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GRADE 11 LEARNERS' AND TEACHERS' CONCEPTIONS OF SCIENTIFIC INQUIRY IN RELATION TO INSTRUCTIONAL PRACTICES

Washington Takawira Dudu

A thesis submitted to the Wits School of Education, Faculty of Humanities, University of the Witwatersrand, in fulfillment of the requirements of the degree of Doctor of Philosophy.

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Abstract

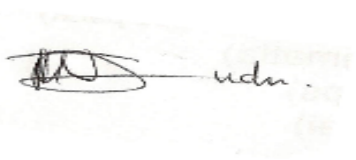
This exploratory, descriptive and interpretive study investigated the interactions among learners' conceptions of the nature of scientific inquiry (NOSI), teachers' conceptions of NOSI and teacher instructional practices when teaching investigations in Physical Science. The participants were South Africa, Grade 11 learners (n= 167) and teachers (n=5), from five schools in the Johannesburg region of South Africa. The schools were conveniently and purposefully sampled. Learners' and teachers' conceptions on six NOSI tenets were investigated. These tenets are: difference between laws and theories; difference between observation and interpretation; there is no one method in science; accurate record keeping, peer review and replicability in science; socially and culturally embeddedness nature of scientific knowledge; and the role of human creativity and imagination in the development of scientific knowledge. Data on learners' and teachers' conceptions of the NOSI was obtained through; questionnaires, probes and interviews. Teacher instructional practices were determined using laboratory class observations, questionnaires, teacher and learner interviews, and analysis of instructional materials. The data was quantitatively analyzed using mainly, descriptive statistics, correlations, Regression Analysis and Multivariate Analysis of Variance (MANOVA). Qualitative data was analyzed using a combination of analytic induction and interpretive analysis. The results show that learners' NOSI conceptions were inconsistent, fragmented and fluid, with the majority of the learners displaying naïve conceptions. Teachers were found to hold mixed NOSI conceptions ranging from static, empiricist-aligned to dynamic, constructivist-oriented. Teacher instructional practices were found to be a repertoire of contrasting methodological approaches lying along a continuum ranging from *close-ended* inquiry to *open-ended* inquiry. The study found the interactions between and among the investigated variables to be weak and not direct and simple, but complex and under the governance of a variety of factors in the instructional milieu. Curriculum and assessment demands were found to be major factors possibly responsible for weakening the interactions. For the investigated variables, it is posited that the interaction between variables is under the governance of both the context in which the instruction takes place and some factors already embedded in the teacher's or learner's conceptual ecology. Recommendations and implications for the practice of science education and future research are raised and discussed.

Key Words

scientific inquiry, instructional practice, nature of scientific inquiry, conceptions of NOSI, investigations, teachers, learners, Physical Science, interactions

Declaration

I declare that this thesis is my own unaided work. It is being submitted for the degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.



_____

Washington Takawira Dudu

29th.....day of January.....2013

Dedication

I dedicate this dissertation to the most important people in my life.

To my wife and best friend, Annah Dudu: for your encouragement, love, support and understanding.

To my daughters Takudzwa and Isabel: for your love and support.

To my dad and mom, Christopher and Miriam Makumbo: for encouraging me to be the best I could be.

To my sisters, Violet and Ruth: for being not only my sisters, but sources of inspiration.

Publications and Presentations Emanating from this Research

Publications

Dudu W.T. & Vhurumuku, E. (2012). Exploring South African Grade 11 learners' perceptions of classroom inquiry: validation of a research instrument. *Science Education International,* Volume 23, Issue 2, pp.150-165. International Council of Associations for Science Education (ICASE) (June 2012). ISSN: 2077-2327. Retrieved on July 11, 2012 and Available online from http://www.icaseonline.net/seiweb/index.php?option=com_content&view=article&id=55&Itemid=63

Dudu W.T. & Vhurumuku, E. (2012). Teacher Practices of Inquiry when teaching Investigations: A Case Study. *Journal of Science Teacher Education,* Volume (23) 6, 579-600. (DOI) 10.1007/s10972-012-9287-y. ISSN: 1046-560X. Retrieved on April 3, 2012 and Available online from http://www.springerlink.com/openurl.asp?genre=article&id=doi:10.1007/s10972-012-9287-y

Dudu W.T. & Vhurumuku, E. (2011). Exploring learners' understandings of the nature of scientific inquiry: validation of a research instrument. *The International Journal of Learning,* Volume 18, Issue 2, pp.67-84. Common Ground Publishers, ISSN: 1447-9494.Available from http://thelearner.com/2011/10/27/learning-journal-volume-18-issue-2-available/

Presentations

Dudu W.T. & Vhurumuku, E. (2012). *Teacher Practices of Inquiry when teaching Investigations: A Case Study.* Proceedings of the Twentieth Annual Meeting of the Southern African Association of Research in Mathematics and Science Technology Education (SAARMSTE) Conference hosted by University of Malawi, Zomba, Malawi on 16th – 19th January 2012 *(Long Paper).* ISBN #: 978-0-9869800-3-9

Dudu W.T. & Vhurumuku, E. (2012). *Exploring learner perception of classroom inquiry: validation of a research instrument.* Proceedings of the Twentieth Annual Meeting of the Southern African Association of Research in Mathematics and Science Technology Education (SAARMSTE) Conference hosted by University of Malawi, Zomba, Malawi on 16th – 19th January 2012 *(Long Paper).*ISBN #: 978-0-9869800-3-9

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Dudu W.T. & Vhurumuku, E. (2011). *Exploring teachers' and learners' understandings of nature of scientific inquiry (NOSI): the validation of a research instrument.* Proceedings of the Nineteenth Annual meeting of the Southern African Association of Research in Mathematics and Science Technology Education Conference hosted by North West University, Mafikeng Campus, RSA on 18th - 21st January 2011 (*Short Paper*).

Dudu W.T. & Vhurumuku, E. (2010). *South African teachers' and learners' understandings of scientific inquiry in relation to instructional practices.* Proceedings of the Eighteenth Annual meeting of the Southern African Association of Research in Mathematics and Science Technology Education Conference hosted by KwaZulu Natal University, Durban, RSA on 18th - 21st January 2010 *(Short paper).*

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List of Acronyms

AR	Argumentative Resource framework
CASS	Continuous Assessment
CLES	Constructivist Learning Environment Survey
COLLES	Constructivist Online Environment Survey
COS	Classroom Observation Schedule
EFG	Evaluation Facilitation Group
LO 1	Learning Outcome 1
LPCI	Learner Perception of Classroom Inquiry
LUSSI	Learners' Understanding of Science and Scientific Inquiry
MANOVA	Multivariate Analysis of Variance
MD	Multidimension framework
NOS	Nature of Science
NOSI	Nature of Scientific Inquiry
PSI-S	Principles of Scientific Inquiry-Student
PSI-T	Principles of Scientific Inquiry-Teacher
RTOP	Reformed Teaching Observation Protocol
SEVs	Students' Epistemological Views of science
TPCI	Teacher Perception of Classroom Inquiry
UD	Unidimension framework

CHAPTER ONE

Introduction to the study

1 Introduction

This study investigated South African Grade 11 learners' and teachers' conceptions of the nature of scientific inquiry (NOSI) and how these conceptions related to teacher instructional practices. Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work (Anderson, 2002; Grandy & Duschl, 2007). Specifically, the study sought to explore the relationships between: learners' NOSI conceptions and teacher instructional practices when teaching investigations; learners' NOSI conceptions and their teachers' NOSI conceptions; teacher NOSI conceptions and their teaching practices when teaching investigations; and the interactions among teacher practices, learner NOSI conceptions and teacher NOSI conceptions. Conceptions of the nature of scientific inquiry are an individual's ideas, beliefs, assumptions and understanding about the scientific process, what scientists do and how scientific knowledge is developed and validated (Schwartz, Bell, & Lederman, 2003; Vhurumuku & Mokeleche, 2009). Teacher instructional practices refers to both what the teacher does and what the learners do during the teaching and learning of investigations (Vhurumuku, Holtman, Mikalsen, & Kolsto, 2006). It is about the extent to which teachers practice scientific inquiry during their teaching of practical investigations. The study was done within the context of a South Africa, Grade 11 Physical Science classroom.

Essentially, this exploratory, descriptive and interpretive study adds some light to present knowledge about the interactions among the investigated variables, which are: learners' NOSI conceptions, teachers' NOSI conceptions and teacher instructional practices when teaching investigations. While some studies investigating the interactions among these variables have been done (e.g., Bartels, Lederman, & Lederman, 2012; Laws, Rosborough, & Poodry, 2006; Patel, Trumbull, Fox, & Crawford, 2009; Sampson & Grooms, 2008;

Sandoval & Reiser, 2004; Shin & McGee, 2002; Songer, Lee, & McDonald, 2003; Stump, Hilpert, Husman, Chung, & Kim, 2011), the results of these studies have been contradicting and far from being conclusive. The results of some studies point towards some interactions among all three variables (e.g., Bartels, et al., 2012; Sampson & Grooms, 2008; Sandoval & Reiser, 2004; Songer, et al., 2003; Stump, et al., 2011), while other studies show that the three variables are not related (e.g., Laws, et al., 2006; Patel, et al., 2009; Shin & McGee, 2002). Interestingly, these studies have conflated the nature of science (NOS) and NOSI. Conflation here refers to the two constructs being taken to mean the same thing.

For this thesis, the term "nature of science" refers to an individual's views, ideas, beliefs, assumptions and values about scientific knowledge *only* (Lederman & Lederman, 2005; Schwartz & Lederman, 2008; Schwartz, Lederman, & Abd-El-Khalick, 2012). The NOS refers to descriptions of the products of science. By the products of science, it is meant the facts, theories, principles, models, etc. making the body of knowledge called science. To Schwartz (2007), nature of scientific inquiry (NOSI) refers to the processes and elements therein of scientific investigations and methods of justifying knowledge. Conceptions of the nature of scientific inquiry are not the abilities or skills to perform (to do) investigations, but rather the beliefs, views, perceptions and assumptions attached to the activities by the individual. In view of the fact that NOS aspects are those that pertain to the *product* of inquiry, the scientific knowledge and NOSI aspects are those that pertain most to the *processes* of inquiry, the "how" the knowledge is generated and accepted. Processes of inquiry refer to activities such as asking or framing research questions, designing investigations, experimenting, observing, concluding and inferring. This study focuses on NOSI and not NOS. This study is the first to specifically look at this interaction from a NOSI lens using a semi-naturalistic mixed-methods triangulation embedded approach and a mixed method sequential explanatory design.

It is noteworthy that most of the studies referred to in the preceding paragraph, have placed emphasis on evaluating the correctness of learners' and teachers' NOS or NOSI

conceptions or classifying conceptions according to predetermined philosophical positions (Bell, Blair, Crawford, & Lederman, 2003; Khishfe, 2008). These studies have ended up evaluating and classifying learners' and teachers' NOS or NOSI conceptions into such categories as realist, positivist, inductivist, instrumentalist, empiricists, naïve or informed and adequate or inadequate. But as Keiser (2010) warns, evaluating the "correctness" of learners' and teachers' conceptions in this way is problematic, because the philosophical positions and tastes of the researchers are likely to impair their interpretations. Going beyond this tradition of evaluating learner and teacher conceptions into predetermined philosophical positions along a continuum of "naive" to "informed," or dichotomously dividing the conceptions into categories, the study being reported here further uses and adapts a newly developed framework (Deng, Chen, Tsai, & Chai, 2011) to robustly describe learners and teachers NOSI conceptions. This framework called the *multidimensional framework* (Deng, et al., 2011) views of NOSI conceptions as being made up of multiple dimensions that are more or less independent. The framework posits that NOSI conceptions cannot be understood by simply categorizing as they do not necessarily develop in a hierarchical and synchronous way.

