratory Programmes Variables Inventory (tLPVI) questionnaire adapted from the instrument of Abraham (1982). The instrument was actually administered to twelve teachers and 72 students at twelve schools in three of Zimbabwe's nine schools' administrative provinces. Part of the data from that administration is presented here to help form the picture of the nature of practice. The instrument asks teachers or students to respond to statements about the organization and implementation of instruction for inquiry in their laboratory classes. Additionally each of the six teachers was also interviewed about his laboratory work teaching.

Students' images of the NOS were determined through an open-ended questionnaire and semi-structured interviews. At each school all the six students completed a written response to five open ended questions on selected aspects of the issues: the role of experiments in Chemistry, the generation and validation of scientific knowledge (nature of the scientific process), the nature of scientific knowledge, the nature of scientific observations and the nature of data obtained during laboratory work. Semi-structured interviewing of three students at each of the six schools was done with questioning and probing designed to capture students' views on each of the five areas covered by the open-ended questionnaire. The three interviewed students were selected from the six who completed the open-ended questionnaire. Interviewing also sought to elicit students' views on the nature of instruction in their laboratories.

7.7 Results and discussion

7.7.1 A comparison of teachers' and students' perceptions of the nature of laboratory inquiry.

As indicated in the preceding section, some of the results presented here are from the survey of the twelve teachers and 72 students at twelve schools; using the LPVI. As Figure 7.1 below shows, teachers' and students' perceptions of the nature of inquiry in the schools are completely different from each other. Teachers generally perceive their instruction to be of higher inquiry level compared to the way students look at the instruction. Only at school K is the teacher LPVI score (72.0) close to the students' average LPVI score (70.0). The gap between the two is widest for school G, teacher score (83.0) and students' average score (56.2). These gaps are in line with the findings of Tsai (2003) who reports similar results in his study of Taiwanese students and teachers. For school G the teacher perceives his instruction to be of medium inquiry whereas students see it as of low inquiry (according to the categorization done in Chapter 4). Both the teacher and the students at school K see the level of inquiry as low and to more or less to the same extend. The gap is also small at schools I and J (Figure 7.1).

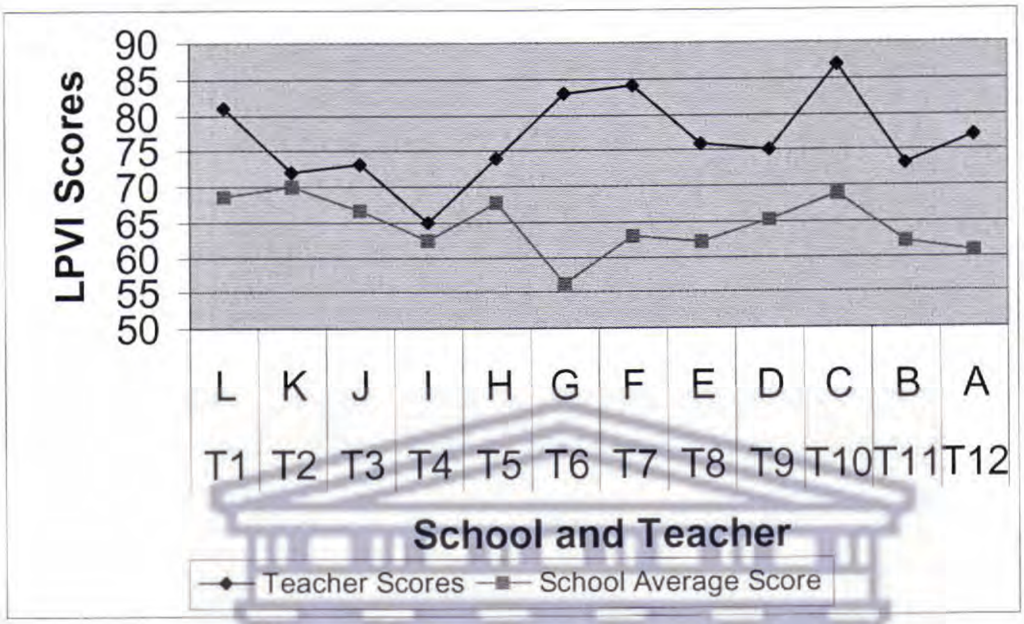

Figure7.1: A comparison of teachers' and students' perceptions of the nature of laboratory inquiry.

The gap between students' and their teacher's perceptions at school G can be explained in terms of the differences in the way students and the teacher view the purpose of laboratory work. All the interviewed students at school G thought the major purpose of laboratory work was to prepare them for examination whereas their teacher thought it was to inculcate in the students the habits of scientists and to make students appreciate the NOS (Paper 1). One of them GS39 did not see the teacher's emphasis on accuracy as a requisite habit for scientists but as a way to prepare for examinations. He said:

> GS39: The teacher wants us to be accurate because he wants us to pass the examination.

Their teacher on the other hand thought it was necessary for him to emphasize accuracy so that students as scientists would "learn to believe their own results". This difference might result in different interpretations of laboratory work and hence diverse opinions about the nature and purpose of instruction. It is also interesting to note that while the lesson observations show the teacher at School G (Zivanai) to be practicing medium level inquiry, his students perceive the level of inquiry as low. This could serve to confirm what Fraser and Tobin (1998) have asserted about alpha and beta press. Alpha press refers to description of the learning environment as assessed by the detached observer (researcher) and beta press, the learning environment as assessed by the milieu inhabitants (teachers and students). It is not uncommon for alpha and beta press to differ from each other. Equally tenable is the observation that although the sampled students in class G on the average see instructional practice as of low inquiry (mean score on LPVI = 56.2), the six students did not view the instruction in exactly the same way (score range 43 to 62). According to Fraser and Tobin (1998) each student has an idiosyncratic view (individual beta press) which could be the same or different from the class average (consensual beta press).

At schools K, I and J where both the teacher and the interviewed students see the main purpose of their laboratory as to prepare students for examinations, the gaps are smaller. At these schools, students like their teacher also view laboratory work as designed to help them learn Chemistry by demonstrating or verifying theory.

> JS59: I think when we experiment we want to find out what we will have learnt in theory. To prove that the theory part is correct we do experiments. The teacher comes to explain theories from a new reaction.

It is also interesting to note that at these three schools the level of student-student interactions (scientific discourse or argumentation as described by Newton et al., 1999) was observed to be generally low (paper 1). At school G where the gap is widest, the level of student-student interaction is relatively high.

7.7.2 Laboratory instruction and students' images of science in very low, low and medium inquiry laboratories.

In this section results are presented on the nature of students' images of science and laboratory instruction in those classes identified in paper 1 as being of very low and low inquiry. Data is sourced from students' and teachers' open-ended questionnaires and/or the semi-structured interviews. The teachers identified as practicing very low inquiry are: Kundai (at School K), Fidel (at School I) and Abongile (at School J). Teachers Martin (at School L) and Mawonde (at School H) were categorized as practicing low inquiry. Zivanai was categorized as practicing medium inquiry.

Very low inquiry classes

The common features of the very low inquiry laboratories are that the teacher uses the strategy of always giving the practical before discussing its theory, the level of student-student interaction is generally very low and the instruction is strongly examination focused and individualistic (see Chapter 4). Although the teachers attempt to have some form of guided discovery, this is negated by the verificationism they practice when they revise practical exercises. This is seen by the frequency of teacher demonstrations in these classes.

Students in these three classes share some common ideas. For example students at both schools mention the idea that scientists are hardworking, deep-thinking and skillful people who spent a long time carrying out investigations. Such a glamorous image of scientists is not uncommon among high school students in many parts of the world (Song and Kim, 1999). Student JS56 mentioned part of that idea in the open-ended questionnaire:

> JS56: They [scientists] spent lots of time doing experiments because a short time for experiments is an initiative for confusion. I think they indulge themselves deeply because it is difficult to get conclusions.

KS63 had a similar idea:

> KS63: After hard work and repeated experiments scientists arrive at conclusions.

These students' images of scientists might have their sources in the fact that, in their teaching Fidel, Abongile and Kundai place emphasis on doing practical work in specified time ("short time for experiments is an initiative for confusion") as a way of preparing for examinations. According to Hogan (2000) students are said to move from an awareness of their own experiences (proximal images) towards more generalized notions about the NOS (distal images). The students could reflect on their own experiences, resulting from the teacher's organization of practicals and form images of how real scientists work. Because in their own laboratory work they work under strict schedules of time, they might begin to imagine different or similar scenarios for the professional scientist's laboratory. This could also reinforce the ideas they already hold. Student JS56 further said (interview):

> JS56: The scientists themselves do it [practical work] in their own time. They are more at ease because no one will mark their work as correct or incorrect hence they will do their practicals as accurately as possible.

There appears to be a link between Student JS56's laboratory experiences (or at least his perceptions of experiences) and his image of how scientists work. The examination centered nature of the instruction organized by the teacher looks like the factor positively attenuating that linkage. The instruction appears to be carrying an implicit image (Abd-El-Khalick and Lederman, 2000; Hodson, 1996b) about the way practical professional scientists work. Although the image of a scientist shown by student JS56 is traditional, the laboratory experience looks like positively fostering the interaction of proximal understanding into distal NOS image.

The attenuating effect of verificationistic instruction on the proximal-distal image interaction is further suggested by this exchange between the researcher and student JS60:

> JS60: We [in the student's own laboratory] are like merely repeating what scientists have done. Scientists try to find out more about things that are not known.
>
> Interviewer: How different is it exactly?
>
> JS60: It's like in qualitative analysis we are asked to find ions in FA something which is already known by the teacher and the examiner.

The verificationistic experiments done by this student in qualitative analysis appear to be linked to the idea that scientists do not simply verify knowledge that is already known but foray into the unknown. The student's idea about the nature of experiments in qualitative analysis is interacting into his image of the practice of professional science. When the teacher organizes verificationistic laboratory, the effect on the student might be to "strengthen" the belief in the difference between school and professional science. This is positive *in vitro* attenuation.

Those students who think that what they do in their Chemistry laboratory is similar to what the scientists do in their own laboratories blame inadequacy of resources in the school laboratory for the difference. In the previous chapter these students were called "limitationists". The limitationists also blame faulty apparatus, contaminated reagents and laboratory conditions as being responsible for their getting inaccurate results or failing to make accurate observations (nature of laboratory data). Within this group some of the students admit guessing and fudging of results.

> JS56: The data we collect is sometimes untrue because sometimes it is obtained by guesswork.
>
> IS48: Sometimes we do wrong calculations to deceive the teacher. For example when we carry out titrations every one knows the accurate values must not differ by 0.1 dm^3 and we just do one titration and forge the others as the titration rarely comes out as expected.

During volumetric titrations students are normally expected to do at least three titrations (within 0.1 cm^3 of each other) and then use the values of their titres to get an average volume and use it for calculating molarities of solutions, etc. This is not the first time that a study has shown students can admit fudging. Rigano and Ritchie (1995) report high school students in Tasmania as having admitted that they forged their experimental data to fit theory.

When "examination-focused" instruction places too much emphasis on accuracy of observations and measurements and students fail to get marks because they have not followed instructions or get poor results because 'apparatus are faulty' the students might not only become "inferiorists" but also reinforce their imaginations of scientists as people who always make accurate observations and produce accurate data. Students' own proximal experiences, build into and interact with their images of a professional scientist. The examination-focused instruction in very low inquiry laboratories (Fidel, Abongile and Kundai) appears to positively reinforce that interaction. It was demonstrated in the previous paper (Chapter 6) that there are also instances when examination centered/focused instruction appears to negatively influence the proximal-distal NOS interaction. This was called negative *in vitro* attenuation.

While the students' views on the nature of scientists appear to be common within the three very low inquiry classes, the students show some differences within classes when other NOS issues explored in this study are considered. This is common in all the three classes. These differences however are within the general homogeneity of the student sample. Within each of the three classes the binomial distribution of students views on each of the other explored NOS aspects is tilted in favour of traditional views. This is a general characteristic of the whole student sample. Some students within the classes (average 2 out of six per NOS issue) display fairly non-traditional views on the source and validation of scientific knowledge, the nature of observations, the purpose of experiments in Chemistry, the validity of knowledge from Chemistry laboratories. The nature of these views is discussed in the previous chapters. Being in a class where the instructional practice is of very low inquiry does not mean holding traditional views. This however is not to mean that the instruction does not have some effect on the students' views.

Low inquiry classes

The teachers' instructional practices in the low inquiry practices have three common characteristics (from Chapter 4). Both Martin and Mawonde use the strategy of giving the theory behind the practical before students do the practical, the instruction is verificationistic and examination focused and the level of student-student interaction is fairly high. The higher level of student-student interaction distinguishes them from the very low inquiry classes otherwise there is little difference between very low and low inquiry classes.