Using this framework as the pivot of interpretation of learners' and teachers' NOSI conceptions, the study being reported here advances the thesis that the translations of teachers NOSI conceptions into classroom practices or for that matter into learners' NOSI conceptions are not simple direct processes, but a complex entities influenced by a variety of factors in the instructional milieu. Within this effort, the study employs a mixed methods approach to explore, describe and interpret the different ways in which high school learners and teachers think about the nature of scientific inquiry in relation to instructional experiences and practices.

Some of the results presented in this thesis have been published in international journals[1,2,3] and presented at several international science education conferences. The results of the study are presented in the order of the four research questions (see below) which guided the study. These results are presented in Chapters 5, 6, 7 and 8. While each of the results chapters can stand on its own in addressing the posed question, it contributes to the bigger picture by providing the relevant pieces of evidence that help to illuminate and elucidate the interactions among the explored variables. Before the study recommendations and conclusions are discussed, the pieces of illuminative evidence are coalesced in Chapter 8. The point of focus is the nature of interactions among the explored variables.

1.1 Background and rationale

During the last three decades, the science education community has established a research agenda calling for more studies focused on learners' and teachers' understandings of the NOSI (Crawford, 2000; Keys & Bryan, 2001; Schwartz, Lederman, & Lederman, 2008; Windschitl, 2002). Recent research (e.g., Bartels, et al., 2012; Hacıeminoğlu, Yılmaz-Tüzün, & Ertepınar, 2012; Macarolu, Taþar, & Cataloglu, 1998; McNeill, Lizotte, & Krajcik, 2005; Reiser, et al., 2001; Sampson & Grooms, 2008) and curriculum reform documents (American Association for the Advancement of Science, 1993; National Research Council, 1996) advocate critical roles for teachers in structuring and guiding learners' understanding of NOSI. As earlier noted, research efforts in this regard have often conflated or combined nature of science (NOS) and NOSI conceptions under "students'

[1] Dudu W.T. & Vhurumuku, E. (2011**).** Exploring learners' understandings of the nature of scientific inquiry: validation of a research instrument. *The International Journal of Learning*, Volume 18, Issue 2, pp.67-84. URL link: http://ijl.cgpublisher.com/product/pub.30/prod.3136. Common Ground Publishers, ISSN: 1447-9494.

[2] Dudu W.T. & Vhurumuku, E. (2012). Exploring South African learners' perceptions of classroom inquiry: validation of a research instrument. *Science Education International,* Volume 23, Issue 2, pp.150-165. URL link: http://www.icaseonline.net/seiweb/index.php?option=com_content&view=article&id=55&Itemid=63. International Council of Associations for Science Education (ICASE), ISSN: 12077-2327.

[3]Dudu W.T. & Vhurumuku, E. (2012). Teacher Practices of Inquiry when teaching Investigations: A Case Study. *Journal of Science Teacher Education*. Volume (23) 6, 579-600. (DOI) 10.1007/s10972-012-9287-y. ISSN: 1046-560X. Retrieved on April 3, 2012 and Available online from http://www.springerlink.com/openurl.asp?genre=article&id=doi:10.1007/s10972-012-9287-y

understandings of science" (Schwartz, et al., 2008, p. 3). To avoid confusion, it is important to ensure that a clear distinction between NOSI and NOSI is made. This is especially important because the literature is replete with instances where a description of the two constructs, NOS and NOSI are indistinct, overlapping and consequently confusing (see for example, Bell, Maeng, Peters, & Sterling, 2010; Lederman & Lederman, 2005; Schwartz, et al., 2012; Schwartz, et al., 2008).

This study focuses on interactions among teacher NOSI conceptions, classroom practice and learners' conceptions of the NOSI. As mentioned earlier, on the subject of studies on relationships between learners' NOSI conceptions and instructional practices, researchers investigating relationships between or among these variables have produced contradicting findings. However, these studies have largely been done outside Africa, and this study argues that not much research has been done to explore and validate such an interaction or relationship in Africa, specifically in South Africa hence research is worth pursuing. Still on the same subject, McNeill, et al. (2005) assert that research should instead focus on ways that provide guidance on types of teacher practices that may help learners' understandings of scientific inquiry. The stance taken here is that such propositions have not paid much attention to the potential influence of teachers' own understandings of inquiry and their instructional practices on learners' conceptions of NOSI (Anderson, 2002; Keys & Bryan, 2000). Teaching behaviour and actions might as well depend on teachers' conceptions and beliefs about scientific inquiry (Keys & Bryan, 2001). These in turn might permeate learners' conceptions of the NOSI. Moreover, there is not enough evidence to suggest that learners' NOSI conceptions cannot influence other areas of pedagogical endeavour such as teacher decision-making and instructional practice. Not much research has been done to explore and validate such an association or to demonstrate the association. There is also little on studies of interactions among teacher NOSI conceptions, classroom practice and learners' conceptions of the NOSI. Hence, the study being reported here fills an important niche.

Research has produced contradicting findings regarding the relationship between teachers' understandings of the NOSI and their instructional practice when teaching investigations. This delves into the validity of the assumption that engaging learners in *scientific investigations* can eventuate in the learners picking up and building their understandings of nature of scientific inquiry and the processes of its development and validation. Scientific investigations are activities in which learners take the initiative in finding answers to problems (Jones, Simon, Black, Fairbrother, & Watson, 1992). In most cases, the problems for scientific investigations require some kind of exploration in order to generate information which will give answers. Historically, the school laboratory has been assumed to be of critical instructional importance in teaching and learning (Hodson, 1996; Nott & Wellington, 1996). The school laboratory has mostly been used for the hands-on scientific experimentation. There is the underlying conviction that lab activities are a central part of knowledge construction in science and provide opportunities for identifying teachers' NOSI conceptions and understanding reasons for teaching actions. The centrality of investigations in school science teaching, and the importance of investigations in nurturing learners' ideas about the NOSI, is critical in understanding teachers' practices and perspectives when teaching investigations. While history and assumption have perfected an ideal linkage between teachers' practices of inquiry during laboratory work and their conceptions of NOSI; not much research has been done to explore and validate such a relationship or interaction. Of interest is the fact that very little attention has been paid to the role of teachers' practices of inquiry in the high school science laboratory (McNeill, et al., 2005) in relation to their NOSI understandings; and in particular during investigations.

Sandoval (2005) and Schwartz, et al. (2003) are some of the few researchers who have investigated possible relationships between teachers' conceptions about nature of scientific inquiry and their instructional practices. Their studies however have not been conclusive. A study by Schwartz, Lederman, and Crawford (2004) investigated relationships among teachers' views of scientific inquiry, authentic scientific inquiry experiences, learning outcomes and guided reflections in a science research internship course. The study came to the conclusion that teacher practices of authentic inquiry (less inquiry or more inquiry) did

not influence teachers' views of scientific inquiry as measured by self reports. This study however did not assess learning outcomes related to scientific inquiry and teaching of nature of scientific inquiry. Moreover, the study conflated views of nature of science and NOSI. For this thesis, the focus is on teachers' conceptions of NOSI in relation to their instructional practices. As already mentioned, it makes a distinction between NOS and NOSI. Adding credibility to the study by Schwartz et al. was the finding by Tiberghien, Veillard, Le Marechal and Buty (2002) that for a sample of French Physics teachers, there was a weak association between some features of the teachers' laboratory practice and some aspects of their NOSI. Tiberghien et al. found that what the teacher actually plans for the learners to do during practical work based on what the teacher perceives to understand are not exactly the same. As Gess-Newsome and Lederman (1995a) suggested, the assumption that teachers' views of certain philosophical aspects and pedagogy (teaching practice) are related is certainly possible.

Studies on the relationship between teachers' and learners' conceptions of NOSI have also produced contradicting findings. Some studies having investigated teachers' NOSI understandings (Garnett, Garnett, & Hackling, 1995; Lederman & Abd-El Khalick, 2002) and the apparent misconceptions possessed by both high school learners (Bady, 1979; Lederman, 1992; Rubba, Horner, & Smith, 1981) and science teachers (Burgoon, Heddle, & Duran, 2011). However, these studies have not looked at teachers' NOSI conceptions within the specific context of the scientific investigations. Furthermore, many of these studies have erroneously lumped together teachers' and learners' conceptions of NOS with their conceptions of NOSI into one category of "understandings of science". Some studies (e.g. Abd-El Khalick & BouJaoude, 1997; Lederman, 1992; Lederman, 2007a) have even explored the purported linkage between teachers' and learners' conceptions using the conflated category of "understanding of science."

Focusing only on NOSI, this study attempts to build off the work by Keys and Bryan (2001) using an explanatory mixed method research approach who assert that teaching behaviour and actions might as well depend on teachers' understandings, knowledge and beliefs of

scientific inquiry, which in turn might permeate learners' understandings of inquiry. Studies done around the world (Abd-El-Khalick & Lederman, 2000b; Lederman, 1992; Lederman, 2008b) have consistently shown that the majority of secondary school teachers have inadequate understandings of the NOSI. Interestingly, research has shown that teachers do not teach what they do not know (Abd-El-Khalick & Lederman, 2000a; Lederman & Zeidler, 1987). Given this, the classroom interactions involving teachers and learners vis-a-vis their conceptions of inquiry become interesting.

It was against this background that a myriad of questions emerged. For example: Do teachers own misconceptions about inquiry permeate learner thinking? If both teachers and learners do not understand inquiry, what sort of classroom interaction and discourse occur in the classroom? Are teachers' laboratory instructional practices related to their conceptions of the NOSI? Is it not possible that teachers through their laboratory practices inherently or overtly translate their conceptions about the NOSI onto their learners? What is the nature of South African Grade 11 learners' and teachers' conceptions about NOSI? What is the nature of Grade 11 teachers' practices of inquiry? The major focus of this study was to try and answer these questions. While the study sought to illuminate the interactions among variables by addressing these questions, its basic design was purely descriptive, exploratory, interpretive, and correlational. No attempt was made to establish causality. As already noted, the context chosen for this study is teaching and learning of scientific investigations at Grade 11 level in five schools in and around Gauteng, South Africa.

1.2 The South African curriculum context

In order to fully understand the context in which this study was undertaken, it is important to briefly examine the South African Physical Science curriculum. In line with international fashions and trends, South Africa introduced a new Physical Science curriculum in 2006 (Department of Education, 2005). The new curriculum, the National Curriculum Statement (NCS) at Further Education and Training (FET) phase, Grades 10–12, advocates for teaching and learning of science through inquiry. It requires learners to be involved in practical investigations which are assessed and form part of the Physical Science

summative assessment for the Senior School Certificate, called Matriculation. The investigations contribute 40 % to the Continuous Assessment (CASS) mark, which is school-based, meaning that this component has a huge weighting on the overall assessment. The teaching and assessment in Physical Science is guided by three learning outcomes (LOs) (Department of Education, 2005). A learning outcome is a statement of the intended result of teaching and learning. Learning outcomes describe the knowledge, skills and values that learners should acquire as a result of going through a curriculum. Broadly, the LOs aim to develop learners' understandings of scientific knowledge and NOSI, science process skills and problem-solving abilities. Learning outcome 1 (LO1) specifically focuses on *scientific inquiry* and *problem-solving*. It reads as follows:

> The learner should be able to use process skills, critical thinking, scientific reasoning and strategies to investigate and solve problems in a variety of scientific, technological, environmental and everyday contexts (Department of Education, 2005, p.13).