There appears to be a wider dispersion on some of the students' NOS views in the low inquiry classes compared to the very low inquiry classes. By this it is meant that students show a wider variety of views on some of the explored NOS issues compared to the very low inquiry classes. For example in Mawonde's class the following dispersion of students' views on the nature of scientific observation was obtained with the six students who completed the open-ended questionnaire.

- scientific observations depend on the prior theory of the observer = 1 student
- what we observe during Chemistry practicals is real = 1 student
- students sometimes fake observations = 1 student
- observations prove that scientific theories are correct = 1 student

- different people make different observations = 2 students

A similar dispersion is observed with Martin's class with the difference being that in Martin's class the dispersion is centered around the idea of limitationism, i.e. poor apparatus, contaminated reagents, poor student observational skills, and lack of sophisticated equipment limit school Chemistry laboratory observations. This differs slightly from the very low inquiry classes were students tended to aggregate into two categories of saying observations are objective or subjective. The observed dispersion can partly be explained by the fact that in the low inquiry classes students are allowed to interact among themselves and exchange ideas. This might be related to their viewing the NOS aspects in different ways. Let it be mentioned that this is more hypothetical than a point of fact because of the small sample size. Otherwise studying reasons for dispersion of students' NOS ideas within a class could constitute another strand of research endeavour.

In the low inquiry classes the students' views on the generation of scientific knowledge range from Baconian ideas with students saying that scientific knowledge comes from observation and experimentation to "anarchism" with students saying scientific knowledge comes from many sources including dream, guessing, creativity and shear God-given ingenuity.

> LS70: From my Chemistry practical work I say scientists arrive at conclusions after much perseverance and patience and careful analysis of results. Looking at observations and experiments involving for example indicators and titrations one has to be careful not to overshoot the end point so that conclusions can be made after careful work.

> HS43: Scientists sometimes guess some can have wide imagination mostly creativity counts and also guessing of the actual thing […] I also think knowledge comes from observations.

Student LS70's view appears to have some linkage to what the student does during volumetric analysis experiments. The laboratory experience could be a link between the students' image of the nature of his laboratory work and his ideas about how scientists arrive at conclusions. Most of the students' ideas on this issue do not appear to be linked to their laboratory work. The ideas expressed by student HS43 above cannot be easily linked to laboratory work experiences. On this issue one student appeared to be struggling in conflict as to whether he should believe observation and experimentation as ways of generating scientific knowledge as evidenced by his laboratory work experiences or whether as he was made to believe probably from theory lessons or from reading literature, scientific ideas can come through dream.

> HS43: I think in our Chemistry practical work we perform experiments, which show that an acid changes colour of an indicator. You can carry out an experiment and conclude that this substance for example orange juice or soap is a base or an acid. So scientific knowledge comes from doing experiments and observing. But yaa Kekule dreamt about the benzene ring so maybe scientists just guess, but I think Kekule must have been doing some experiment of some sort. I don't know maybe he just dreamt.

This student links his doing experiments in qualitative analysis (proximal experience) to how professional scientists produce knowledge. One of the activities is to add indicators to various substances in daily use and sort of discover which substances are acidic or basic. While he wants to make that interaction, there is also a belief inherent in him that scientists can also dream. This belief could have been built over time and does not change easily. Maybe the student's mind is in a state of flux. The student also referring to his belief in Kekule's dream however makes the linkage between the two ideas weak. He is not definitely saying scientific knowledge comes from observation and experiment only because that is what we do in the laboratory. The belief in Kekule's dream is a factor weakening the interaction between the student's ideas or views. It is an *in vivo* negative attenuator. *In vivo* factors were described as that collection of beliefs, personal theories, metaconceptual aspects, etc. forming part of an individual's conceptual ecosystem or ecology. The influence of this factor could exist in a state of flux with the positive attenuating effect on the linkage of the student's laboratory experiences coming as a result of the teacher's organization of instruction. It is reasonable to postulate that i*n vivo* and *in vitro* attenuation could exist in a state of fluctuating equilibrium. For this student what eventually attenuates from image of school laboratory instruction to image of professional science could be but a trickle characteristic of the state of that equilibrium.

Most of the students in the low inquiry classes hold the view that scientific knowledge is validated through the repetition of experiments. This view is also shown by their teachers and could have partly emanated from that source. Additionally the fact that students repeat experiments when they get wrong results could also play a part in building this image. It is difficult to locate the real source with outmost precision. One student however showed a fairly sophisticated view.

> LS67: Normally when they disagree they have to sit as a Board. Taking for example they disagree with information that has been published they need to carry out experiments as a Board, have results and analyze results as a group bring about deduction as a group not as one scientist. The new information they would have agreed on is the solution to a problem [dispute].

This view appears to be in tandem with the contemporary idea that science is consensus about consensible items. Part of this idea could also come from the group activities done by the student in laboratory work. The student's teacher reported that he sometimes organized class activities to settle disputes about differing student results. This is a possible source of the image displayed by the student LS67.

Some students also hold the views that experimental data is collected to prove that theory is correct.

> LS65: Data is used to tally theory to show that theory is correct.

For that reason they think that they should be accurate so that they can make the right conclusions. Right conclusions are those that fit theory.

> HS43: It is important to be accurate so that you won't be deceived and you will know the accurate thing in the books. After that we revise with the teacher and he has to correct us.

Sere et al. (1998) report a similar finding. In their study they report students as having shown the view that theory, data and the methodological aspects of labwork are interrelated. Within these classes some students also hold limitationist views and think that they fail to collect accurate data because of faulty apparatus or contamination of reagents. These views are also expressed in very low inquiry classes.

Almost all the students in the two classes were of the view that the laboratory is the place where scientific knowledge can be generated. When asked the question (open-ended questionnaire): "Do you think the Chemistry laboratory is a place where scientific knowledge can be generated? Explain your answer", their answer was affirmative with most going on to say they thought so because scientific knowledge could be verified in the laboratory. Some of these students also said the laboratory was a place for generating scientific knowledge because it helped them to learn Chemistry. In their study, Saunders et al. (1999) report students equating personal learning of science to generating scientific knowledge. The sampled students in the two classes failed to see themselves as sources of scientific knowledge. Most of the students in these two classes also thought knowledge from the Chemistry laboratory was always true because it is verifiable. To them truth is verifiability. Students' ideas on these issues appear to be linked to their doing of verificationistic experiments.

For the sample as a whole, some students also thought of generation (open-ended-responses) in terms of "source of knowledge" whereas others thought of it in terms of "scientific process". This suggested that the students could have interpreted the probe question (given in preceding paragraph) in two ways. Additionally in their responses some students appeared to have reflected on their own Chemistry laboratory experiences and the others appeared to draw upon their images of a "professional scientist's laboratory". In many cases though, whichever way the student looked at the question, the link of the response to verificationistic experiences appeared evident.

The medium inquiry class

Zivanai's (School G) instructional practice was found (Chapter 4) to be characterized by: starting the instruction by practical work and following it up with theory, high level of student-student interaction, occasional group activity, and less examination-centered compared to other teachers in the sample. Like the low inquiry and very low inquiry classes, problems for laboratory investigations also come from the teacher or past examination papers. For mainly this reason the level of inquiry cannot be considered to be high. Students in Zivanai's class however were observed to be engaging in more meaningful student-student discourse during which the validity of interpretations and conclusions was discussed (Driver et al., 2000).

The six students who answered the open-ended questionnaire in Zivanai's class show non-traditional and traditional views on the explored items of the NOS. The binomial distribution on the issues is slightly tilted in favour of non-traditional views. Table 7.1 below shows the binomial distribution.

Table 7.1 Binomial distribution of students' NOS views in Zivanai's class

NOS Issue	Frequency of non-traditional image	Frequency of traditional image
Role of laboratory/experiments in science	3	3
Generation and validation of knowledge (nature of scientific process)	4	2
The nature scientific knowledge	1	5
Nature of scientific observations	4	2
Nature of laboratory data	4	2

The binomial distribution might have been different if at least two classes had been considered or if a larger sample had been used. This distribution shows that slightly more students hold views that are more on the side of non-traditionalism compared to low inquiry and very low inquiry classes. It cannot be said certainly that the medium inquiry instruction is responsible for this distribution. What can be said with reasonable confidence is that some of the displayed NOS images appear to be linked to the students' laboratory experiences. The apparent linkage is present in both open-ended responses and interview data.

This is what one of the students said about the observations made by scientists.

> GS39: They tend to fit to the theory, which the scientist has in mind. I think this is also what happens in our Chemistry practical work. When I perform an experiment I expect to see something. If I don't see something because chemicals don't react its still an observation.

Student GS39 idea that observations "tend to fit to the theory, which the scientist has in mind" could be linked to Zivanai who also expresses a similar view:

> Zivanai: If you have a theory, observations maybe biased towards the theoretical background.

This image of the nature of professional scientific observations appears to be linked to what happens in A-level Chemistry laboratory activities. Zivanai normally tells his students to record observations whether they are positive (see something) or negative (nothing happens). At the same time he encourages students not to make observations with pre-conceived ideas. Students are also known to approach qualitative analysis observations with pre-conceived ideas. Zivanai explained:

> Zivanai: They have views that they bring to the classroom about reactions. When you give a test in qualitative analysis for example you find that students have their own idea about what the unknown cation is. If they come suspecting that the teacher is going to test on iron (II) ions and you give them nickel (II) ions they tend to make observations which prove their suspicion. You find a student saying it's a blue precipitate when the precipitate is green.

It is probable that what Zivanai tells his students about scientific observations and his encouragement of students to try and remove pre-conceptions from observations both filter onto the students in such a way that they build images about the nature of scientific observations. If the teacher frequently says "Don't say that FA8 contains iron (II) ions because you suspect its what the examiner is testing this year. Base inferences on observations", students might end up developing the image that scientists approach observations with pre-conceived ideas. This could be so especially when they the see themselves as being unable to shake off their own pre-conceptions when making observations.

This could also partly explain why some students say qualitative analysis observations involving colour changes are difficult. It could be the effect of the preconceptions they bring onto their laboratory observations. Perhaps what was said earlier about teachers not doing enough to train students to observe should have taken cognizance of the need to diagnose, and get rid of student misconceptions. Shiland's (1999) suggestions on constructivism in the Chemistry laboratory become handy.

Students own laboratory proximal knowledge about observations appears to be linked to their ideas about the nature of professional scientific observations (distal knowledge of the NOS). Student GS39 and Zivanai's responses could be suggestive of students' misconceptions *(in vivo factor)* and their laboratory experiences *(in vitro factor)* attenuating the interaction between proximal and distal knowledge of the NOS.

Views similar to what the students said about the nature of observations were also expressed about the data collected during laboratory work. Student GS41 commented (open-ended questionnaire):

> GS41: The data collected during Chemistry laboratory work are more guided with theory than for discoveries [professional science] because there is a set of reagents to be used resulting in an answer that is expected to suit the theories or assumptions made already, for example in a titration the amount of base to be used is given together with the amount of acid to be used.

What this student is attempting to put across is that the data they collect in their laboratories is known already compared to what happens during scientific discoveries. The student also believes data can be collected to show that theory is correct. Leach et al. (1998) have reported High School students displaying a similar image. This could be a reaction to verificationistic laboratory work or a reflection on such an experience. One of the students showing clear traditional views on the question: "What can you say about the data you collect during laboratory work?" had this to say (interview):

> GS37: The data is accurate and portrays things as they are because when experiments are carried out we let things happen on their own and then we make deductions.

Repetition of experiments was the most popular way suggested for the validation of scientific knowledge. This could mean that although in his instruction Zivanai attempts to organize activities for students to appreciate the real nature of science through for example encouraging student-student discourse, students themselves might not get the implicit message. Students might fail to get the inherent message carried by Zivanai's instructional strategy especially if they also regularly repeat experiments to validate class results.

Students were equally divided on the issue of whether the knowledge emanating from the Chemistry laboratory was always true. The students who said it was always true gave the reason that the knowledge could be proved or demonstrated in the laboratory. One student said it was always true except when faulty apparatus or contaminated reagents were used. This idea was categorized as traditional limitationism but put into traditional category. The three students who said it was not always true gave the reasons that sometimes students fake data, or that most of it was based on assumptions.

7.7.3 The nature of interaction between students' laboratory work experiences and their images of the nature of science.

This study indicates some interaction between teacher laboratory instructional practices and their students' images of the nature of science (NOS). That interaction however is not a causal relationship. It is not evident that being in a class where the level of instructional inquiry is low means holding traditional or fairly traditional images of the nature of science. In very low inquiry, low inquiry and medium inquiry classes' students are found who hold traditional NOS images. Students holding non-traditional images are also found in all the three classes.