Learning Outcome (LO2) focuses on *constructing* and *applying scientific knowledge*. It reads:

> The learner should be able to state, explain, interpret and evaluate scientific and technological knowledge and can apply it in everyday contexts (Department of Education, 2005, p.14); and

Learning Outcome (LO3), focusing on the *nature of science* and its *relationship* to *technology, society* and the *environment.* It says:

> The learner should be able to identify and critically evaluate scientific knowledge claims and the impact of this knowledge on the quality of socio-economic, environmental and human development (Department of Education, 2005, p.14).

For this study only Learning Outcomes (1) and (3) are of interest since they relate to learners understandings of the NOSI. It is noteworthy, that the skills and processes which

learners are expected to use and develop in their study of the Physical Sciences are similar to those practiced by professional scientists in their daily activities. Inherently, South Africa's new science curriculum assumes that by "doing inquiry" learners will come to understand the NOSI. There is nowhere in the curriculum where an explicit understanding of NOSI is mentioned. The explicit approach advances that the goal of improving learners' NOSI conceptions ''should be planned for instead of being anticipated as a side effect or secondary product'' of varying approaches to science teaching (Akindehin, 1988). This approach intentionally draws learners' attention to aspects of NOSI through discussion, guided reflection, and specific questioning in the context of activities, investigations, and historical examples. On the other hand, the implicit approach contends that by doing science, learners will come to understand the nature of scientific inquiry (Hodson & Hodson, 1998; Jelinek, 1998; Moss, Abrams, & Kull, 1998; Sandoval & Reiser, 2004) and advocates the use of hands-on inquiry-oriented activities and/or science process skills instruction—lacking explicit references to NOSI—to enhance learners' conceptions of NOSI. Thus an *implicit* inquiry-based pedagogical approach refers to the absence of specific attention to NOSI. Research has shown that doing inquiry does not necessarily translate into understanding NOSI (Bell, et al., 2003; Clough & Olson, 2004; Wong & Hodson, 2008). What then exactly happens in South African classrooms with regards to implementation of the new curriculum and learners' understandings of NOSI? This is an interesting research issue.

While LO1 appears implicit about developing learners' NOSI understandings, a closer examination of LO3 shows that learners' understanding of the NOSI is a pre-requisite for the achievement of this outcome. In order for learners to "identify and critically evaluate scientific knowledge claims they must of necessity have an understanding of the NOSI. Of course the translation of this intention into reality might be entirely dependent on teachers own interpretation of the outcome which in turn depends on their own understandings of the NOSI. Learning Outcome 1 is implicit in that there is an underlying assumption that learners will learn about the NOSI by simply participating in investigative activities. This is similar to the cognitive apprenticeship approach which is an implicit teaching approach

based on the assumption that learners can understand inquiry through doing inquiry (Sandoval & Reiser, 2004). Hodson and Hodson (1998) have called it 'enculturation'; initiating learners into the beliefs, values, practices and styles of discovery of the scientific community by doing science.

The curriculum requires that learners do two assessed practical investigations at each grade level at FET phase (Grades 10–12), one in Physics and one in Chemistry. The skills and abilities which learners are expected to develop as a result of doing investigations are listed as follows: (1) plan investigations; (2) conduct investigations; (3) interpret data and draw conclusions; (4) solve problems; and (5) communicate and present information and scientific arguments (Department of Education, 2005). It is noteworthy that these skills and abilities encompass frameworks of scientific inquiry as described by several authors (Campbell, Abd-Hamid, & Chapman, 2010; Chambers, 2003; Hegarty-Hazel, 1986; Minstrell & van Zee, 2000). Campbell et al. (2010), for example, describe scientific inquiry as involving, asking/ framing research questions; designing investigations; conducting investigations; collecting data; and drawing conclusions.

1.3 The Research Questions

This study investigated interactions among: learners' NOSI conceptions and teacher instructional practices when teaching investigations; learners' NOSI conceptions and their teachers' NOSI conceptions; and teacher NOSI conceptions and their teaching practices when teaching investigations. The study was guided by the following questions:

1. What are learners' conceptions of the nature of scientific inquiry?
2. What are teachers' conceptions of the nature of scientific inquiry?
3. What is the nature of teachers' practices of inquiry when teaching practical investigations?

4. What is the relationship (if any) between: (i) learners' NOSI conceptions and teacher instructional practices when teaching investigations; (ii) learners' NOSI conceptions and their teachers' NOSI conceptions; and (iii) teacher NOSI conceptions and their teaching practices when teaching investigations?

Question four is about examining the interactions among three variables which are; teacher practices, learner NOSI conceptions, and teacher NOSI conceptions?

1.4 Overview of the theoretical framework

A theoretical framework is a collection of interrelated concepts which guide the research, determining what things the researcher will investigate and how he/she will analyze and interpret data (Borgatti & Foster, 2003). This study is embedded within the theory of social constructivism (Hutchins, 1995). From this viewpoint, constructivist thinking is acknowledged, especially the claims for deep and active learning. In social constructivism, learners are said to acquire knowledge by participation in authentic tasks situated in an environment that is permeated with "distributed" knowledge (Hutchins & Klausen, 1996; Lave, 1988; Lave & Wenger, 1991). In other words, learning is seen as participation in a practice (participation metaphor) rather than as acquiring knowledge per se (acquiring metaphor) (Sfard, 1998) while at the same time recognizing that there is an ontological reality, which has been established by scientists by repetitive and routine confirmation.

The framework of social constructivism encompasses such constructs as; scientific inquiry, conceptions of scientific inquiry, extent of inquiry during teaching investigations and teacher instructional practices. The assumption is that engagement in inquiry activities similar to those done by professional scientists provides a learning context conducive to developing knowledge about the methods and activities through which science progresses. This in turn leads to developing desired conceptions of the nature of scientific inquiry. The social constructivist framework guided both the methodology and data analysis for this study.

This study is guided by four interrelated theoretical constructs which are: what is scientific inquiry?; nature of scientific inquiry; learners' and teachers' conceptions of nature of scientific inquiry; and practices of inquiry. Below, each of the four theoretical lenses is explicated.

1.4.1 What is scientific inquiry?

In *professional science*, scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work (Anderson, 2002; Grandy & Duschl, 2007). To Schwartz et al. (2004), scientific inquiry refers to the methods and activities that lead to the development of scientific knowledge. In *school science*, scientific inquiry involves learner-centred projects, with learners actively engaged in inquiry processes and meaning construction, with teacher guidance, to achieve meaningful understanding of scientifically accepted ideas targeted by the curriculum (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Minstrell & van Zee, 2000; National Research Council, 1996; Roth, 2008). This entails using a variety of activities to develop learners' knowledge and understandings of both scientific ideas and how scientists study the natural world. This involves what is called 'inquiry learning', as a strategy for learning both scientific ideas and the nature of inquiry.

Naturally, the promotion of inquiry learning has been associated with the use of "inquiry teaching" as an instructional tool, strategy and approach. Wetzel (2012) believes scientific inquiry causes a fundamental change in science education, moving it away from traditional teaching practices of lecture and demonstration to a collaborative relationship between teacher and learner. In these collaborative environments, learners take risks without fear of ridicule and begin to think about science. Teachers become facilitators of their learner's inquiry by: modeling and immersing their learners in scientific inquiry; ask guiding questions which provoke thought and reflection; allow learner creativity in experimental design; and allow learners to discover investigations can be successful, yet fail to answer

the original question being investigated (National Research Council, 2000; Paulson, 2009; Songer, et al., 2003).

In this study, the construct of scientific inquiry guided the methodology and analysis by checking whether learner involvement in science investigations moved them from passive learners to active learners. The yardstick was to check if learners made personal connections when using scientific inquiry with subsequent internalization of the new knowledge taking place. Key attributes which the study expected learners to exhibit as a result of going through practical investigations included learners: learning how to design investigations; learning how to ask questions; internalizing new knowledge; realizing how findings depend on experimental design; formulating explanations of findings; presenting their findings; reflecting upon their findings increasing their level of understanding of science; and learning to investigate like scientists. In a nutshell, scientific inquiry is the process of active exploration by which learners use critical, logical, and creative thinking skills to raise and engage in questions of curriculum relevance.

1.4.2 Nature of scientific inquiry

Having defined scientific inquiry, need arises to operationalize the term "nature of scientific inquiry". According to Schwartz (2007), nature of scientific inquiry (NOSI) refers to the processes and elements therein of scientific investigations and methods of justifying knowledge. To Schwartz, et al. (2008), NOSI aspects are those that pertain most to the *processes of inquiry*, the "how" the knowledge is generated and accepted. Scientific processes of inquiry are activities related to collecting and analyzing data, and drawing conclusions (American Association for the Advancement of Science, 1990, 1993; National Research Council, 1996). Examples of scientific processes include observing, hypothesizing, experimenting, concluding and inferring. As mentioned before, in this study the term NOSI is used to refer to the ideas, beliefs, views, perceptions and assumptions about the investigative processes of scientific inquiry, harboured by an individual. This is taken to include an individual's ideas about the scientific processes and the scientific enterprise such as experimenting, observing, concluding and inferring.

1.4.3 Learner and teacher conceptions of nature of scientific inquiry

Conceptions of NOSI refer to how learners and teachers view professional scientific inquiry. What constitutes understandings of nature of scientific inquiry (NOSI) are not the abilities or skills to perform (to do) investigations, but rather the beliefs, views, perceptions and assumptions attached to the activities by the individual. This study investigated beyond the skills of scientific inquiry (i.e., what learners should be able to do) and focused on the knowledge about scientific inquiry (i.e., what learners should understand about the nature of scientific inquiry). Hence the study focused on learners' and teachers' conceptions of inquiry basing on the kinds of products the processes of scientific inquiry intend to construct and evaluate.

Teacher and learner conceptions of nature of scientific inquiry were elicited for six tenets. For the NOSI, tenets are the ideas, principles, opinions or doctrines about scientific knowledge and the scientific process that are generally believed or held to be true by members of the science education community (McComas, 1998). These tenets are: (1) laws and theories serve different roles in science; (2) observations are theory-laden; (3) scientists use a variety of methods to conduct scientific investigations; (4) scientists require accurate record keeping, peer review and replicability; (5) scientific knowledge is socially and culturally embedded; and (6) scientific knowledge is partly the product of human creativity and imagination.

However, numerous studies done around the world (Bell, et al., 2003; Clough & Olson, 2004; Crowther, Lederman, & Lederman, 2005; Matkins & Bell, 2001; McComas, 1998) suggest that these six tenets also belong to nature of science (NOS). Though there are areas of overlap and connectivity (Abd-El-Khalick & Lederman, 2000a; Hipkins, Barker, & Bolstad, 2005; Rudolph, 2003; Schwartz, et al., 2008), this study argues that the six tenets mainly belong to NOSI because they centre on the *processes* of science rather than the *knowledge* itself. The tenets were chosen because of their relevance to the South African Physical Science curriculum. As mentioned earlier, for the new curriculum, assessment

focuses on clearly defined learning outcomes (Department of Education, 2005). Learning Outcomes (LO1) and (LO3) relate both to the six tenets and NOSI. Furthermore, the tenets were also chosen because they convey the ideas that teachers are expected to develop from the teaching of scientific investigations and development of learners' NOSI understandings at Grade 11 level. According to Clough (2007) these tenets can provide an acceptable level of generality regarding the NOSI that can be accessible for a level such as Grade 11. This is the Grade level chosen for the current study. In addition, the elements carried by these tenets are consistent with current philosophical views of science and useful for combating learners' naive views of scientific inquiry. Having explicated on learners' and teachers' understandings of NOSI, focus is now on practices of inquiry.