The interaction between a teacher's instructional practice and students' image of the NOS appears not to be simplistic but quite a complex system. While the students' laboratory experiences and consequently, teacher instructional practice appear to have some influence on both proximal and distal images of the NOS developed by students, their attenuation into an 'effect' is both complicated and difficult to locate, illuminate and elucidate. The complexity of this "attenuative interaction" appears to resonate around the context of the laboratory instruction and factors embedded within the student's conceptual ecology. By context of laboratory instruction, it is meant: the curriculum or syllabus demands, the examination focus of instruction, the nature of practical work assessment, the availability of apparatus, chemicals and other materials and the nature of students and teachers (Songer et al., 2003). Other than images of the NOS, students already hold and continuously develop personal theories, metacognitive theories, motivational attributes (Hogan, 1999), attitudes, values, assumptions, other beliefs and sub-beliefs all constantly interrelating and possibly fluctuating. These aspects and many others form part of the individual's conceptual ecology.

In essence, this study has cast a faint ray on the validity of the assumption that, the engagement of students in laboratory activities can eventuate in the students' picking up and building images about the nature of scientific knowledge and the processes of its development and validation. This assumption is the basis of the so-called implicit approach to development of students' NOS conceptions (Abd-El-Khalick and Lederman, 2000; Hodson, 1996a). The pieces of illuminative evidence gleaned from the observations of laboratory classes, teacher and student interviews, appear to give some weight to the validity of some translation of students' laboratory experiences into students NOS notions or images. The shades of instructional practice (or in reality laboratory experiences) that manifest into students' NOS images appear to be governed by an "attenuation equilibrium" between the context of instruction and the interplay of a set of variables located in the student's conceptual ecology.

What eventual filters from laboratory experience to NOS conception can only be located by way of inference? There is always the principle of uncertainty emanating from the very complexity of the human mind. Images of the NOS build into and form part of an individual's belief system and conceptual ecology. It is absurd to claim that the source of a belief can be located with outmost precision. As Wickman (2004) points out we can only know about mental structures by observing human behaviour and listening to people. These appear to be the only surgical tools available for us to open up and understand the complexities of the conceptual system. According to Ryder et al. (1999) students' images of the NOS are built from a variety of sources (television, newspapers, theory lessons, textbooks, etc.). The location of the source of an image is an interpretive act requiring the researcher to sift and carefully judge available information with the aim of establishing antecedents and congruency between the proposed source and the available evidence. By the same process the researcher can establish congruency between students' proximal and distal NOS images.

Tiberghien et al. (2002), have pointed out that what the teacher actually plans for the students to do during practical work and what they actually experience are not exactly the same. Equally teacher instructional practices and students' laboratory work experiences cannot easily be equated blow by blow. While it is true to say that students experience what the teacher practices (plans, organizes and implements) the effect of that practice might vary from one student to the next. Students might also act and experience phenomena in a way not intended by the teacher. At the same time the teacher directs and shapes the learning process, what students do and experience is actually a direct result of the teacher's actions. This is a further complication in the teacher instructional practice and students' images of science equation. The divide line between what the teacher does (the instructional practice) and what the students actually experience as a result of the instruction is microscopic and also difficult to locate and concretize. It is an interwoven interactive system.

One way to avoid the arising complication is to make the assumption that students' laboratory experiences are not only indicators of instructional practices but also their mirror image. Instructional practice is a consummate of teacher actions and students' experiences. Figure 7.2 below gives a picture of the mesh of the nature of interaction among teacher instructional practices and those factors identified above as influencing attenuation of teacher practices into students' NOS images.

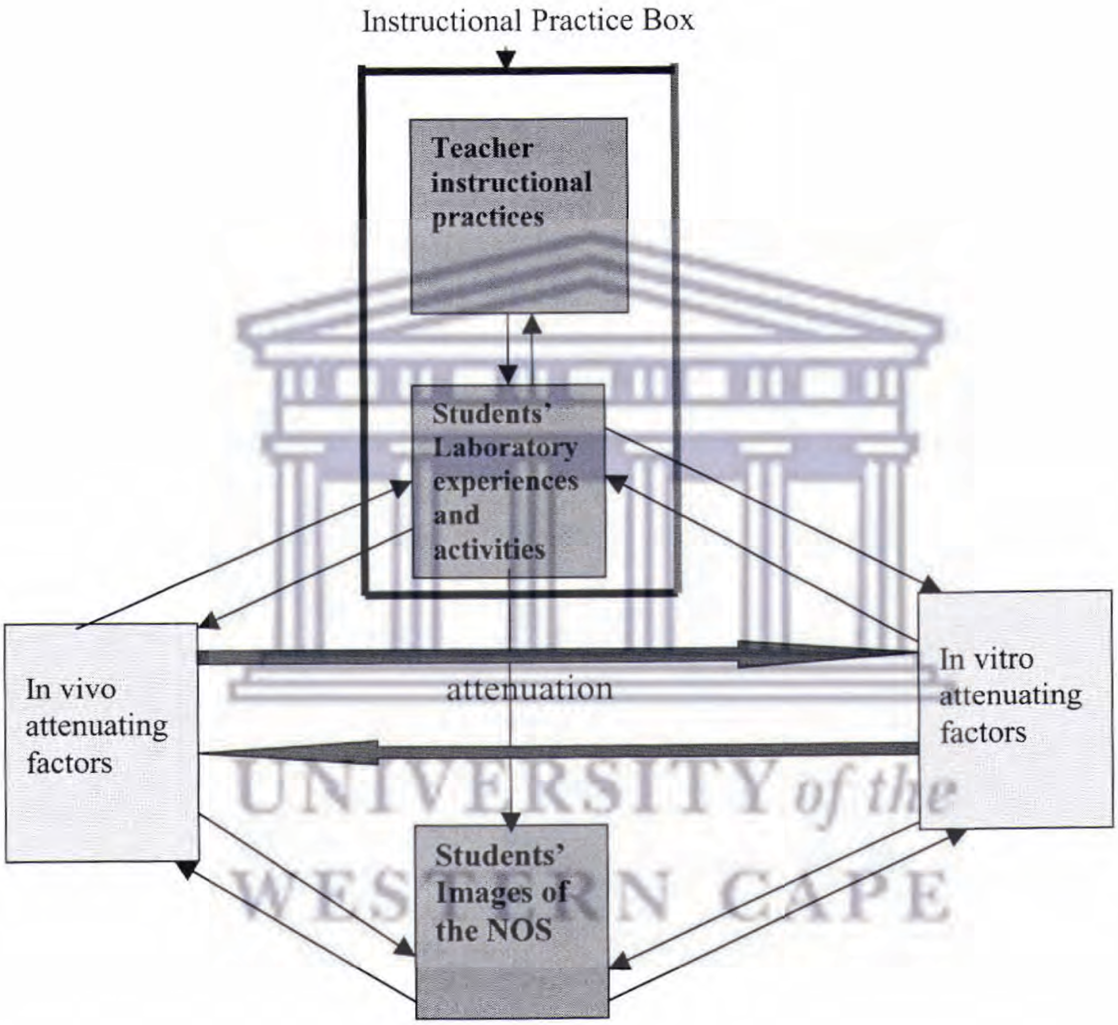

Figure 7.2: Interactions among teacher practices, students' experiences, students' NOS images and attenuation

The big arrows represent the influence of *in vitro* and *in vivo* factors on what it is of the practice that filters onto or translates into the students' NOS images (thin single arrow pointing downwards). As pointed out what eventually filters from instructional practice to NOS images is determined by the attenuation equilibrium between the two attenuators. The two big arrows represent this. There are also interactions among *in vivo* factors and the students' experiences as shown by the arrows penetrating the instructional practice box into the students' experiences box. This is shown by the arrows pointing in opposite directions because some factors embedded in the conceptual ecology, for example, motivation can also interact with students' actions and experiences. Images of the NOS also interact with *in vivo* factors in a two-way interactive system where NOS images can also influence *in vivo* factors. *In vitro* attenuating factors interact with both the instructional practice and NOS images. Although in this study attenuation of students experiences is thought of as mono-directional, from experiences to the images, studies done (Leach, et al., 1998; Sere et al., 1998, Ryder et al., 1998) show that it is possible for students to draw upon their NOS images when doing laboratory tasks. Some sort of "reverse attenuation" cannot be ruled out. It is suffice to point out that while Figure 7.2 shows boxes, the boxes might actually be a "fabrication" and it would be safer to map the interactions in terms of a mesh where all things belong together.

7.8 Conclusions and implications for Chemistry Education

The major findings of this study can be summarized as:

(i) There is no relationship between the nature of inquiry practiced by a teacher and his students holding traditional or non-traditional images of the NOS.

(ii) The sampled A-level Chemistry students appear to develop some images of the NOS from their participation in laboratory work.

(iii) The interaction between teacher instructional practices and students' images of NOS is a complex system, which appears to be governed by the nature of equilibrium between *in vitro* and *in vivo* attenuating factors.

If maximization of translation of instructional practices into benefits in the form of students' NOS understandings is to be achieved, teachers must not only be aware of the existence of attenuating factors but also be equipped with techniques for planning and implementing laboratory instruction in such a way as to minimize negative attenuation. This is particularly so where instructional practice filtrates desirable or non-traditional students' NOS images. Chemistry teacher education in-service and pre-service programmes need to train students on ways to adapt instruction to suit examination requirements as well as attain the development of desirable students' NOS images. Some teachers have the belief that teaching for examinations and for desirable NOS understandings are parallel and irreconcilable. Part of the teacher training must be to convince teachers that by engaging students in inquiry they are also attaining the goal of preparing students for examinations. There is certainly more to education than preparing students for examinations. For Zimbabwe, there is certainly a need to do away with the examination disease reminiscent of the "Diploma Disease". The newly introduced teacher performance appraisal system in which judgement of teacher performance and effectiveness appears to hinge on examination results can only serve to entrench examination focused instruction to the detriment of providing students with a wholesome Chemistry education in which students can appreciate and practice science as inquiry.

The Zimbabwean A-level Chemistry curriculum development is a centralized top to bottom one (coming from central government to schools). It would be interesting to investigate attenuation in de-centralized curriculum systems where teachers have significant latitudes to plan and implement curricula as well as determine the form of terminal assessment (end of A-level course assessment). It would also be interesting to investigate how teachers' NOS conceptions interact with students' NOS conceptions. This interaction could have been fully examined in this thesis but the author felt such an exploration would have widened the study beyond the limits of available time and resources. Finally this study will not claim to have fully understood the nature of teacher laboratory practices and their interaction with students' NOS images. It has only gnawed a big complex system. Attenuation is only a tiny window through which a faint ray of understanding of the system can be made manifest.

CHAPTER EIGHT

Putting it all together

Study summary, conclusions and recommendations

8.0 Introduction

This study set out to investigate the nature of A-level Chemistry teachers' science epistemological beliefs (SEBs), teachers' laboratory instructional practices and students' images of the nature of science (NOS). The study's major effort was to explore and elucidate the features and characteristics of the interactions among/between the investigated variables. Within that effort, the study also contributed to the unveiling and illumination of the Zimbabwean *status quo* on each of the investigated variables. By this it is meant that something is known now about some ideas of the NOS held by some of Zimbabwe's A-level Chemistry teachers and their students. Equally important is the fact that an illuminative ray has been cast on the nature and state of the practice of inquiry in some of Zimbabwe's A-level Chemistry laboratories. The pieces of *evidence* gathered in exploring the nature interactions among/between the investigated variables, together with complementary theoretical tenets *peeled off from the literature* provided rivulets of insights leading to *the hypothesis posited in this thesis*.

In this concluding chapter, the nature of interactions unveiled by the study and the postulated hypothesis, *the attenuation hypothesis* are discussed. The contributions of each of the four papers making the study are highlighted and evaluated. The gaps filled by the research are pinpointed and areas for further research identified. Finally the recommendations coming out of the study are given.

8.1 A-level Chemistry teachers' science epistemological beliefs and laboratory instructional practices

This section puts together the findings and insights relating to the issue of the nature of interaction between teachers' science epistemological beliefs and their laboratory instructional practices, that is, their practice of inquiry. Much of what is discussed in this section is relevant to answering the first major question posed in Chapter 1 of the thesis. What is the nature of A-level Chemistry teachers' epistemological beliefs and their laboratory instructional practice?

8.1.1 Teachers' science epistemological beliefs

In the first paper of the study teachers' SEBs and their instructional practices were investigated. Both individually and as a group, the sampled teachers were found to habour traditional and non-traditional beliefs about; the purpose of experiments in science, the nature of scientific observations, the generation and validation of scientific knowledge and the nature of scientific knowledge. Some of the teachers were of the positivist view that valid scientific knowledge is based on experiments and observation only. The teachers were also found to habour the beliefs that the purpose of experiments in science is to demonstrate or prove theory, that scientific knowledge is culture free, and that scientists settled disputes by repeating experiments. That these beliefs were haboured by some of the teachers was evidenced by the teachers' responses to both the interview probes and the TSEBQ. Interestingly, five of the six the interviewed teachers were of the view that scientific observations are subjective (depending on individual point of view) and that when making observations scientists made use of their prior ideas. On this issue however, the teachers appeared to contradict their responses to the TSEBQ where most had agreed to the assertion that when making observations scientists eliminate their beliefs and values. Some of the studied teachers were also found to habour the non-traditional and contemporary beliefs that: scientific knowledge could be generated in various ways for example through, dream, serendipity, guessing, etc.), and the instrumentalist view (Dawson, 1991) that the purpose of experiments in science was for scientists to solve human problems of needs and wants.