1.4.4 Teacher practices of inquiry

Teacher practices are essential for supporting learners in scientific inquiry practices of framing research questions, designing and conducting investigations, collecting data, and drawing conclusions (Dudu & Vhurumuku, 2012). Given the centrality of investigations in school science teaching and the importance of investigations in nurturing learners' ideas about the NOSI, it is critical to understand teachers' practices and perspectives when teaching investigations. Such an understanding is essential for the development of both pre-service and in-service science teacher education programmes that are responsive to classroom challenges (Wu, 2009). An understanding of teacher practices when teaching investigations can be useful in the crafting of constructivist-oriented pedagogies aimed at explicitly developing learners' understandings of the NOSI.

In this study, teacher practices was about both what the teacher did and what the learners were doing during teaching and learning of scientific investigations (Vhurumuku, et al., 2006). In other words, practices of inquiry are the extent to which investigations are more or less open-ended (Hegarty-Hazel, 1986). Establishing practices of inquiry aimed at determining the extent to which the practices were open-ended. Open endedness is measured here by the degree or latitude given to learners by the teacher to ask or frame questions for investigation; design and conduct investigations; collect their own data;

interpret results; and draw their own conclusions (Dudu & Vhurumuku, 2012). Teaching of investigative activities is described as closed or low-inquiry-oriented if the teacher asks learners to follow step-by-step instructions; answer specific questions; be passive recipients of information; and use teacher and textbook explanations for observed phenomena (Vhurumuku, 2011). Closed-inquiry lessons are also characterized by teacher lecturing to the class or to groups of learners; low levels of learner– learner and learner–teacher argumentation; and having the outcome of experiments known prior to the investigation (Vhurumuku, 2010b).

To the contrary is *open ended inquiry*, which is learner-centred and associated with such activities as: learners formulating their own problems and questions for investigation; seldom following step-by-step instructions from the teacher or laboratory guide; investigating problems that come up in class; offering alternative explanations to phenomena; high levels of learner-learner and learner-teacher argumentation; and outcomes of experiment being unknown prior to the experiment (Domin, 1999; Shiland, 1999). In general, the greater the latitude given to learners to practice the above activities, the more open-ended the inquiry, i.e. the larger the extent of inquiry. Determining the extent of open-endedness of investigations became an important theoretical construct in this study methodologically, analytically and interpretively because very few studies have specifically focused on determining the extent to which teacher practices of inquiry are open-ended (Keys & Bryan, 2001).

Some reflections on the South African teacher education context suggest that teachers find it difficult to implement open-ended inquiry in science classrooms. According to Kriek and Grayson (2009), the state of science education in South Africa is a cause for concern. This situation can be attributed, in part, to many science teachers' limited content knowledge, ineffective teaching approaches, and unprofessional attitudes. However, content knowledge alone is not enough, as indicated by Adler and Reed (2002, p.25), who write, "The issue is how to integrate further learning of the subject with learning about how students in school acquire subject knowledge". They

suggest that teachers need to learn "subject knowledge for teaching". This kind of knowledge is acquired during teacher training and to the South African science teachers; this is obtained during pre-service or in-service programmes at universities since they are the only institutions of teacher training. Teacher training colleges were long shut down. Robinson (1999) elaborates troubles of South African science educators by saying that they are confronted with learners from different racial and economic backgrounds who speak different home languages. The teachers do not know how to teach them. This is impounded by the new curriculum which demands that teachers should use learner-centred or cooperative teaching methods. No-one has ever shown these teachers how to use these methods. Teachers are told to do continuous assessment instead of regular tests. But what exactly is continuous assessment, and why should they do it? Teachers are asked which textbooks they would like to order for their subject. They have never thought about this before and do not know how or what to choose. The principals say there will be an appraisal process at the school and the teachers must give other teachers feedback about their teaching. What should they say? And teachers are not sure whether to study further as it is not clear if this will be recognized for salary purposes. Clearly there are vast and complex challenges for those in South Africa who would wish pre-service and in-teacher education to be a strategy for educational reconstruction. There are countless issues on which have not even begun to be touched, for example, the acceptance that classes of 40 learners is a reality which is here to stay; not to mention the budgetary constraints that make it unlikely that most schools will be able to purchase apparatus and chemicals for scientific investigations to allow teachers to practice inquiry.

1.5 Delimitations

For both teachers' and learners' conceptions, the study limits itself to understandings of the nature of scientific inquiry (NOSI). The focus of this study is on NOSI and not on NOS. Additionally, the study specifically focuses on how teacher instructional practices when teaching investigations relate to teachers' and learners' understandings of the nature of scientific inquiry. For instructional practices, the specific point of interest was what happens during science lessons in which practical investigations are involved.

1.6 Overview of the methodology

An explanatory mixed methods design was utilized, and it involved collecting qualitative data after a quantitative phase in order to explain or follow up on the quantitative data in more depth. In the first quantitative phase of the study, the Learners' Understanding of Science and Scientific Inquiry (LUSSI), Probes, Learner Perceptions of Classroom Inquiry (LPCI) and Teacher Perception of Classroom Inquiry (TPCI) instruments were used to collect data from both learners and teachers at five schools to determine their NOSI understandings. An interpretative framework which is also organizational known as the multidimension (MD) framework was adapted and used as the lens of analysis. The framework for analyzing probes' open-ended responses followed a *hybrid model* produced after fusing the Ibrahim, Buffler and Lubben's (2009) coding model with Liang et al.'s (2009) rubric for scoring Students' Understanding of Science and Scientific Inquiry open-ended responses as described in Chapter 3. The second qualitative phase was conducted in order to explain the quantitative results in more depth with qualitative data (e.g., statistical differences among groups and individuals who scored at extreme levels). In this exploratory follow-up, learners and teachers' NOSI conceptions and teacher practices were tentatively explored with 23 learners and 5 teachers using interviews and classroom observations at all the five research sites. The study initially intended to use 25 learners for interviews but two of them pulled out leaving 23. The reason for the exploratory follow-up was to help explain or build upon initial quantitative results. The LPCI was adopted as the lens of analysis for teacher practices.

1.7 Thesis chapter overview

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

1.7.1 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 rationale for the study section introduces and defines some of the key terms used in the study. Detailed definitions and operationalization of the terms is done in Chapter 2. The theoretical framework of the thesis is also shaped in this chapter after which the delimitations of the study and an overview of the methodology are explicated.

1.7.2 Chapter two: Conceptual framework and review of literature

Chapter 2 explores and discusses major concepts and ideas providing conceptual framework for thesis The major terms explored include; scientific inquiry, nature of scientific inquiry, *conceptions of NOSI*, basic tenets of NOSI (including special focus on the six covered by the thesis), *instructional practice*- teaching as scientific inquiry, learning as scientific inquiry- covering the forms and types of inquiry –closed to open ended providing conceptual framework(s) for data analysis; scientific investigations and teacher practices when teaching investigations. This exploration is permeated by historical and philosophical analyses.

1.7.3 Chapter three: Research Methodology

First the rationale for using mixed method research is stated. Secondly, the 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. Quantitative and qualitative analytic data frameworks for each method and instrument used are also described together with their justifications.

1.7.4 Chapter four: Results from the pilot study

In this chapter, focus is on the validation of two instruments which were adopted for this study namely; the Learners Understanding of Science and Scientific Inquiry (LUSSI) and the Learner perception of Classroom Inquiry (LPCI). In both instruments, the validation is based on quantitative data collected from South African Grade 11 learners (n = 88; n = 90

respectively) which were not part of the main study and interviews of science education experts (n =4) and Grade 11 learners (n =10). Using Multiple Regression analysis, the criterion and construct validity of the instrument items are investigated. Corroborative interview data is also used to give insights into the face, content and construct validity of the instrument. Recommendations and implications of the validation process are highlighted.

1.7.5 Chapter five: Learners' conceptions of the nature of scientific inquiry

This chapter provides the description of results of the learners' conceptions of the nature of scientific inquiry (NOSI) through presentation of quantitative and qualitative analyses of the study's sub-first research question; what are learners' understandings of the NOSI? It is both quantitative and qualitative. Learners' understandings of the NOSI are analyzed using the adapted multidimension (MD) framework lens of the nature of scientific knowledge. Problems encountered with the coding process are explained. Methodological issues about the validity of learner interpretation of questions in the study are raised. Some issues are raised on corroboration of LUSSI, probes findings and interview results. Results are discussed in the light of findings from related studies.

1.7.6 Chapter six: Teachers' conceptions of the nature of scientific inquiry

What are teachers' understandings of the NOSI? Chapter 6 of the thesis tackles this question. It provides the description of results of teachers' understandings of the nature of scientific inquiry (NOSI). This is done through presentation of mainly qualitative analyses of the study's sub-second research question. The characterization of each teacher's personal conception of the NOSI (from the probes instrument) with results of the analyses of the teachers' responses to interview probes is presented. Teachers' understandings of the NOSI are analyzed using the adapted multidimension (MD) framework lense of the nature of scientific knowledge. Use of this framework implies that teachers' views of the NOSI are not necessarily expected to develop in a coherent manner. Additionally each teacher's

understandings of the NOSI is classified and discussed under various philosophical positions when all the six explored NOSI tenets are considered.

1.7.7 Chapter seven: Teachers' instructional practices

The chapter addresses the question; what is the nature of the teachers' laboratory instructional practice? In particular the chapter presents the nature of inquiry in the teachers' laboratories. Methodologically, it combines quantitative instruments, interviews and classroom observations to get insights into the nature of teachers' laboratory work instructional practices. The theoretical framework is in the form of related studies on inquiry teaching and a synthesis of laboratory class activities constituting inquiry. A comparison of teachers' and learners' perceptions of the nature of laboratory inquiry is also presented. Results from the chapter suggest that teachers' profiles reveal a repertoire of divergent, contrasting and to a lesser extent relatively distinct instructional practices when teaching practical investigations.

1.7.8 Chapter eight: Exploring interactions among the three investigated variables

This chapter puts everything together and addresses the major question guiding the study which is; how do Grade 11 learners' understandings of the NOSI relate to their teacher instructional practices and teachers' understandings of the nature of scientific inquiry? This is an attempt to explicate possible relationships (if any) between learners' NOSI understandings, teacher instructional practices and teachers' understandings of NOSI. The combination of quantitative, observational and interview measures provides the exploration of possible relationships between learners' NOSI understandings and teachers' instructional practices, teachers' and learners' NOSI understandings, as well as teachers' NOSI understandings and instructional practices. Possible relationships are discussed and related back to the key nature of scientific inquiry (NOSI) literature as well as inquiry and teacher instructional practice education literature.

1.7.9 Chapter nine: Conclusions, implications and recommendations

In this concluding chapter, a summary of the key findings and conclusions of the thesis is raised. The findings from the three results chapters discussed in the previous chapters are woven together. Pieces of substantiation gathered in exploring the nature of interactions among/between the three investigated variables; learners' understandings of the NOSI, teachers' conceptions of the NOSI and teacher instructional practices when teaching investigations are revealed. Recommendations and a distinction between NOS and NOSI, and areas for future research coming out of the study are given. Limitations of the study are also highlighted.