It is not surprising that the studied teachers hold traditional beliefs about some aspects of the NOS. This result confirms what is in the literature (Abd-El-Khalick and Lederman, 2000; Haidar, 2002; Lederman, 1992; McComas, 1996; Ruggieri, Tarsitani and Vicentini, 1993; Tsai, 2002). Secondary school teachers around the world are known to habour various misconceptions about the NOS. It is equally not an exciting finding that some teachers hold fairly sophisticated views on some aspects of the explored NOS issues. This is also in tandem with the literature; which says: on some NOS issues teachers can harbour fairly sophisticated views.

8.1.2 Teachers' laboratory instructional practices

For most of the observed laboratory sessions, the nature of inquiry was found to be generally low. It was not evident as reported in the literature (Hashweh, 1996; Tsai, 2002) that a teacher holding constructivist (non-traditional) views of the NOS teaches in ways that are completely different from one holding traditional or empiricist beliefs. The fact that a weak relationship was found between teachers' beliefs about the NOS and their perception of their practice appears to give support to this finding. This result supports the finding of Schraw and Olafson (2002) who found that teachers' epistemological beliefs were not strongly related to teaching practices. In the current study, both traditional and fairly non-traditional teachers were found to teach in ways, which were designed largely to prepare students for examinations. However, the examination focus of instruction was slightly weaker in the classes of the teachers holding non-traditional NOS beliefs.

The data obtained from the observations laboratory sessions and the teacher and student interviews and questionnaire, revealed that the sampled teachers conducted laboratory instruction in ways which can be described as mostly: individualistic and examination centered (effort concentrated on preparing the individual student for examinations), and conformistic/verificationistic (most practical work activities are designed to verify Chemistry knowledge). The level of inquiry in the laboratories can be described as low based on the following peg marks (findings):

- Teachers are the ones who almost always provide the problem for laboratory investigation, which in most cases is sourced from past A-level Chemistry examination papers.
- Students are rarely allowed to engage in the kind of laboratory interactions which can be described as promoting scientific argumentation, for example, arguing about the merits and demerits of procedures, hypotheses, data interpretations, etc. Only in one class did the teacher appear to encourage the kind of classroom discourse

described as characteristic of the practice of inquiry (Newton et al., 1999; Driver et al., 2000).

- The teachers tended to discourage group activities and only used them as an instructional expediency to solve the problem of shortage of resources.
- The latitude given to students to plan and design their own experiments, and make decisions about data interpretation and presentation; or the degree of open-endedness of investigations (Tamir, 1991), was limited by the curriculum and examination requirements.

Irrespective of the teacher's SEBs being traditional or non-traditional teachers were also found to be using two strategies of laboratory instruction. Both strategies do not appear to raise the level of inquiry. One way is for the teacher to start by giving students practical work activities and then following it up with discussion of the theory behind the practical or experiment. The other strategy is that the teacher would start by discussing the theory behind the experiment and then asking the students to do the practical. Teachers using either of the strategies appear to be convinced that it is the best way to prepare students for examinations.

8.1.3 Attenuation equilibrium and teacher laboratory ecological interactions

Given the above features and characteristics of teachers' SEBs and the nature of their practice of inquiry, an exploration was made to find out if some of a teacher's SEBs permeated his/her laboratory instructional practices. By examining each of the teacher's SEBs, and analyzing and interpreting data from both observed laboratory sessions and the teacher interview, an effort was made to understand better *the nature of the relationship or interaction* between a teacher's practice of inquiry and his/her SEBs.

It emerged that some of the teachers' science epistemological beliefs (SEBs) filter into their laboratory instructional practices. For example teacher Abongile's belief that scientific knowledge can be proven in the laboratory appeared to be linked to her frequent use of verificationistic laboratory activities. Another example is that of teacher Zivanai whose belief that scientists generated and validated knowledge though the process of argumentation appeared to reflect itself through the relatively higher level of student-student argumentation he allowed in his laboratory classes. While some filtration or attenuation of teacher SEBs into instructional practices appeared evident, the filtration appeared to be weak and under the guidance of competing factors located both in the teacher's instructional environment and the teacher's conceptual ecology.

Borrowing terminology from other fields of intellectual endeavour, (Biology, Medicine, Geochemistry, etc), the author coined those factors originating from the instructional environment *in vitro* factors and those whose origin was the teacher's conceptual ecology, *in* vivo factors. The concept of the translation or filtration of the teacher's SEBs into practice was coined *attenuation*. It was called attenuation because whilst it appears evident, the magnitude of that filtration is not strong. Teachers practice what they believe about the NOS but only to a limited attenuated extend. The observation that teachers' SEBs only feebly translate into their practices of inquiry supports what is found in the literature (Duschl and Wright, 1989; Hofer and Pintrich, 1997; Lumpe et al., 2000; Martin, 1999; Pajeras, 1992; Schraw and Olafson, 2002) about the interactions among teacher beliefs in general, teacher decision making and their instructional practices. This literature together with the findings of the current study, led the author into proposing the concept of *attenuation equilibrium*.

In making instructional decisions, which eventually turn into practices, the teachers appear to consider such factors as the need to prepare students for examinations, the availability of resources, time for content coverage, administrative expectations on the teacher, and the syllabus content and objectives. These instructional environment factors were identified as or more accurately coined *in vitro factors* or *in vitro attenuators* by the author. Decision-making here refers to teacher choice of instructional strategies, laboratory activities and how those activities are going to be organized and implemented. Of these factors it is the need to prepare students for examinations, which appears to be the most influential.

While teachers appear to weigh the instructional context factors given above, their decision-making also appears to come under the influence of some other factors located in their conceptual ecology. Beliefs about assessment, pedagogy (teaching and learning), their understanding of the subject matter and motivational factors also appear to influence teacher instructional decision-making and consequently the nature of their practice. For example there appears to be a link between teacher Mawonde's saying about his teaching: "Designing experiments is most difficult especially in reaction kinetics." and his laboratory work teaching strategy of concentrating on developing the skill of "designing experiments" when students are in lower Sixth compared to Upper Sixth when his strategy becomes more examination focused. Such a belief about students' learning difficulties has been called an "internal belief" (Martin, 1999). It is already embedded in the teacher's conceptual ecology. Such beliefs also appear to influence teacher decision-making and instructional practice confirming what is found in the literature (Lumpe et al., 2000; Martin, 1999). They are part of an individual's conceptual ecosystem. The factors embedded in the teacher's conceptual ecology were termed *in vivo factors* or *in vivo attenuators.* Apparently these factors also interact with the teacher's science epistemological beliefs. That interaction appears to have an attenuating effect on the translation of teachers' SEBs into laboratory practices.

It looks like what eventually filters from SEBs to teacher laboratory instructional practice is determined by the effect or influence of these attenuating factors. The attenuating factors could have opposing effects (be in competition), or they could also both positively reinforce the translation of a teacher's SEBs into practice. In whichever way it is taken, the qualitative magnitude of the filtration of SEBs to practice appears to be governed by the state of balance reached by the competing or reinforcing factors (attenuation factors). When a state of balance is reached the teacher makes and implements an instructional decision. It is the decision-making, which determines the nature of the realized instructional practice. This appears to be a daily feature of the observed teachers' laboratory instructional practice. The state of balance can be called *attenuation equilibrium*.

Although governed by factors inside and outside the individual, equilibrium attenuation or attenuation equilibrium is a feature of the individual's cognitive ecology. It is a mental, epistemic and affective activity involving the processes of assessment and evaluation. Judgemental decisions are made about the merits and demerits of instructional choices. The teacher appears to be constantly asking himself or herself: "Under these circumstances could this be the best approach to use?"

The location of contextual or *in vitro* factors into the teacher's conceptual ecosystem is a feature occurring through perception. Perception here is both mental and epistemic. It is an interaction of sensory data with the cognitive system. The teachers reflect on the nature of their instructional practice. They think about and continuously locate features of the instructional environment context into their conceptual ecosystem. ; an *ecological system* that is replete with interacting factors.

Figure 8.1 below shows a picture of attenuation equilibrium and teacher laboratory ecological interactions. On the figure the big double arrows represent the equilibrium attenuation between *in vitro* and *in vivo* factors. The thin arrow pointing from the SEBs box to the teacher instructional practice box shows the filtration or attenuation of SEBs into practice, which is governed by the state of attenuation equilibrium.

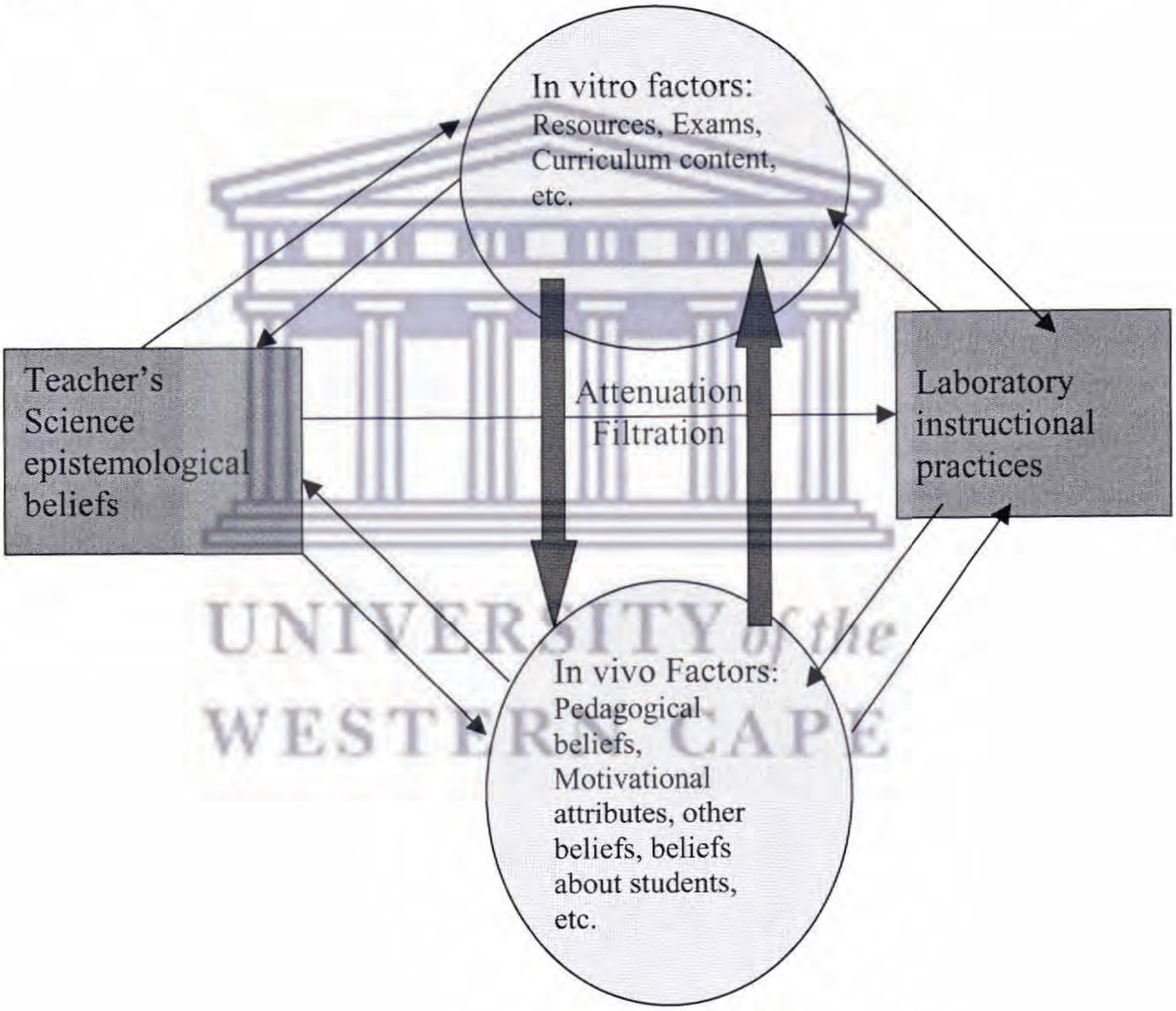

Figure 8.1: Diagrammatic representation of attenuation equilibrium and a teacher's laboratory ecological interactions.