CHAPTER TWO

Conceptual framework and review of literature

2 Introduction

In this chapter, the major concepts and ideas shaping the conceptual framework for the thesis are explored and discussed. The exploration puts in a nutshell a literature survey of contemporary term or concept usage in science education. This exploration is permeated by historical and philosophical analyses. Logically, this examination of concepts culminates in the terms being operationalized. The major terms explored and operationally defined are: scientific inquiry; nature of scientific inquiry; conceptions of NOSI; basic tenets of NOSI - with special focus on the six tenets investigated in this thesis; instructional practices; teaching as scientific inquiry; learning as scientific inquiry- covering the forms and types of inquiry-closed to open ended which provide conceptual framework(s) for data analysis; scientific investigations; and teacher practices when teaching investigations.

2.1 What is scientific inquiry?

Inquiry in general refers to the activities of learners in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (National Research Council, 1996). As already mentioned another view of inquiry (Hinrichsen, Jarrett, & Peixotto, 1999; Windschitl, 2002), 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. According to Dow (1999) inquiry has its deeper roots in the Socratic inquisitiveness of Athenian times. Inquiry can be understood as the search for truth or knowledge by questioning which Socrates and his disciples sought to do. 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 individual wants to know (Exploratorium Institute for Inquiry, 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).

Scientific inquiry as the practice of professional science refers to the various ways of studying the natural world, asking questions, proposing ideas, collecting evidence to justify assertions and explanations and communicating results (Hofstein & Lunetta, 2004; National Research Council, 1996). To Schwartz and Lederman (2008), scientific inquiry as the practice of professional science refers to the characteristics of the processes through which scientific knowledge is developed, including the conventions of its development, acceptance, and utility.

School science inquiry is seen as similar to the inquiry done by professional scientists as learners also investigate the world, propose ideas and justify explanations based on collected evidence. Chinn and Malhotra (2002), however, argue that school based inquiry is cognitively and epistemologically different from authentic scientific inquiry (practice of professional science). It is noteworthy 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. School science does not operate at the frontiers of scientific knowledge. When examining inquiry in the context of school science, it should always be borne in mind that this inquiry is within the cognitive and epistemological boundaries of school science. What comes out to this point is that this study is about conceptions of scientific inquiry as practiced by professional scientists. Conceptions of NOSI refer to how learners and teachers view professional scientific inquiry.

2.1.1 Scientific inquiry in school science

In school science, perhaps the most confusing thing about inquiry is its definition (Bybee, 2000; Flick & Lederman, 2004). Precise descriptions of what inquiry means for science education vary. The meaning of inquiry has been the focus of much debate but little agreement for decades (Bennett, Persky, Weiss, & Jenkins, 2007). During the second half of the twentieth century, *good science teaching and learning* came to be distinctly and increasingly associated with the term inquiry (Anderson, 2002). Presently, inquiry teaching serves as the buzzword for sounding dissatisfaction with current practices in elementary and high school science teaching (Abd-EL-Khalick, et al., 2003). In school science education, the use of the term inquiry is replete with confusion because it is used to describe both teaching and doing science. Confusion about the meaning of inquiry and its appearance in the classroom continues to exist among classroom teachers and teacher educators (Bennett, et al., 2007). Despite this confusion, inquiry is at the heart of the scientific enterprise, and as such, demands a prominent position in science teaching and learning (Bell, et al., 2010; Donovan & Bransford, 2005).

One way to look at inquiry is to think of it as a coin with two distinct sides. On one side is the content that learners need to learn, including what learners should be able to understand about *scientific inquiry* as well as the attitudes and abilities they should develop by actively engaging in inquiry. *Scientific inquiry* in this case refers to the characteristics of the processes through which scientific knowledge is developed. This includes the conventions of development, acceptance, and utility of scientific knowledge. Learning Outcome 1 (LO1) of the South African National Curriculum Statement (NCS) implicitly focuses on this aspect of scientific inquiry. On the other side of the coin are the teaching approaches and learning strategies that enable teachers to teach science concepts through inquiry. Regardless of various "*standards"* and their companion documents having tried to explicate the meaning of *inquiry*, many teachers still seem uncertain about the meaning of term (Bennett, et al., 2007).

Researchers have found that some teachers describe scientific inquiry as discovery learning projects (Windschitl, 2002), hands-on activities or activity-based instruction (Crawford, 2000; Windschitl, 2002), process skills linked with the scientific method (Ayers & Ayers, 2007; Knabb, 2006; Suits, 2004), authentic problems (Crawford, 2000; Kang & Wallace, 2005), or classroom discussion and debate (Carnes, 1997). Others equate "inquiry" with an increased level of learner direction, that is, allowing learners to ask their own questions, design procedures and determine which data to collect (Carnes, 1997; Deters, 2004; Kang & Wallace, 2005). Although each of these characteristics may be a part of an inquiry experience, they do not give a full picture of scientific inquiry in the classroom (Asay & Orgill, 2010). Many science educators argue that inquiry should focus on the thinking practices through which learners understand and construct scientific ideas, as well as practices that cannot be formalized into a rigid method (Louca & Zacharia, 2007). However, scientific inquiry is not simply hands-on science, a lab activity that verifies what has been taught, discovery learning, a formula for teaching, or a set of skills to be practiced (National Research Council, 2000, 2005; Trumbull, Bonney, & Grudens-Schuck, 2005).

For this study, *scientific inquiry* refers to a process where a fundamental re-examination of the relationship between the teacher and the learner is required whereby the teacher becomes a facilitator or guide for the learner's own process of discovery and creating understanding of the scientific concepts. In a nutshell, *scientific inquiry* is a process of active exploration by learners during which there is use critical, logical, and creative thinking skills to raise and engage in questions of curriculum relevance.

Learners' classroom experiences can be examined through a lens of the nature, form and extent of inquiry woven through the teaching and learning activities. Vhurumuku, Holtman, Mikalsen and Kolstoe (2004) describe school science learning activities as belonging along a continuum ranging from closed inquiry oriented to open ended of inquiry. As earlier mentioned, teaching and learning experiences can be described as *closed inquiry*, when they are characterized by being; teacher centred, expository, verificationistic, and transimissionistic. In closed inquiry laboratories, learners are given little or no opportunities

to propose problems for investigation, ask questions, formulate hypotheses, design procedures, process answers and explanations, predict and communicate results as well as identifying assumptions, use logical and critical thinking and engage in argumentation. According to Vhurumuku (2011) closed inquiry laboratories are associated with such activities as: learners following step-by-step instructions from the teacher or laboratory guide; learners are required to answer specific questions - posed by the teacher or laboratory manual; problems that come up in class are not investigated; there is no search for alternative explanations to phenomena; teacher lectures to the class or to groups of learners within the class; low levels of learner-learner and learner-teacher argumentation; outcome of experiment known prior to the experiment; and use of textbook or teacher explanations for observed phenomena.

To the contrary is *open ended inquiry*, which is learner centred and associated with such activities as: learners formulating their own problems and questions for investigation; seldom following step-by-step instructions from the teacher or laboratory guide; investigating problems that come up in class; offering alternative explanations to phenomena; high levels of learner-learner and learner-teacher argumentation; and outcomes of experiment being unknown prior to the experiment (Domin, 1999; Shiland, 1999). In general, the greater the latitude given to learners to practice these activities the more open-ended the inquiry; i.e. the larger the extent of inquiry.

2.2 The nature of scientific inquiry (NOSI)

2.2.1 Conflation of NOS and NOSI

Any attempt to conceptualize the *NOS* and *NOSI* must of necessity cognize the fact that, in the literature, these terms have been conflated. The use of terminology that has been associated with each construct has made conceptual characterization difficult. Each construct has been defined in a variety of ways and authors have also taken the two terms to be synonymous. For each construct descriptions have been multi-dimensional in nature. This has been largely due to the variety of disciplines from which definitions have been

derived and a lack of consensus across the disciplines of history, philosophy, and the academic sciences.

Conflation of NOS and NOSI is abundant in the literature. Meichtry (1993; 1998), for example describes the term "nature of science" as having been used interchangeably in literature to refer to understandings of both the nature of scientific inquiry and the nature of scientific knowledge. Scientific inquiry is defined as:

> "... a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results" (National Research Council, 1996, p. 23).

This definition highlights the importance of a variety of activities to develop learners' *scientific knowledge* and understandings of both scientific ideas and the processes of science. Scientific knowledge is defined as a product of the human process of science and its social context (Meichtry, 1998). This as it may, during the past five decades; some authors have defined the NOS in ways which make it synonymous to NOSI. If scientific inquiry is about making observations, formulating hypotheses, gathering and analyzing data, and forming conclusions from that data (American Association for the Advancement of Science, 1990, 1993; National Research Council, 1996), then, it must logically follow that the construct NOSI must be about individually held ideas about these processes. Nature of Scientific Inquiry aspects are those that pertain most to the *processes of inquiry*, the *how* the knowledge is generated and accepted (Schwartz, et al., 2008). Examples of scientific processes include observing, hypothesizing, experimenting, concluding and inferring. Some definitions of the NOS, used by authors that show conflation with NOSI can be given. Examples include: an understanding of the nature of scientific knowledge (Cotham & Smith, 1981; Rubba & Anderson, 1978); describing the nature of the scientific process (Klopfer, 1964); the epistemological commitments underlying the activities of science

(Abd-El-Khalick, Bell, & Lederman, 1998). From these definitions questions can be asked; does nature of science refer to understandings of the nature of scientific knowledge (NOSK), referring to the knowledge itself ***only*** rather than the processes through which it is generated? When one says, "Scientific knowledge is empirically based" does one refer to the knowledge itself or the process by which it is developed and validated? Can knowledge be separated from the process through which it is generated? What are the epistemological and ontological properties of knowledge?

This gives birth to problems in explicating NOS from NOSI. The stance taken by this thesis is that to believe that scientific knowledge does not change is to habour an idea about NOS. The same would be true for subscribing to the ideas that scientific knowledge is absolutely true and that it is totally objective. Schwartz, Lederman and Crawford (2004) have referred to the ideas, views, beliefs, assumptions and values which people have about the activities and practices of scientists as Views of the Nature of Scientific Inquiry (VNOSI). As already noted, scientific inquiry involves investigative processes including problem formulation, hypothesizing, questioning, predicting, observing, collecting data, constructing meaning, explaining, reflecting and comparison of information with other sources. Being able to perform investigative processes including problem formulation, hypothesizing, questioning, predicting, observing, collecting data, constructing meaning, explaining, reflecting and comparison of information with other sources is not in itself to understand the 'nature of scientific inquiry'. Neither does nature of science mean an individual's ability to practice scientific activities or science processes. Rather, as Lederman (1999) puts it, what is called the "nature of science" are the values, beliefs and assumptions which the individual attaches to the activity. In this thesis, the term NOSI is used as referring to the ideas, beliefs, views, perceptions and assumptions about the nature of scientific inquiry, harboured by an individual. This is inclusive of an individual's ideas about the scientific process and the scientific enterprise. The scientific process has to do with what scientists do in producing scientific knowledge or crudely, it has to do with the methods of science. The NOS is about the knowledge itself and NOSI is about the nature of the scientific process. This study focuses on NOSI and not on NOS.