Attenuation of teachers SEBs into practice is also complex because all factors are interrelated. They all might have an influence on each other. For example teacher practices have been reported to have some influence on teachers' philosophical orientations and beliefs about teaching (Gwimbi and Monk, 2002; 2003). Attenuation equilibrium therefore can also be about laboratory practices influencing teachers' SEBs.

On the figure the arrow (small thin arrow) points in one direction only because in this study the effort is to illustrate the nature of filtration of teachers' SEBs to instructional practice. It is possible then to refer to another state of equilibrium between the opposing influences of SEBs to Practices and Practices to SEBs. The filtration of beliefs into practice could also be influenced by the state of this equilibrium. This further complicates the nature of interaction. The states of these equilibria might always be continuously fluctuating. What might influence the direction of filtration is the state of the attenuation equilibrium, which in itself could also be in a constant state of flux.

One issue that arises is the question of where to locate teachers' perceptions of instruction within the system represented by Figure 8.1.The way teachers perceive instruction influences their instructional decision-making. According to Brewer and Lambert (2001) perceptions are said to inextricably interact with high-level theoretical beliefs. The meaning of this is that it is difficult to separate beliefs from perceptions. Is it possible to see without believing? Can teachers perceive themselves as involving students in problem solving without their believing that they do so? If perception is inseparable from belief, then the kind of perception relevant to the issue under consideration necessarily belongs to the individual's conceptual ecology. As already said the kind of perception being referred to here is both mental and epistemic. By that argument perception of practice is an *in vivo* instructional factor. At the same time it interacts with and is also located in and is part of the instructional practice. Teachers' perceptions of their instruction provide a reflective and evaluative mirror through which they can make judgements about the merits and demerits of instructional decisions vis a viz their beliefs about the NOS. Because teachers continuously reflect on their instructional practices, the realization of attenuation equilibrium is not a sub-conscious activity but a conscious purposeful activity feeding into daily decision-making and instructional practice. Attenuation equilibrium is partly a product of the input of perceptual data.

8.2 Students' images of science and their participation in laboratory work.

The major issues discussed and summarized in this section relate to question 2 of the study: What is the nature of A-level Chemistry students' images of science and their participation in laboratory work? Papers 5 and 6 of the thesis tackled this question.

8.2.1 Students' participation in laboratory work and their proximal images of school Chemistry

This study shows that from their participation in A-level Chemistry laboratory work students build images of the nature of school Chemistry knowledge and their own knowledge building. Students' responses to the SINOS, the sLPVI, the open-ended questionnaire and interview probes have revealed that the following features dominate the sampled students' views about their Chemistry laboratory work:

- School Chemistry laboratory work is mainly aimed at helping students to learn or understand theory in order to prepare them for examinations.
- School Chemistry knowledge can be verified through observation and experimentation.
- In their Chemistry laboratory work students do not generate their own knowledge but prove that Chemistry textbook knowledge is true and real.
- Students encounter learning difficulties in qualitative analysis experiments especially those activities requiring detection of colour changes.
- Their laboratory learning experiences are dominated by experiments or activities, which are conformistic and verificationistic.
- Students recognize that curriculum and examination constraints are impediments to their practice of inquiry in A-level Chemistry laboratory work.
- Their practice of inquiry could be improved if their Chemistry laboratories did not experience the problems of shortage of apparatus, chemicals and other materials.

Students' perceptions of the nature of inquiry in their laboratories were not found to be related to gender or the type of school (Boarding or Day) in which the student was.

8.2.2 Students' distal images of the NOS

Through analyzing and interpreting students' responses to open-ended questions and interview probes the study was able to tease out some ideas about the nature of professional science students appear to develop from their participation in A-level Chemistry laboratory work. These ideas however also appeared to be simultaneously under the influence of other student knowledge and experiences. Students displayed mainly traditional images of the NOS. Some non-traditional images were also exhibited but these were not prevalent. The sampled students' traditional and non-traditional ideas about the nature of scientific knowledge and the processes of its development and validation were dominated by the following:

Traditional views

- The science or inquiry practiced by the professional scientist was completely different from school science[5]. Professional science operated at the frontiers of knowledge whereas school science verified ready-made science or textbook knowledge.
- Scientific knowledge could be proven through observation and experimentation; that is, making observations and collecting experimental data.
- Scientists validated knowledge through repeating observations and experiments.
- Scientists were intelligent and highly skillful people who did not make mistakes in observations and measuring entities.
- Scientific theories emerged directly from making observations and collecting experimental data.

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[5] It could be argued that this image should not be categorized as a traditional image but really as a sophisticated understanding of the difference between school and professional science. While the author categorizes this image as a traditional conception he would not object to that kind of alternative thinking.

laboratory experiences and influences from other sources. At the same time student responses also indicated that some of the distal NOS images were related to some of their ideas about the nature of school science or school Chemistry. For example some of the students who displayed the view that the school Chemistry laboratory demonstrated or verified Chemistry textbook knowledge are also the same ones who held the notion that scientific knowledge could be proven by carrying out experiments. The same students were also the ones who perceived the nature of inquiry in their laboratories to be verificationistic. Both student laboratory experiences and their proximal understandings appeared to be linked to some of the expressed distal NOS understandings. Students' laboratory experiences are a direct consequence of the nature of the teacher's instructional practice.

It made sense then to posit another *laboratory conceptual-ecological system* involving the student. Figure 8.2 below shows this system and its interacting components. As was the case with the teacher, the student's ecological system has attenuation equilibrium at its center. The student's conceptual ecology is enmeshed with a set of interrelated and constantly interacting factors.

The exploration of the interaction between students' perceptions of instruction and their images of the NOS indicates that students' perception of laboratory instruction could be the conduit through which the proximal-distal image linkage is given shape and direction. Students perceive and reflect on their laboratory experiences. As a result of that reflection they build images about the nature of both school and professional science. They can also reinforce pre-existing notions about science from both those experiences and other sources. Students' perceptions of laboratory instruction, their proximal images and their distal images form an intricately interwoven ecological system.

Students' images of the nature of school science are influenced by their laboratory experiences, curriculum and examination constraints, availability of laboratory resources etc. These instructional environment context factors have been called *in vitro factors* or *in vitro attenuators.* The attenuators also interact with the student's distal images of the NOS. At the same time other factors embedded in the student's conceptual ecology; *in vivo factors* or *in vivo attenuators* (beliefs about teaching, motivational attributes, personal theories, etc.) also interact with both proximal and distal NOS understandings. The whole system embeds a matrix of contextual and cognitive ecological factors also interacting with and influencing the translation of proximal images to distal NOS understandings. As a whole, the system might be considered macroscopic but each component is microscopic and could still contain attenuation equilibrium mediated interactions. What is shown on Figure 8.2 therefore is an attempt to make sense out of an extremely complex system.

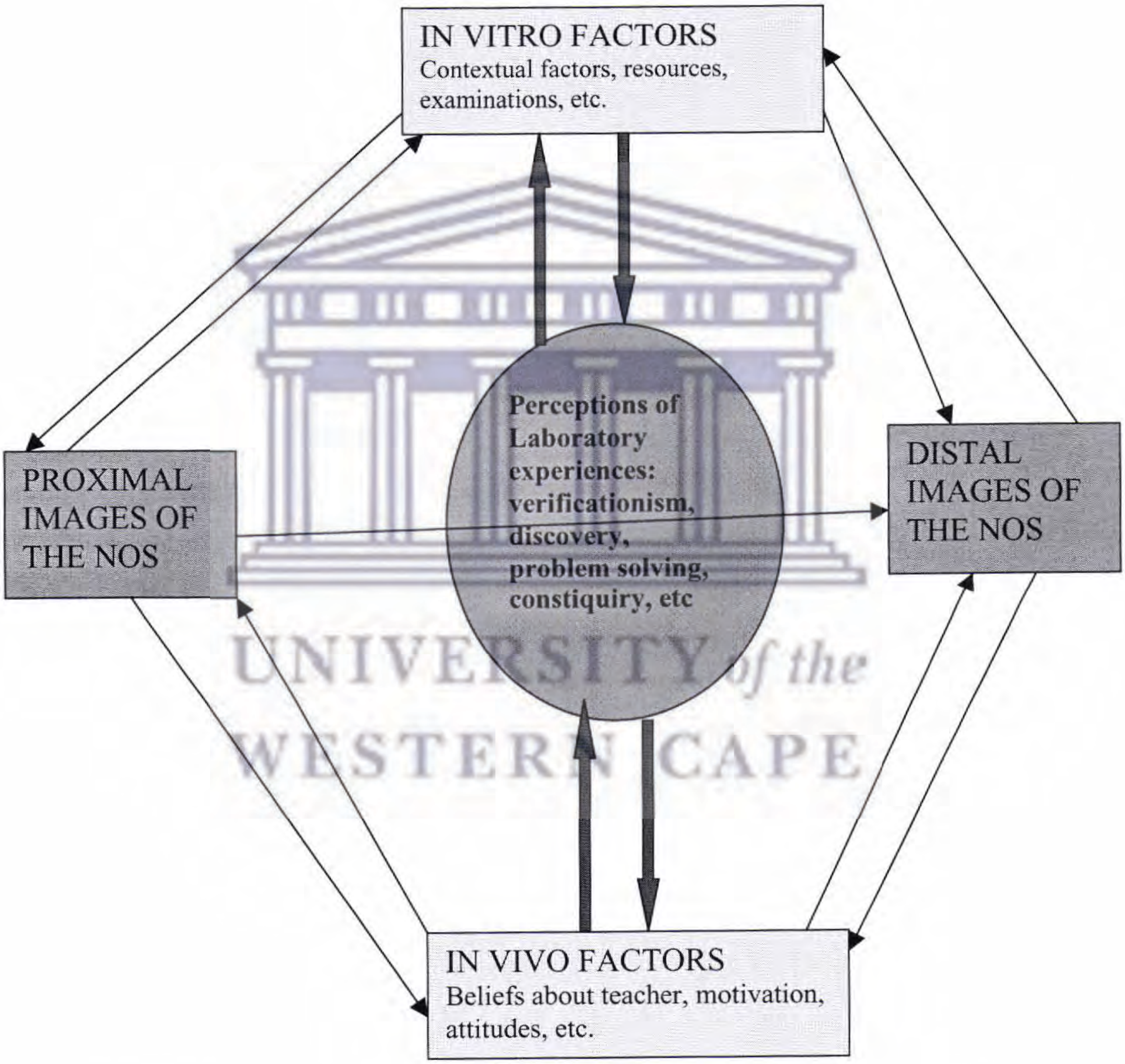


Figure 8.2: Attenuation equilibrium, perception and students' proximal and distal NOS images.

On Figure 8.2, the thin arrow passing through the circle shows the feeble attenuation of students' proximal images to distal images. *In vitro* and *in vivo* attenuation equilibrium is represented by the big double arrows (going into the circle at the center) pointing in opposite directions. As is the case with the teacher's ecological system, students' perceptions of laboratory instruction are also partly located in the *in vivo* matrix. The feeble filtration of proximal understandings to distal images of the NOS is also under the governance of the state of attenuation equilibrium between *in vitro* and *in vivo* factors. Perceptions are the conduit through which that equilibrium is given shape and direction. In a way the manner in which the student perceives and experiences discovery, problem solving, verificationism and other laboratory instructional strategies feeds directly into shaping the nature of attenuation equilibrium. As the whole system is a mesh of interwoven interactions, it is difficult to completely isolate or extract each of the components and cognize it as independent from the others.

Hogan (2000) reports that distal images have also been known to influence students' proximal understandings. This could mean another interaction or attenuation equilibrium between filtration of proximal images to distal images and filtration of distal images to proximal images. The direction in which feeble attenuation will obtain might be a property of the state of the *in vitro-in vivo* equilibrium. If for example, students have much stronger beliefs about the nature of scientists obtained from television, newspapers, theory lessons, etc, those images located in their *in vivo* matrix might actually negate an influence about the nature of scientists coming from students' laboratory experiences. The distal-proximal equilibrium will be tilted in the direction of distal influencing proximal understandings. But if there is strong positive attenuation of students' building distal images from their laboratory experiences the direction of that equilibrium might change to favour attenuation of proximal images to distal understandings. This might be called field *in vitro* positive attenuation. In this instance, the beliefs located in the student's *in vivo* matrix might be acting as negative attenuators for the translation of proximal images to distal understandings. But in terms of the distal to proximal translation this might be viewed as positive attenuation. The direction of the proximal-distal slender will be determined mainly by the state of attenuation equilibrium.

8.3 Teacher instructional practices and students' images of the NOS

In this section the major ideas from the thesis's four papers are combined with the effort to summarize those issues pertaining to answering research question 3 of the thesis: What is the nature of teachers' laboratory instructional practices and their students' images of science?