While a distinction is made here between NOS and NOSI, it is important to note that in the literature (see, for example, Bell, Lederman, & Abd-El-Khalick, 2000; Clough & Olson, 2004; Matkins & Bell, 2001) this distinction fails to be that clear cut especially when the issue of what would constitute the tenets of each of these constructs is considered. In their recent study, Bartels, Lederman and Lederman (2012) outlined three tenets -there is no single set and sequence of steps followed in all scientific investigations, laws and theories serve different knowledge in science, and imagination and creativity are used in scientific investigations, as belonging to the NOSI yet there are several studies (Abd-El-Khalick, 2006; Keiser, 2010; Liang, et al., 2008; Schwartz, et al., 2008), where these and other tenets are said to belong to the NOS. For the NOS and the NOSI, tenets, are the ideas, principles, opinions or doctrines about scientific knowledge and the scientific process that are generally believed or held to be true by members of the science education community (Abd-El-Khalick, 2006). The surveyed literature (e.g., Bell, et al., 2000; Clough & Olson, 2004; Matkins & Bell, 2001) reveals that some tenets have been categorized as belonging to both the NOS and the NOSI.

2.3 Conceptions of NOSI

In Chapter1, conception of the NOSI was defined as an individual's ideas, beliefs, and assumptions and understanding about the scientific process; what scientists do and how scientific knowledge is developed and validated. When this broad definition is examined closely, it is apparent that there are such terms as ideas, beliefs, assumptions and understanding that require further explication. The assumptions made about the synonymity of the terms understanding, views, perceptions 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 understandings of NOSI the same as NOSI 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 (1972) terminology arises.

Schwartz, et al. (2012), Allchin (2011), Lyons, Slater, and Slater (2011), Dudu and Vhurumuku (2011; 2012), Vhurumuku (2011), Rubba and Andersen (1978) all refer to understandings of the NOSI. However, they do not distinguish understandings from conceptions about the NOSI. For example, in a paper on impact of scientific inquiry of a backwards-faded scaffolding approach to inquiry-based space science, Lyons, et al. (2011) uses the term understanding as having the same meaning with view of the NOSI and conceptions of the NOSI. Dudu and Vhurumuku (2012), in an article entitled, *Teachers ' Practices of Inquiry When Teaching Investigations: a Case Study*, uses the terms understandings of the NOSI and conceptions about the NOSI as meaning the same thing. In the same paper they mention perceptions of the NOSI and views of the NOSI in the same vein as conceptions of the NOSI. Using an adapted Schwartz, Lederman and Thompson's (2001) VOSI instrument, Bartels, et al. (2012) measure what Schwartz et al. (2001) call views and coins it understandings of Knowledge of Inquiry (KOI). In her study, Lematla (2011) describes views about the NOSI as having the same meaning as understanding of the NOSI. The same study refers to conceptions about the NOSI as meaning the same as understandings of the NOSI. A study by Eastwood, Sadler, Sherwood and Schlegel (2012) on conceptions of scientific inquiry of students participating in an interdisciplinary study uses the phrase 'understanding of scientific inquiry' interchangeably with the phrase 'conceptions of scientific inquiry'. Vhurumuku (2011), in an article entitled *High School Chemistry student's scientific epistemologies and perceptions of the nature of laboratory inquiry* gives the impression that views about the NOS and the NOSI are the same as conceptions of the NOS and the NOSI. Carey, Evans, Honda, Jay and Unger (1989) have used the term conception of the NOS in the same way. Sampson and Grooms (2008) make some separation of students' conceptions of the NOSI from students' views about the NOSI. 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 and NOSI has also been used (Bell, et al., 2003; Gess-Newsome & Lederman, 1995a; Khishfe & Abd-El-Khalick, 2002) to refer to the same phenomenon, as understanding of the NOS and NOSI. Beliefs and understandings have

also been taken to mean the same thing in a research by Steel and Levy (2009). The study by Steel and Levy (2009) gives the impression that understandings and belief is one and the same thing. Of interest is that, while different terminology has been ascribed to the NOSI by these researchers, the instruments they have used to measure each of the constructs have more or less been the same. Most of the instruments are adaptations and/or adoptions of the Views of Scientific Inquiry (VOSI) and Views of Nature of Scientific Inquiry (VNOSI) instruments (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman & O'Malley, 1990; Schwartz, et al., 2008). This appears to be the case irrespective of whether the research is quantitative or qualitative or both. A question is then asked: What then have the researchers been measuring or assessing; perceptions, beliefs or understandings, or views or conceptions? This question warrants literal examinations of these terms.

An analysis of the term usage with regard to the NOSI conceptions produces two categories of terms. The terms: view, understanding, perception and conception form the first category. They generally refer to mental processes or representations, ideas of entities and phenomenon. An entity or phenomenon in this study could refer to a construct of the nature of scientific inquiry, for example, use of imagination and creativity in scientific investigations. Minsky (2007) describes understanding as the ability to connect a representation to many other representations. Thus if an individual understands something in only one or two ways, it implies that the individual scarcely understand it at all. To Talsma (1997), understanding is 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. A view of the NOSI can be taken to mean the same as perception, understanding or conception of the NOSI. According to Hofer and Pintrich (1997), beliefs are psychologically held understandings, premises or propositions about the world that are thought to be true. This supports Pajares (1992) whose assertion is that epistemic conceptions with affective characteristics are better described as beliefs. Hence in this study perceptions or conceptions of an entity, for example, the nature of scientific inquiry is taken as embedded within an ecological system which includes knowledge and

beliefs. In his review of research on beliefs, Pajares (1992, p. 309) 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...

In this study, beliefs are further taken to refer to feelings of certainty about what something means. This is closely related to the meanings of perception or conception. The term *knowledge* falls into a different category of meaning. Chisholm (1977) defines knowledge as justified true belief. Thus, knowledge can be tacit (meaning it is subjective and experiential and cannot be expressed in words, sentences, numbers, or formulas, i.e. context-specific) or explicit (meaning it is objective and rational and can be expressed in words, sentences, numbers, or formulas, i.e. context-free). In this study knowledge is taken as information and skills acquired through experience or education in social interaction; the theoretical or practical understanding of a subject. In this case, the subject is the nature of scientific inquiry. Knowledge and conceptions are therefore different. What comes out to this point is that understanding and conception go together; belief does not require justification, whereas knowledge and understanding do.

For this study, conceptions of the nature of scientific inquiry refer to ideas, views, perceptions, and assumptions held by individuals about the scientific process as practiced by professional scientists' not scientific inquiry as in school science. From their own experiences of school science inquiry, learners build conceptions about the NOSI as practiced by professional scientists. In sum, the stance taken by this thesis is that conceptions of the NOSI are taken to mean a person's views or perceptions, understanding, preconceptions, dispositions and convictions of the scientific process.

2.4 The NOSI: historical and philosophical origins

As a prelude to the discussion of tenets of the nature of scientific inquiry investigated in this study, this section looks at philosophical orientations and positions around the NOSI. These include rationalism, empiricism, inductivism, realism, instrumentalism, fictionalism, constructivism, and conventionalism.

Ideas, views, perceptions, assumptions, understandings, preconceptions, dispositions and convictions held by individuals about the scientific process as practiced by professional scientists can be traced back to the origins of the Greek philosophy. The nature of scientific inquiry has its deeper roots in the Socratic inquisitiveness of Athenian times (Dow, 1999). This is attributed to one of Western history's most celebrated teachers – Socrates. He is perhaps the wisest and most noble Athenian to have ever lived. Hare (1985) reports that Socrates challenged the youth of his day to be open-minded, think for themselves, question the wisdom of their elders, and construct arguments in their quest to resolve mysteries of the natural world. Socrates neither revealed answers nor truth but taught his students to discover how they could *pull* truth out of their own minds and use their minds to answer fundamental questions. Subsequent practitioners of the Socratic ideal included Copernicus, Galileo, Descartes, Newton, Bacon, Locke, and Rousseau (Dow, 1999). Building upon the wisdom of his teacher, Socrates, as well as that of Parmenides, Plato, who was a rationalist, argued that reality is known only through the mind. Plato believed there is a higher world, independent of the world we may experience through our senses (Dombrowski, 2006; Sayre-McCord, 1994). He believed that there existed a world of unchanging and invisible ideas about which it is possible to have exact and certain knowledge. Plato's philosophy is described as rationalism.

Aristotle who was Plato's student considered human nature, habit and reason to be equally important forces to be cultivated in education. Thus, for example, he considered repetition to be a key tool to develop good habits. Repetition was and is still considered to be an interpretive concept hence Aristotle saw individually held ideas about scientific processes as a persistent examination of the nature of the mind. 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. Aristotle's philosophy is the root of empiricism. Empiricism holds that valid knowledge is knowledge that is based on experience and sensual data only. Empiricism further posits that knowledge that is true comes from the senses.

In 1620, Bacon, often referred to as the father of scientific method, proposed induction as the logic of scientific discovery and deduction as the logic of argumentation (Malhotra, 1994). His works established and popularized deductive methodologies for scientific inquiry, often called the *Baconian Method* or simply, the scientific method. His demand for a *planned procedure* of investigating all natural things marked a new turn in the rhetorical and theoretical framework for science, much of which still surrounds conceptions of proper methodology today. Historically the practice of scientific inquiry was associated with procedural following of a so-called scientific method. The history of science tells us that the NOSI has been distorted and misrepresented, especially with the advent of school science. Today we know that scientific inquiry is a much more complex activity involving a variety of processes and which can be done in various non-procedural ways. According to Bacon, it was important that scientists observe nature without preconceptions, and use inductive logic to make generalizations from observation (Martin, 1992). 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.

Dawson (1991) gives another dichotomy of conceptions that provide direction to the process of scientific inquiry. He writes that there exist realists. To the realists, there exists an objective truth about nature that is independent of one's thinking (Lynch & Nusirjan,

2003). According to this view, the purpose of science is to understand nature, the motive being to quench human curiosity. The realist view which can be described as rational, objective, positivistic, logico-empiricist, Baconian and inductivist holds that whatever we believe now is only an approximation of reality and that every new observation brings us closer to understanding reality (Blackburn, 2005). 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. Instrumentalists however object to this conception and argue that observations alone cannot generate scientific knowledge (Dawson, 1991). To instrumentalists, theories are no more than instruments of calculation, permitting the scientist to infer from one set of observable circumstances to another set of observable circumstances at some later point in time. A version of this is fictionalism which contests the existence of many of the objects favoured by the realist and regards them as merely expedient means to useful ends (Fine, 1986). Thus, fictionalism is a doctrine that certain concepts are simply convenient fictions.

Then there is constructivism as encompassing the epistemology of science (Yore, 2001). Constructivism maintains that scientific knowledge is socially constituted and *facts* are made by individuals (Atherton, 2009). Thus constructivism challenges the objectivity of knowledge, as the realist understands objectivity, and the independent existence that realism is after. Constructivism emphasizes that science is open-ended and highlights the role of unforced judgment in scientific practice, challenging the picture of a strict scientific method and of decision-making forced by rationality at every turn. 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). To Matthews (1998b, 1998c) constructivism at its core is viewed as a doctrine committed to post-positivistic, post-modernistic, anti-realist and instrumentalist conceptions of the nature of scientific inquiry. Ontologically, constructivism accommodates both realism and idealism. To this end, as a science epistemological theory, constructivism

is almost anarchical. No wonder, Sutching (1992, p.247) attacks it as "unintelligible, confused and weak in argument".

A philosophy allied to constructivism is conventionalism. It holds that the truths of science ultimately rest on man-made conventions. Conventionalists believe that scientific knowledge and truth are not fixed by nature but are also creations of the mind (Lynch & Nusirjan, 2003). Ontological conventionalists believe that what objects there are is partly determined by our conceptual practices.

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 empiricist conception which holds truth resides in nature and is only got through the senses. The other conception based on rationalism believes 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 (Malhotra, 1994). 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 nature of scientific inquiry and scientific knowledge are creative and skeptical. Additional philosophical orientations and positions around NOSI have been infused in the historical and philosophical tracing of the six tenets of the NOSI. These include: empiricism, logical empiricism, post-positivism and phenomenalism. Having explicated the philosophical orientations and positions around NOSI, focus now shifts to the six tenets that have been chosen for exploration in this study.

2.4.1 Tenets of the Nature of Scientific Inquiry Investigated in this Study

In Chapter 1, it was mentioned that six tenets of the NOSI were chosen for exploration in this study. These tenets are: laws and theories serve different roles in science; observations are theory-laden; scientists use a variety of methods to conduct scientific investigations; scientists require accurate record keeping, peer review and replicability; scientific knowledge is socially and culturally embedded; and scientific knowledge is partly the

product of human creativity and imagination. These tenets were chosen mainly because of their relevance to the South African Physical Science curriculum. The tenets also provide an acceptable level of generality regarding the NOSI that could be accessible for a level such as Grade 11 (Clough, 2007). In Chapter 1 it was mentioned that these tenets were also chosen because of their relevance to the South African Physical Science curriculum. Furthermore, the elements carried by these tenets are consistent with current philosophical views of science and useful for combating learners' naive views of scientific inquiry. Other reasons for the choice of these six tenets were discussed in Chapter 1. These tenets are more of the NOSI than NOS because they are more related to an individual's ideas about the scientific process and enterprise and elements therein of scientific investigations and methods of justifying knowledge (how knowledge is generated and accepted) rather than pertain most to the product of inquiry, the scientific knowledge per se. In the sections below, each of the tenets is philosophically examined. For each tenet some of predominant misconceptions held by teachers and learners, as found from research are highlighted.

Laws and theories serve different roles in science

Scientific laws and theories are different kinds of scientific knowledge. Bell et al. (2010, p. 11) define a scientific law as "…a description of a generalized relationship or pattern, based on many observations". Scientific laws describe what happens in the natural world and are often, but not always expressed in mathematical terms. The working definition of a *scientific law* by Bell et al. (2010) is in line with the idea that knowledge could be deductively obtained from experience in accordance with the rules of logic. This follows Saint Thomas of Aquinas suggestion of combining reason and experience, logic and faith into a system of beliefs, emphasizing experience as the starting point of logic. For logical empiricists, only empirically verifiable claims make genuine assertions about the world and are, in this broad sense, scientific. As mentioned earlier, empiricists such as Bacon and Locke developed from the philosophy of Aristotle. Bacon proposed induction as the logic of scientific discovery and deduction as the logic of argumentation in the year 1620 (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. Empiricists believe that truth resides in nature and is only got through the senses.

On the other hand, scientific theories are defined as inferred explanations for observable phenomena (McComas, 1996). Observations alone cannot generate scientific knowledge. This is a rationalist conception, which holds truth as existing in the mind of the observer. We say something should work 'in theory' when we mean it probably won't work in practice. Theories are therefore speculative and hypothetical – they are *not* reality. But the towering achievements of science are such theories as: Newtonian mechanics, Einstein's relativity, Darwinian evolution. Scientific theories are about the world and how it works. We look to these theories to tell us about reality. According to this conception, it is the imaginative grasp of the observer that provides the incentive for problem solving inquiry (Malhotra, 1994). A hypothetico-deductive conception, which believes scientific knowledge and inquiry are creative and skeptical is produced after the reconciliation of the two conceptions. Bell et al. (2010) acknowledge that scientific theories and laws are similar in that both require substantial evidence and are generally accepted by scientists. Additionally, either can change with new evidence. However, since scientific theories and laws constitute two different types of scientific knowledge, one cannot change into the other tough they are related.

Observations are theory-laden

Observations are descriptive statements about natural phenomena that are directly accessible to human senses (or extensions of those senses) and about which observers can reach consensus with relative ease (Liang, et al., 2008). Scientific knowledge is developed from a combination of both observations and inferences. To Bell et al. (2010), inferences are logical interpretations derived from a combination of observation and prior knowledge. Together, observations and inferences form the basis of most scientific ideas. This notion encapsulates both empiricism and rationalism. Empiricism is *a posterior* and places emphasis on sense data. Rationalism, which largely advocates for *a priori* is the belief that

the world we live in can be understood by the use of reason (Hirschheim, Klein, & Lyytinen, 1995). To Wand & Weber (Wand & Weber, 1993), reason is a tool for solving problems, creating strategies, debunking nonsense and undermining dogmas.

The rationalist conception holds truth as existing in the mind of the observer. The proponent of this reconciliation is Kant who argues that it is impossible to make observations that are free from all preconceptions. However, it has been argued that observations can be false, that our senses cannot be trusted, and that they are always theory-laden (DeBoer, 1991). Critical realism recognizes that all knowledge claims need to be critically evaluated in order to determine the validity of their correspondence with reality. To generate scientific knowledge, scientists use rules of logic and inference to formulate hypotheses or theories to explain the phenomenon under investigation based solely on their subjective observations (Lederman & Abd-El Khalick, 2002). However, scientists do not set aside their personal prejudices, perspectives and beliefs as they engage in scientific inquiry (processes used to generate and test scientific knowledge). Thus all observations embedded in theory, have a horizon of expectation.

Scientists use a variety of methods to conduct scientific investigations

There exists no single *scientific method* used by all scientists (Bell, et al., 2010). Rather, scientists use a variety of approaches to develop and test ideas, to answer research questions and develop scientific knowledge. This scientific conception has its roots in post-positivism. The major proponent of this philosophy is Feyerabend. Feyerabend (1975, p. 9) asserts that "science is an essentially anarchistic enterprise: theoretical anarchism is more humanitarian and more likely to encourage progress than its law-and-order alternatives". Feyerabend argues that the question of Science's worth is not scientific; it is philosophical. His concept of an epistemological anarchist has been described as postmodernist, deconstructionist and anti-intellectualist (Newall, 2005; Preston, Munévar, & Lamb, 2000). He believed that there is no method particular to science. To Feyerabend, the issue of the scientific method is a fairytale not easily recognizable. It begins like the scientific method is the only means to discover the truth. Paul Feyerabend argues this fairytale is taught in the

classroom and in the lecture-hall, found in scientific journals and textbooks and not in coloured storybooks. Such fairytales are spun to describe the theory and practice of science. Feyerabend wrote:

> Everywhere science is enriched by unscientific methods and unscientific results... the separation of science and non-science is not only artificial but also detrimental to the advancement of knowledge. If we want to understand nature, if we want to master our physical surroundings, then we must use *all* ideas, *all* methods, and not just a small selection of them. — Paul K. Feyerabend
> *Against Method: Outline of an Anarchistic Theory of Knowledge* (1975), 305-6.

He objected to any single prescriptive scientific method on the grounds that any such method would limit the activities of scientists, and hence restrict scientific progress. He distrusted the traditional views of science and acknowledged that scientific methodology is pluralistic. Hence his advocating for the only principle that does not inhibit progress is - *anything goes*. Feyerabend (1978/82) believes new theories came to be accepted not because of their accord with scientific method, but because their supporters made use of any trick – rational, rhetorical or ribald – in order to advance their cause[4]. Feyerabend proposed that science might proceed best not by induction, but by counter-induction. Scientists can make meaning of the natural world using a variety of methodologies. To Bell, et al. (2010), what many refer to as the *scientific method* (testing a hypothesis through controlling and manipulating variables) is really a basic description of how experiments are done.

Scientists require accurate record keeping, peer review and replicability

Authentic science involves a variety of approaches to handling anomalous data (Campbell, Lubben, Buffler, & Allie, 2005; Chinn & Brewer, 1993; 1998). Scientists are people who have expectations hence are guided by their current knowledge and theories as they do their daily work. Science advances through logical skepticism hence scientists review and ask

[4] http://en.wikipedia.org/wiki/Paul_Feyerabend Paul Feyerabend - Wikipedia, the free encyclopedia retrieved November 13, 2010

questions about the results of others (National Research Council, 2000). This aspect of nature of scientific inquiry is grounded in the epistemology of science. The term *epistemology* denotes "the nature of human knowledge and understanding that can possibly be acquired through different types of inquiry and alternative methods of investigation" (Hirschheim, et al., 1995, p. 20). Epistemology studies the nature of knowledge which actually means how individuals conceive their surroundings and which tools they apply for this purpose, for example, senses (physiology), or rational and irrational thought. Questions about the certainty of knowledge, the source of knowledge and the validity of knowledge form the core of epistemology (Rozendaal, de Brabander, & Minnaert, 2001). Most important is the third component for the core of epistemology-the validity of knowledge. Recognizing when observations do not fit expectations is a critical part of progress in 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[5]. The dissensionists have argued that scientific research is much more controversy-laden than what the consensualists propose. Anomalies spark more questions and drive further investigation. A variety of approaches like; rejection, ignoring the anomaly, reinterpretation of data among others are ways of handling anomalous data that strengthen validity of scientific claims (Schwartz, et al., 2008). Such approaches exhibit how scientific knowledge is generated and accepted.

Scientific knowledge is socially and culturally embedded

Scientific knowledge aims to be general and universal (Liang, et al., 2008). As human endeavour, science is influenced by the society and culture in which it is practised. "Current scientific knowledge and understanding guide scientific investigations" (National Research Council, 2000, p. 20). The choice of questions scientists choose to investigate may relate to

[5] http://www.brint.com/papers/science.htm, retrieved October 26, 2010

social impact, practicality, economy, or any variety of other reasons (Schwartz, et al., 2008). Scientists are then informed by various philosophies to embark on their endeavours which are socially and/or culturally embedded. For example, scientists may be informed by phenomenalism (the view that objects are logical constructions out of perceptual properties) and empiricism (the philosophical concept that experience, which is based on observation and experimentation, is the source of knowledge). Others may be influenced by instrumentalism which regards the objects of knowledge pragmatically, as tools for various human purposes, and so takes reliability (or empirical adequacy) rather than truth as scientifically central (Worrall, 2007). A myriad of philosophies inform scientists in inquiry processes. History and culture both have influences on the research done by scientists, e.g. the Haber process and the history of beriberi. An example from the history of science is that of the Haber process. The Haber process which is a method for producing ammonia was developed in World War 1. Smil (2001) reports that the Germans needed nitrogen gas for making their explosives. Because the Germans had been blocked off all trade routes by their allies and in the process lost the entire source for sodium nitrate and potassium nitrate their sources for nitrogen, they had to find an alternative source. They found the alternative of nitrogen in air which is 80% nitrogen and this solved their problem with the help of Chemist Fritz Haber who developed the Haber process which as we know today takes molecular nitrogen and combines it with molecular hydrogen to form ammonia gas. As can be seen from the example above, cultural values and expectations determine what and how science is conducted, interpreted. In so doing, socially-based situations (such as diseases) may be solved, human condition may be improved, desired technology may be developed and basic understanding of our world (scientific inquiry) may be advanced.