8.3.1 Conceptual ecological systems in the school Chemistry laboratory

The analysis and interpretation of data from laboratory observations, teacher and student interviews and/or questionnaires indicates that teacher instructional practices have some influence or bearing on the images of the NOS students develop from participating in laboratory work. In particular the following features and laboratory activities organized by the teacher and experienced by the students appeared to have a link to the images of the NOS displayed by the students:

- Activities during which students repeated experiments to validate measurements or observations. Students appeared to link this to the way professional science is validated.
- Practical exercises or activities, which were run under strict schedules of time. These appeared to reinforce the notion that scientists do not work under the schedule of time.
- Teacher over-emphasis on accuracy of observations and measurements (for example, values of titres in titrations). Students tend to compare their own inaccuracies with imagined notions of scientists being extremely careful and accurate people.
- Students' own experiences with shortages of apparatus, chemicals and other laboratory resources. This appeared to be linked to the idea that professional scientists have an unlimited access to resources.

Gaps were also observed to exist between a teacher and some of his/her students' perceptions of the purposes of school Chemistry laboratory work and the nature of the inquiry practiced in the laboratory. It emerged that two distinct conceptual ecological systems constitute the school Chemistry laboratory, each with its own state/s of attenuation equilibrium. The teacher's system is one component and the student's system another. Figure 8.3 below shows the ecological systems.

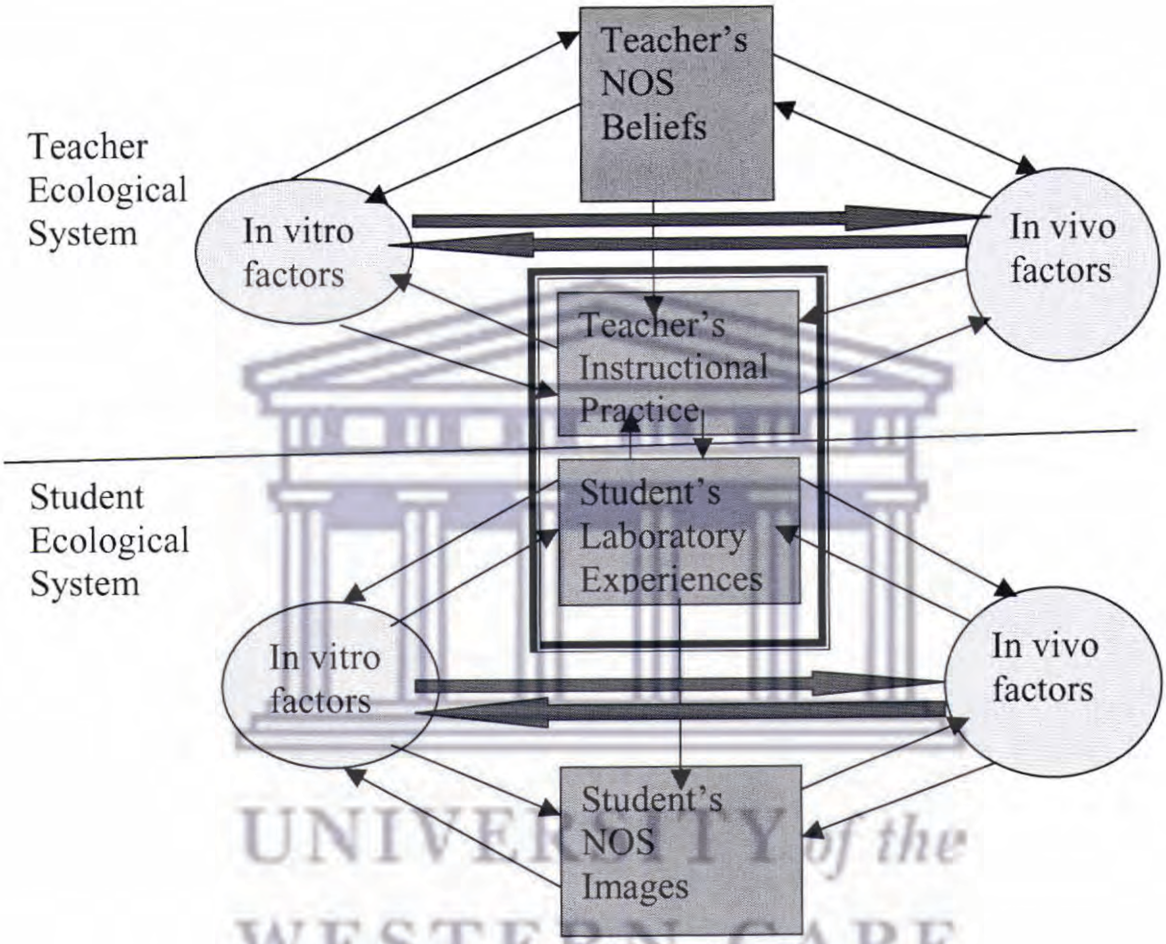


Figure 8.3: Teacher and student laboratory ecological systems

The box in the center represents instructional practice, which is a consummate of teacher practices and students' experiences. Decisions made by the teacher about what to plan, which Chemistry laboratory activities to do, what strategies to use, and how to evaluate student laboratory learning are a direct result of the state of attenuation equilibrium in the teacher. These decisions ultimately determine the nature of instruction and the form and nature of students' laboratory experiences. Through the teacher-student laboratory interaction, the teacher's own NOS beliefs might filtrate into the students. Teachers' epistemological beliefs have been associated with setting the tone for teacher-student interactions and changing students' beliefs (Schraw and Olafson, 2002). The classroom argumentation orchestrated by the teacher could be a mediating variable in the filtration of teachers' beliefs onto the students. Such a filtration could occur within the black box in the center of Figure 8.3. Some of the ideas about science expressed by the students in the current study are almost exactly the same as those expressed by their teacher. This study did not fully explore the relationship between teachers' and students' NOS conceptions. It was felt that such an exploration would make the study too wide. Such a study however can further illuminate the nature of the ecological interactions described here.

What is being described here is based on interpretation of research data from a curriculum and pedagogical system assuming implicit translation of students' laboratory experiences into understandings of the nature of science. According to Abd-El-Khalick and Lederman (2000) and Lederman (1992), the goal of enhancing or building students' understandings of professional science can be planned for and attained through classroom instruction. Students' NOS understandings are not anticipated as a side effect or secondary product of the instruction. This entails a curriculum and pedagogy that has content and learning experiences deliberately designed to bring about pre-planned students' NOS understandings. Such an approach has been called the explicit approach. It is assumed that the translation of students' proximal images to distal images can more easily be achieved through explicit rather than implicit approaches. The nature of the interactive systems described in this thesis might be different where explicit instruction is concerned.

Whether that be so or not, it appears that, for instruction to achieve a positive or desirable translation of proximal to distal images, it must of necessity, operate on both *in vivo* and *in vitro* factors. Pedagogical practices must start with a diagnosis of potential positive *in vitro* factors and negative *in vivo* factors. The identification of the latter might be best achieved through constructivist-inquiry or constiquiry approaches. These approaches start from identification of students' prior beliefs and understandings. Instructional activities can then be organized for students to build desirable NOS images. Teacher awareness of students' beliefs can enable them to help students change their conceptions about science (Ledbetter, 1993).

An interesting observation coming out of the current study is that a teacher's practice of relatively more inquiry-oriented laboratory instruction appears to be no guarantee that his/her students will develop desirable (non-traditional) images of the NOS. As was discovered in this study, even in the class where the teacher's practice of inquiry is relatively high, students were found to hold traditional views on many aspects of the explored NOS issues. Students in classes designated as of low inquiry were found to habour both traditional and non-traditional views of the NOS. It would appear that going through inquiry oriented laboratory experiences is not the only variable mediating the development of desirable images of the NOS in students. There is the fact that gaps exist between what instruction is aimed to achieve (for example, put across a message about the NOS), what the student gets out of a learning experience (Tiberghien et al., 2002) and the student's perception of the intentions of instruction. Instructional practices/learning experiences have idiosyncratic effects on students. One could posit that; in terms of student understandings of the NOS, what a student actually gets out of an experience might be a feature of the state of attenuation equilibrium within his ecological system. This varies from one student to the next. States of attenuation equilibrium are necessarily idiosyncratic.

8.4 The attenuation hypothesis: opening a small window

This thesis has proposed the hypothesis of attenuation to describe and explain the nature of interaction between:

- Teachers' science epistemological beliefs and their laboratory instructional practices.
- Students' laboratory experiences and their images of the nature of science.
- Students' proximal and distal NOS conceptions.

It was pointed out that while both instructional practice and students' laboratory experiences have physical characteristics, they are actually located through perceptions, into the student's conceptual ecosystem. The same was said of *in vitro* attenuation factors (context of instruction and learning). It is important to clearly define and explain the concepts associated with the hypothesis.

Attenuation is the directional tapering interaction of one variable into another. It can also be visualized as a thin line of linkage between two variables. Attenuation is a translation of an aspect of or aspects of one conceptually located variable so that it appears as a feature in another related aspect in a different conceptually located variable. To put it simply, it is the feeble or weak 'influence' of a conceptually located variable on another conceptually located variable. For example, both a student's proximal and distal images of the nature of science can be taken as conceptually located variables. If a student's proximal understanding of the NOS is seen to be weakly related to (or if allowed have some weak influence on) the student's distal image of the NOS, it could be said that there is filtration or attenuation of the proximal understanding into the distal image.

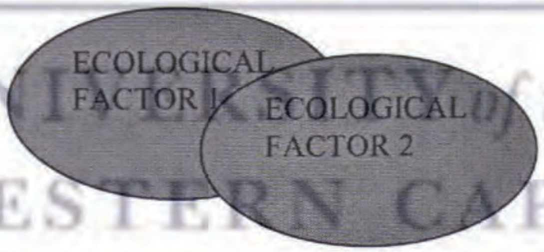
The concept of attenuation was adopted to explain the linkage where interaction or effect between the two apparently related variables appears to be weak. To take the examples of the variables given above, teachers' science epistemological beliefs have some influence on the nature of instructional practice employed by the teacher. That influence or interaction appears to be weak. The SEBs are said to slender or taper into the instructional practice. The tapering is the attenuation.

Where the interaction between two conceptual ecological factors appears to be under the influence of another factor or set of factors, the factor appearing to influence the interaction is called an *attenuation factor* or *attenuating factor*. When a factor appearing to influence translation between the two factors under consideration has its source in the context in which translation is occurring it is called an *in vitro* attenuation factor. To take our example of the translation of SEB into laboratory instructional practices, the context in which instruction occurs (resources, examination focused education system, etc.) appears to have an effect on teachers' translation of SEBs into laboratory practices. The context or aspects of it becomes an *in vitro* factor. *In vitro* factors are similar to (or could be taken to be similar to) what has been described as constraints or intervening variables (Abd-El-Khalick and Lederman, 2000; Harwell, 2000; Lederman, 1992) or external beliefs by Martin (1999) or context beliefs (Ford, 1992). These researchers have for example cited content coverage, motivation, resources, institutional constraints, etc. as impeding the translation of teachers' NOS conceptions into practice. The same constraints have been assumed to intervene in the translation of students' laboratory experiences into NOS conceptions.

The concept of attenuation is different from the concept of constraints described above because with attenuation, so-called constraints are located not in the physical environment (for example size of laboratory) but in the teacher's or student's conceptual ecology. This location occurs through perception. Once placed in the conceptual ecological system the so-called constraint becomes an attenuator. Where the attenuating factor appears to originate from aspects already located in the individual's conceptual ecology for example teacher beliefs about students' learning, the factor is called an *in vivo* attenuating factor.

In vitro and *in vivo* attenuating factors can interact in such a way as to either encourage or discourage the tapering of one variable into another. The interaction between the *in vitro* and *in vivo* factors constitutes attenuation equilibrium. Attenuation equilibrium appears to govern the 'magnitude' of the amount of the interaction of one ecological variable into another. The combined effect of the *in vitro* and *in vivo* factors can be either to oppose or to have a reinforcing effect on the attenuation. When the total effect is to reduce further the tapering or the slender of one variable into the other, the attenuation effect is described as *negative attenuation*. If the effect of the attenuation equilibrium is to promote the slender it is called *positive attenuation*. Figure 8.4 below illustrates positive and negative attenuation.

Positive attenuation strengthens interaction



Negative attenuation weakens interaction

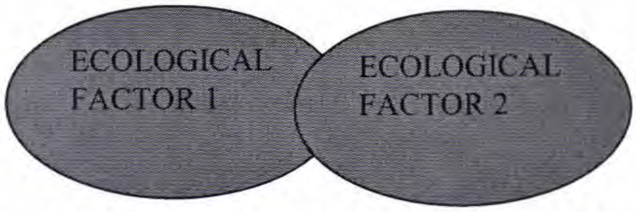


Figure 8.4 An illustration of the effects of positive and negative attenuation on ecological interaction

Negative and positive attenuation could possibly operate on a cybernetic principle of negative and positive feedback. Further research could look into that area.

The conceptual ecological system could be replete with equilibria. There are various other forms of equilibria interacting with the attenuating equilibria as well as the factors whose interaction is under the governance of attenuation equilibria.

The attenuation hypothesis does not claim to be the HYPOTHESIS for explaining the nature of interaction between ecological factors. It is only a small window through which interaction might be viewed from a different perspective. While the hypothesis appears to be a useful tool in examining the interactions between the variables investigated in this study, it will not claim universality. Probably it does not work when interactions between other variables in the conceptual ecosystem are considered. This is an area for further research. Even in its present state it is safer to propose that the hypothesis is still embryonic. More still needs to be done to get it to a foetal stage. It does show however, that there is more to constraints than the sizes of laboratories and the amounts of available laboratory reagents.

8.5 Some recommendations for Chemistry teacher education and laboratory instructional practices

The teachers and the students in this study are speaking with one voice about the examination centeredness of the Chemistry curriculum and pedagogy. These voices need to be heard. Moving instruction from a focus on examination preparation to an inquiry oriented one might be helpful in the implicit translation of students' laboratory experiences into more desirable NOS conceptions. This might help students to make connections between their own laboratory experiences and the real nature of professional science. Many of the students in this study did not see what they were doing in their laboratories as the real practice of science. To these students school science is school science and what the professional scientist did something completely different. Unfortunately some teachers also subscribe to this view. Although school science inquiry and professional science inquiry could be different (Chinn and Malhotra, 2002), both teacher instructional practices and curricula should be constantly reviewed and reformed in a way as to narrow the gap. Teacher education preparation programmes must equip students with techniques and strategies to narrow that gap. One way is for pre-service and in-service teacher education programmes to change beliefs about the purposes of school science laboratory work. As Hodson and Hodson (1998) and Hodson (1996b) have recommended teachers should be made aware of the fact that different types of laboratory activities can be organized to achieve different goals or objectives of laboratory work.

If the goal of scientific literacy for all citizens is to be taken seriously, and if as is believed the practice of inquiry in science teaching promotes students understanding of the NOS, then something needs to be done about creating conditions which will enable teachers to practice inquiry in the laboratory. It is heartening to know that the impediments to inquiry mentioned by the students and the teachers in the present study have also been identified world wide as threats to the practice of inquiry (Abd-El-Khalick Boujaoude, Duschl et al., 2004). The true practice of classroom inquiry can only be realized if the social, economic, political, philosophical and ideological problems threatening to drive inquiry out of the classroom are addressed with the urgency they require. It is sad for Zimbabwe that it is not just the practice of inquiry, which is under threat, but also the very existence of laboratory instruction.

Students in this study have expressed that they have difficulties in practical work in qualitative and volumetric analysis. Part of the reason for this expression could be that teachers appear to be concentrating their energies more on making students do things on their own as a way for examination preparation rather than first training students to do things. If students are simply asked to make observations without the teacher training them how to do so, they might never learn how to do things properly. Teachers could organize qualitative laboratory activities whose sole purpose would be to make students develop observational skills. It is dangerous for teachers to assume that students can learn how to observe on their own. Making observations is more than just seeing (Johnstone and Ali-Shuaili, 2002). According to Gabel (1999) students might find Chemistry difficult if they are made to make observations at the macroscopic level and then be asked to explain the observations at a microscopic level. Students need to be trained not only to make observations but also how to interpret and explain them. Rickey and Stacy (2000) describe a technique in which students are explicitly asked to reflect upon the implications of their Chemistry laboratory observations. Such a technique is said to enhance students' meta-cognitive abilities, conceptual understanding and ability to solve examination problems. There is need to encourage practicing Chemistry teachers to constantly engage in critical evaluation and re-evaluation of their pedagogy. Teachers must not only be consumers of research but also engage in action research in order to improve their own pedagogy. The array of instructional techniques for Chemistry laboratory instruction is very wide and teachers need to be aware of and use as many techniques as possible.

Teachers also need to address the gaps between their perceptions of the purpose of laboratory work and those of their students. Students' perceptions of the purpose of laboratory work are known not only to affect their learning during laboratory activities (Roth, 1994) but could also be related to their images of the NOS. If students are to get maximum benefit from their participation in laboratory work, then teachers might need to make students aware of the purpose of Chemistry laboratory work. Wilkinson and Malcolm (1997) have recommended that teachers should also make students aware of the link between laboratory work and everyday life. Such a linkage might be helpful in developing students' non-traditional conceptions of the NOS. It might also help close the gap between the perceived nature of school and professional Chemistry. Students need not be led to think that the major purpose of their laboratory work is to prepare them for examinations. The students irrespective of what the practical work syllabus says must know the range of the purposes of school Chemistry laboratory work.

8.6 Some recommendations for further studies

This study has not been able to fully explore the relationship between teachers and students' NOS conceptions. A number of people have recommended that such a relationship be investigated (Abd-El-Khalick and Lederman, 2000; Harwell, 2000; Schraw and Olafson, 2002). It will be interesting to examine that relationship within the context of the laboratory. When the author of this thesis set out on this study, the examination of that relationship was on the agenda. It was however abandoned when it became clear that a thesis like this one is not about solving all problems of the world. As a research neophyte one learns a lot from experience. A single research can only take a small chunk from the carcass of a whale.

In this study the conception of epistemological beliefs or conceptions was narrowed to exclude beliefs about teaching and learning. It would be interesting to explore the filtration of teachers' beliefs about teaching and learning into laboratory instructional practices with the concept of attenuation equilibrium in mind. Another dimension is to look at the interaction between science epistemological beliefs and beliefs about teaching. What could be the nature of equilibrium in this interaction? Do we get any evidence of *in vivo* or *in vitro* attenuation?

Because of the small teacher sample size it was not possible to get meaningful statistical information about the relationships between demographic variables and teachers SEBs and laboratory instructional practices. Research continues to look into this relationship and it would be interesting to find out if any relationships exist within the context of the Zimbabwean educational system. Zimbabwean A-level teachers come from three main sources. Degree holding teachers are from the Zimbabwe-Cuba Programme, the University of Zimbabwe and the Bindura University of Science Education. It might be interesting to find out whether the instructional practices of these teachers are different from each other. The current study appears to point towards no difference. This issue however requires a closer examination with teachers observed across subjects and forms (for example, form 1 to form 3). The teaching styles of the teachers from the three programmes have not been evaluated.

As an effort was made to demonstrate the extraction of students' LABINOS from interview data a number of issues were raised. First, it became clear that it is difficult to locate with precision the source of a student's LABINOS. The methodological approach used in this study was to try and make inferences about the source of a student's image of the NOS from what the student was saying in responding to probes. An attempt was made to show that the probes used could also have shortcomings in terms of their validity. All the same some reasonable inferences or hypothesis could be made about the Chemistry laboratory being a source of identified students' LABINOS. The use of interviews appears to be a viable way of understanding students' LABINOS. This author believes that the methodological approach used in this study could with further development, form the basis for the extraction of students' LABINOS.

8.7 Conclusions

This descriptive, exploratory and correlational study set out to investigate the nature of teachers' science epistemological beliefs, laboratory instructional practices and students' images of science. As the findings of the study show much of what has come out about teachers' science epistemological beliefs and students' images of science confirms what has been said all along; that the majority of secondary school students hold traditional views of the NOS. Teachers' beliefs were also shown to be fairly non-traditional but not clearly sophisticated. This is also what most of the research on the NOS has been saying.

The investigation of the nature of laboratory inquiry showed that generally the level of inquiry in the studied Chemistry classes is low. The examination focus of the curriculum was blamed by teachers as the major reason for their failure to practice inquiry. Students also blame examinations for the low inquiry and individualistic nature of their laboratory experiences. As each paper was discussed, implications and recommendations on these issues were highlighted. This result is not surprising since the nature of inquiry in many secondary school laboratories throughout the world has been known to be low. The implications of the results for the practice Chemistry education for both secondary school and teacher education have been raised.

When the interactions between variables were considered, the qualitative data interpretation revealed some insights into the nature of interaction between teachers' SEBs and their laboratory instructional practices, students' laboratory experiences and their images of science and students' proximal and distal NOS conceptions. It emerged that these interactions appear to be enmeshed in a matrix of competing equilibria. What is apparent is that the translation of an aspect of one variable into an aspect of another variable or form is governed by the context in which the instruction is taking place as well as a set of factors already embedded in the individual's conceptual ecology. The state of balance between the contextual factors and the *in vivo* factors (located in organism) appears to govern what it is that can attenuate from one variable to the other. The hypothesis proposed here, appears to reasonably explain the nature of the explored interactions. However, this does not mean that there is no anti-thesis.

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APPENDIX

APPENDIX A

Students Images of the Nature of Science
SINOS

This questionnaire is about finding out what you think about science and scientists from what you do during Chemistry laboratory work. There is no right or wrong answer. Just respond according to how you feel or see it. Indicate your response by ticking in the appropriate box or space. Before you respond to each question in Part B, please think about and reflect on your experiences in Chemistry laboratory work.

Part A: Demographics

1. Gender Male ☐ Female ☐

2. What other subject are you doing at A level other than Chemistry?

Physics ☐ Biology ☐ Mathematics ☐ Geography ☐

Computer Science ☐ Other (Specify)________________

3. Type of School

Boarding ☐ Day ☐

PART B. Beliefs

This part is about your opinion on some aspects of scientific knowledge, scientific inquiry and the nature of scientists. For each statement indicate what you believe by ticking in the appropriate box or space. You are required to indicate your response by choosing from: Strongly Agree (SA), Agree (A), Not Decided (ND), Disagree (DA), and Strongly Disagree (SDA).

Item No	Statement	SA	A	ND	DA	SDA
1	In Chemistry knowledge is obtained from observations					
2	Discovery in Chemistry often involves playfulness and creativity					
3	When investigating chemists look at things that are not commonly accepted					
4	Intuition plays a role in Chemistry investigations					
5	When making observations Chemists do not use their beliefs and values					
6	Ideas in Chemistry come from science and non-science sources					
7	Chemistry knowledge is absolutely true because it is based on observations					
8	What we do in the Chemistry laboratory can be described as an art					
9	True Chemistry ideas can come from dreams and guessing					
10	Chemistry knowledge can be proven in the laboratory					
11	Our African culture has no influence on the Chemistry knowledge we get in the laboratory					
12	If you want to practice Chemistry you must master the Chemistry knowledge					
13	Chemistry is based on experiments which any other competent scientist should be able to repeat at will					
14	Chemists are neutral human beings when they perform experiments					
15	Chemistry knowledge does not change as it is based on observations					
16	When making inferences from observations we rely on theory					
17	Observations in Chemistry depend on what we want to find out					
18	The aim of experiments in Chemistry is to control nature					
19	When working in the laboratory scientists always follow the scientific method					
20	What we do in the laboratory shows that if you follow the scientific method you will always get the truth					
21	Chemistry knowledge does not depend on how one looks at things					
22	Currently accepted Chemistry knowledge will one day be changed in future					
23	What you observe in Chemistry practical depends on s on the material being observed and not on what you like					
24	The observation a chemist makes depend on his values and beliefs					
25	Different cultural groups have different ways of obtaining scientific knowledge					
26	It is necessary for Chemists to be aware of the rules they follow and the apparatus they use when looking for knowledge					
27	If you follow the scientific method you will always get correct results					
28	The results we get from Chemistry experiments might depend on theory					
29	Our Chemistry practical work shows that more than one theory can explain the results we get from experiments					
30	Our Chemistry practical work shows that there is no difference between theory and observation					
31	Chemists can enjoy themselves during practical work					

Appendix B

Teachers Science Epistemological Beliefs Questionnaire

(TSEBQ)

This questionnaire seeks to find out what your views of science are. There is no right or wrong answer. Just indicate what you believe in. The information is required for research purposes only and will be kept in strict confidence. Please feel free to ask any questions when you need assistance or don't understand something. Indicate your response by ticking in the appropriate box or space.

Part A: Demographics

1. Gender Male ☐ Female ☐

2. Academic and Professional Qualifications

B.Ed (Chem) U.Z. ☐ B.Sc. (Chem) U.Z. ☐ B.Sc.Ed (BUSE) ☐

Lit.Cert. (CUBA) ☐ M.Ed. ☐ M.Sc. ☐

Other (Please specify) ____________________

3. Type of School

Boarding ☐ Day ☐

4. Teaching experience

0 to 2 yrs ☐ 3 to 5 yrs ☐ over 5yrs ☐

5. Have you ever been exposed to the History and Philosophy of Science during, before or after your University training?

YES ☐ NO ☐

PART B. Beliefs

This part is about your opinion on some aspects of scientific knowledge, scientific inquiry and the nature of scientists. For each statement indicate what you believe by ticking in the appropriate box or space. You are required to indicate your response by choosing from: Strongly Agree (SA), Agree (A), Not Decided (ND), Disagree (DA), and Strongly Disagree (SDA).

Item No	**Statement**	**SA**	**A**	**ND**	**DA**	**SDA**
1	Scientific knowledge starts from observation of nature					
2	The process of scientific discovery often involves a high degree of playfulness and creativity					
3	The process of scientific investigation often involves an ability to look at things that are not commonly accepted					
4	Intuition plays a role in scientific inquiry					
5	When making observations scientists eliminate their beliefs and values					
6	Scientific ideas come from science and non-science sources					
7	Scientific knowledge is true and objective description of the natural world because it is based on observations					
8	The actual work of a scientist can be described as an art					
9	Legitimate scientific ideas sometimes come from dreams and guesses					
10	Scientific knowledge can be proven					
11	Culture and social attitudes have no influence on scientific knowledge					
12	The best way to prepare to become a scientist is to master the scientific body of knowledge					
13	Science is based on experiments which any other competent scientist should be able to repeat at will					
14	There is a significant amount of scientific knowledge in African traditional folklore and myths					
15	Scientists are scientifically neutral human beings					
16	Scientific knowledge is tentative					
17	The process of scientific inquiry often involves purposeful discard of accepted theory					
18	The aim of scientific knowledge is to control nature					
19	Most scientists rely on theories to guide them in interpretation of experiences					
20	Scientific knowledge is influenced by myths					
21	Scientific observations depend on what scientists want to find out					
22	When working in the laboratory, scientists do not always follow the scientific method					
23	Scientific knowledge is free from human perspectives					
24	Currently accepted scientific knowledge maybe be modified in the future					
25	Because the validity of the scientific method, knowledge obtained by its application is determined more by nature itself than by the choices the scientists make					
26	Scientific observations are affected by a scientist's values and beliefs					
27	Different cultural groups have different processes of gaining valid scientific knowledge					
28	The evaluation of scientific knowledge varies with changes in situations					
29	It is necessary for scientists to be keenly aware of the rules which they follow and the tools they use in their pursuit of knowledge					
30	Most real scientists are extremely intelligent people					

Appendix C

Student Laboratory Programs Variables Inventory

sLPVI

This is not a test. We want to find out what you do during you're a level Chemistry practical work. There is no right or wrong answer. Just complete the questionnaire according to your own judgement. You are required to indicate your responses by ticking in the appropriate space or box.

Part A: Demographics

1. Gender Male ☐ Female ☐

2. What other subject are you doing at A level other than Chemistry?

Physics ☐ Biology ☐ Mathematics ☐ Geography ☐

Computer Science ☐ Other (Specify)________________

3. Type of School

Boarding ☐ Day ☐

PART B: Laboratory Practices

This part is about how often the statement given occurs during your laboratory work. Your responses should be based on what happens during practical work sessions only. By indicating in the appropriate box, indicate how often what is described by each statement happens. For each statement indicate by choosing from: 1- Almost never, 2-Seldom, 3-Sometimes, 4- Often, and 5- Almost always. Read each statement carefully.

Item No	Statement	1	2	3	4	5
1	Students follow step by step instructions in the laboratory guide or handout					
2	The experiment reports we write require interpretation of data					
3	Our teacher is always concerned with the correctness of results					
4	Laboratory experiments are used by the teacher to help us understand Chemistry ideas					
5	Our teacher lectures to the whole class.					
6	The teacher asks us to design our own experiments					
7	Our teacher allows us to go beyond regular laboratory exercises and do experiments on our own					
8	Our laboratory practical sessions raise new problems or a result that cannot be easily explained					
9	During practical work my students record information requested by the teacher or the laboratory assistant					
10	Our teacher identifies the problem to be investigated					
11	Our laboratory work requires us to solve problems					
12	Laboratory reports require us to answer specific questions					
13	Our teacher requires us to explain why certain things happen					
14	We use the laboratory is used to investigate a problem that comes up in class					
15	The experiments we do develop skills in techniques and procedures of Chemistry					
16	Laboratory experiments reports require us to use evidence to backup their conclusions.					
17	During practical work students discuss their results					
18	Our teacher asks us questions to state alternative explanations for observed phenomena					
19	During practical work students record information they feel is important					
20	Students propose their own explanations to observed phenomenon					
21	Students identify problems to investigate					
22	During the Practical work students check the correctness of their work with the teacher					
23	In discussion with the teacher we challenge assumptions and want conclusions justified					
24	Students usually know the general outcome of an experiment before doing the experiment					
25	Our teacher gives information to individual students in small groups					

Appendix D

Teachers Laboratory Programs Variables Inventory
tLPVI

This questionnaire is about finding out how you conduct or teach your Chemistry laboratory class. This information is required for research purposes only and will be kept in strict confidence. You are free to ask any questions if you don't understand something or need clarification. Indicate your response by ticking in the appropriate box or space.

Part A: Demographics

1. Gender Male ☐ Female ☐

2. Academic and Professional Qualifications

B.Ed (Chem) U.Z. ☐ B.Sc. (Chem) U.Z. ☐ B.Sc.Ed (BUSE) ☐

Lit.Cert. (CUBA) ☐ M.Ed. ☐ M.Sc. ☐

Other (Please specify) ____________________________

3. Type of School

Boarding ☐ Day ☐

4. Teaching experience

0 to 2 yrs ☐ 3 to 5 yrs ☐ over 5yrs ☐

5. Have you ever been exposed to the History and Philosophy of Science during, before or after your University training?

YES ☐ NO ☐

PART B: Laboratory Practices

This part refers to what you do with your students during laboratory classes or practical work. By indicating in the appropriate box, indicate how often you do each of the given things. For each statement indicate by choosing from: 1- Almost never, 2-Seldom, 3-Sometimes, 4- Often, and 5- Almost always.

Item No	Statement	1	2	3	4	5
1	My students follow step by step instructions in the laboratory guide or handout					
2	My students interpret data in the laboratory reports					
3	I am concerned with the correctness of data					
4	I allow my students to go beyond regular laboratory exercises and do experiments on their own					
5	I use laboratory activities to develop concepts					
6	I lecture to the whole class					
7	I ask my students to design their own experiments					
8	During practical work my students record information requested by me or the laboratory assistant					
9	Laboratory sessions raise new problems or result in data that cannot be explained immediately					
10	I identify the problem to be investigated					
11	Laboratory activities require students to solve problems					
12	Laboratory reports require specific questions to be answered					
13	The teacher or the laboratory assistant requires the student to explain why certain things happen					
14	The laboratory is used to investigate a problem that comes in class					
15	Laboratory experiments develop skills in techniques and procedures of Chemistry					
16	I require students to write reports in which they use evidence to backup their conclusions.					
17	Students discuss their data and conclusions with each other during the lab					
18	I ask students to state alternative explanations for observed phenomena					
19	During the laboratory my students record information they feel is important					
20	Students propose their own explanations to observed phenomenon					
21	Students identify problems to investigate					
22	During the laboratory students check the correctness of their work with the teacher					
23	In discussion with the teacher my students challenge assumptions and want conclusions justified					
24	Students usually know the general outcome of an experiment before doing the experiment					
25	I give information to individual students in small groups					

Appendix E

Student Open-ended Questionnaire

The questions in this questionnaire are asking you to say what you think about science based on what you do during practical work in Chemistry. There are no right or wrong answers. Just write what you think.

Answer all questions on the answer sheets provided. For each question write as much as you want.

1. Do you think the Chemistry laboratory is a place where scientific knowledge can be generated? Explain your answer.

2. Is the knowledge obtained from the Chemistry laboratory always true? Give reasons for your answer.

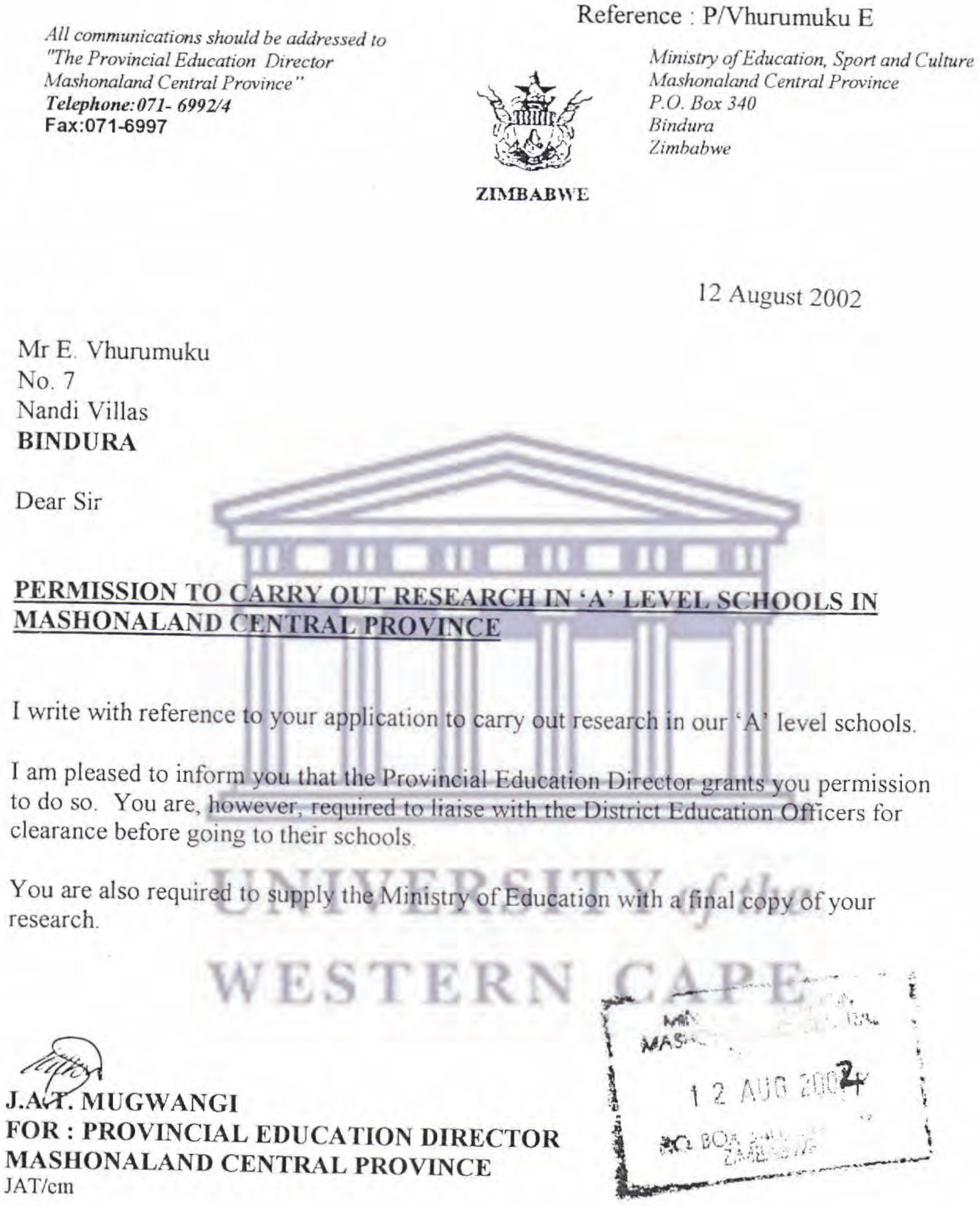
3. What can you say about the observations you make during Chemistry laboratory work?

4. How do scientists arrive at conclusions in building scientific knowledge?

5. Comment on the data you collect during practical work.

Appendix F

Letter of approval: Mashonaland Central Region



Reference : P/Vhurumuku E

All communications should be addressed to
"The Provincial Education Director
Mashonaland Central Province"
Telephone:071- 6992/4
Fax:071-6997

ZIMBABWE

Ministry of Education, Sport and Culture
Mashonaland Central Province
P.O. Box 340
Bindura
Zimbabwe

12 August 2002

Mr E. Vhurumuku
No. 7
Nandi Villas
BINDURA

Dear Sir

PERMISSION TO CARRY OUT RESEARCH IN 'A' LEVEL SCHOOLS IN MASHONALAND CENTRAL PROVINCE

I write with reference to your application to carry out research in our 'A' level schools.

I am pleased to inform you that the Provincial Education Director grants you permission to do so. You are, however, required to liaise with the District Education Officers for clearance before going to their schools.

You are also required to supply the Ministry of Education with a final copy of your research.

J.A.T. MUGWANGI
FOR : PROVINCIAL EDUCATION DIRECTOR
MASHONALAND CENTRAL PROVINCE
JAT/cm

MIN[illegible]
MASH[illegible]
12 AUG 2002
P.O. BOX [illegible]
ZIMBABWE