Scientific knowledge is partly the product of human creativity and imagination.

Liang et al. (2008) assert that scientific concepts do not emerge automatically from data or from any amount of analysis alone. Science is a blend of logic and imagination. This is in tandem with the instrumentalist view of science which believes the purpose of science is to satisfy human needs and wants. 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. In support, Popper, a post-positivist believes there is no logic of discovery, but only logic of testing. Within practices of scientific inquiry, creativity permeates the ways that scientists design their investigations, how they choose the appropriate tools and models to gather data, and in how they analyze and interpret their results. For example, creativity is clearly evident in Darwin's synthesis of the theory of natural selection. As Bell et al. (2010, p. 11) puts it; "Darwin's recognized genius stems from his creative work of synthesizing a powerful scientific explanation from a variety of sources and clues". Creativity thus spans throughout the whole investigative process. From the history of science, a story is told about how Friedrich August Kekule von Stradonitz (1829-1896) dreamt about the structure of benzene (the organic chemical compound made up of a ring of carbon atoms). Many years after he suggested his structure, Kekule wrote:

> ...I turned my chair to the fire [after having worked on the problem for some time] and dozed. Again the atoms were gambolling before my eyes. This time the smaller groups kept modestly to the background. My mental eye, rendered more acute by repeated vision of this kind, could not distinguish larger structures, of manifold confirmation; long rows, sometimes more closely fitted together; all twining and twisting in snakelike motion. But look! What was that? One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lightning I woke...Let us learn to dream gentlemen. [Kekulé von Stradonitz, (Friedrich) August]
>
> *Gillis, J. (1973) in Charles Coulston Gillespie, ed., Dictionary of Scientific Biography. Vol. VII (New York: Charles Scribner's Sons, 1973), pp. 281.*

Whether or not Kekule actually dreamt, this might never be known. Though some people argue that he was in a deep thought and not dreaming, Kekule discovered a very important organic structure - that of a benzene ring. Another example where creativity is clearly evident is in Archimedes' (287-212 B.C.) work. We are told that the famous Greek scientists named Archimedes stepped into a tub full of water at the public bath house. As he settled back and watched the water flow out over the sides of the tub, he was suddenly

struck by a wonderful idea. He leaped out of the tub and wrapped a towel around himself and went running toward home. “Eureka! Eureka” he cried. “I’ve found it! I’ve found it” (Blackwood, 1967, p. 4). What Archimedes discovered when he stepped into that bathtub is what we call today the Law of Specific Gravity. This was an answer to a problem Archimedes had been working on for some time. Creative thinking is not a talent but a skill that can be learnt.

2.4.2 Frameworks of NOSI conceptions as lenses for data analysis

There are several frameworks which can be used as lenses to categorize an individual’s NOSI conceptions. Examples include; the unidimension framework, the argumentative resource framework and the multi dimension framework.

The unidimension (UD) framework

The *unidimension* (UD) framework is a lens which perceives conceptions of the nature of scientific inquiry as a continuum ranging from empiricist through mixed to constructivist perspectives. The unidimension framework has its foundation in two schools of thought, the empiricist and the constructivist philosophies. According to Pomeroy (1993), the empiricist stance presumes that scientific knowledge can be discovered through observation, experimentation or application of a universal scientific method. To Tsai (2000), the constructivist stance posits that scientific knowledge should be seen as contracted tentative reality. The latter view (constructivist) is preferred by researchers who adopt the unidimension framework because they assume views of the nature of scientific inquiry as rather single components (Hammer & Elby, 2002) of stable personal epistemology. Closed form instruments and statistical analysis methods are used by researchers who employ the UD framework. The questionnaire-instruments mostly comprise of bipolar agree-disagree statements on a 5-point Likert scale for both non-traditional (constructivist) and traditional (empiricist) views of the nature of scientific inquiry. High scores indicate constructivist views, whereas low scores point to the empiricist views. Looking at the research questions posed by this study, the methodological

approach employed and research methods (instruments for data collection); the unidimension framework was found inappropriate because the framework does not describe robustly learners and teachers NOSI conceptions from this thesis's perspective. Furthermore, the instruments (probes instrument and LUSSI questionnaire) employed for data collection in this thesis go beyond eliciting views using an empiricist or constructivist stance given that they are structured in a different way compared to instruments usually utilized by unidimension researchers. Regardless of the unidimension framework's strength that it allows quick assessment of an individual's conception of the NOSI, the unidimension framework conceives views of the nature of scientific inquiry as properties of an individual that are independent of the context. This becomes a problem in that contexts vary and are detrimental to a person's views or perceptions, conceptions, preconceptions, dispositions and convictions of the scientific process and enterprise. Perceiving responses to the survey items as a reliable representation of individuals' conceptions of the NOSI in all but different contexts is problematic in that it might not be true. The unidimension framework's treatment of NOSI conceptions is therefore too simplistic and an overgeneralization of reality hence inappropriate for this study.

The argumentative resource (AR) framework

The *argumentative resource* (AR) framework is another lens which can also be used to analyze NOSI conceptions. The argumentative resource framework posits that conceptions of the nature of scientific inquiry should be seen as discursive achievements (Roth & Lucas, 1997) that are illustrated through argumentative resources drawn in practice. The focus on whether learners argue scientific claims in an appropriate manner rather than whether they possess informed declarative knowledge of the NOSI is the foundation in which argumentative resource framework is grounded. The source of the interpretations from which the AR framework has its roots is two-fold. First, Gilbert and Mulkay (1984) content that the term argumentative resource can be treated as interpretative repertoires (IR) which has its origins in pioneering sociological studies. The concept of interpretative repertoires has later been developed in some forms of discourse analysis (Potter &

Wetherell, 1987) as both a theoretical and analytical process. Second, term argumentative resource can be interpreted as a *grasp of practice* (GOP) (Deng, et al., 2011). The *grasp of practice* can be defined as knowing how to produce coherently acceptable claims. This practice is in line and consistent with other sociocultural learning theories such as internalization (e.g., Vygotsky, 1978) and enculturation (Rogoff, 1990) that emphasize the dynamic interactions between an individual and his or her social environment. Interview and observation methods are used by researchers who employ the argumentative resource framework. Most argumentative resource framework researchers treat language as a cultural tool. According to Rortry (1989), language mainly constitutes, maintains and reconstitutes reality rather than represent it.

Again, looking at the research questions posed by this study, the methodological approach employed and research methods (instruments for data collection); the argumentative resource framework was found inappropriate because this thesis is exploratory and as such it was not known whether there was argumentation at all in the science classrooms on how science works. Furthermore, when analyzing data, argumentative resource researchers concentrate more on how the discourse is constructed rather than the content of the discourse itself. This is not the focus of this thesis. Regardless of the argumentative resource framework's emphasis on the role of context in informing an individual's views of the NOSI, this thesis's focus is not on discourse construction but on an individual's conceptions of the NOSI in relation to instructional practice. Thus the argumentative resource framework was found inappropriate for use in this thesis.

The multidimension (MD) framework

The third framework which can be used as a lens to categorize an individual's conceptions of the NOSI is the *multidimension* (MD) framework. As discussed in Chapter 1, the MD framework advocates that an individual's conceptions of the NOSI consist of multiple dimensions. An examination of different dimensions of individuals' conceptions of the NOSI can be done in relation to constructs such as the learning of science, instructional

practice and implementation of various curricular using the MD framework. Various studies utilizing the MD framework have stressed various dimensions. Commonly investigated dimension include: (1) theory-laden nature of science (e.g., Liu & Tsai, 2008), (2) nature of and distinction between observation and inference (Ackerson & Donnelly, 2010; Kim & McKinney, 2007); (3) imagination and creativity in science (e.g., Tsai & Liu, 2005b); (4) socially and culturally embeddedness of science (Constantinou, Hadjilouca, & Papadouris, 2010); (5) nature of scientific methods (e.g., Dogan & Abd-El-Khalick, 2008) among others. In depicting views of the NOSI that do not satisfy natural curriculum documents, some MD framework researchers have used term misconception (e.g., Afonso & Gilbert, 2010). Some MD framework researchers have used the conceptual change model to design curricular interventions for the purpose of changing learners' *incorrect* views of the NOSI to the correct one (Hsu & Roth, 2010). The MD studies unlike the unidimension framework rely less solely on closed form instruments and statistical analysis. Instead, the roles of both data triangulation and method triangulation have gradually been underlined. Among MD studies, three formats of instrumentation have been used for data collection namely; closed form instruments (e.g., Likert scale and multiple choice questionnaire), semi-open form instruments (e.g., multiple choice questionnaire with self generated options), and open form instruments (e.g., open-ended questionnaire, interviews, essay). In their review of studies on the NOS and NOSI, Deng et al. (2011) found that very few MD studies, 11 investigations out of 85 (13%) (e.g., Liang, Lee, & Tsai, 2010) have relied solely on closed form instruments. The argument is that closed form instruments may fail to capture the respondent's real perspective that may be distinct from those predesigned options. Looking at the research questions posed by this study, the methodological approach employed and research methods (instruments for data collection); the MD framework was found appropriate because it allowed use of semi-open form instruments combined with instruments from other formats as opposed to close instruments only. Semi-open form instruments usually provides sets of alternative respondent position statements and sometimes an additional *others* option to capture viewpoints beyond the instrument.

A further look at the research instruments employed in this study to elicit NOSI conceptions shows that six dimensions are contained in each of the instruments. These include the five dimensions stated in the preceding paragraph investigated by other MD researchers. This study however named the dimensions *tenets*. Tenets operationalized here as the ideas, principles, opinions or doctrines about the scientific process and enterprise generally believed or held to be true by members of the science education community. According to Bell (2006), the tenets/dimensions can be conceptualized as a continuum from positivist/empiricist to constructivist/relativist perspectives; this conceptualization was adopted in this study. Usually, positivist/empiricist conceptions are labelled as naive or inadequate views, whereas the constructivist/relativist views are labelled as informed or adequate. This was adopted with the view that holding empiricist views does not mean one is naive as commonly stated in literature. In addition, since the MD framework treats conceptions of the NOSI as a system of more-or-less independent dimensions, this gave again an avenue of looking at the data and how the dimensions were going to be analyzed. To Deng et al. (2011), a large number of MD studies (55%) have used both qualitative and quantitative measures of data collection and analysis. Given that this study falls within the mixed method exploratory realm, the MD framework became relevant. One limitation of the MD framework is that it posits that individuals possess relatively stable conceptions of the NOSI that may be expressed coherently across different contexts. To ensure that analysis was credible and valid, the researcher used a triangulation of research methods, moving into science classrooms to assess if individuals' conceptions (learners and teachers) were not affected by situational factors such as the nature of learning context (see, e.g., Khishfe & Lederman, 2006), the roles of teachers (see, e.g., Meichtry, 1992) and the interactions among learners and teachers (see, e.g., Bell, et al., 2003). Thus the MD framework was adopted as an analytic lense by this thesis.

2.5 Teacher instructional practices as forms of inquiry

In attempting to give meaning to the concept of *instructional practice*, it is rational to give a description of the term *instruction*. Historically, instruction has been viewed as a set of

components used to support the internal processes of learning (Hodges, 1980). In their book *Principles of Instructional Design*, Gagne and Briggs (1974, p.135) define instruction in this manner:

> In making progress from one moment to the next during a lesson, a set of events takes place which acts upon the student, and in which he becomes involved. The set of events is specifically meant by "instruction". These are the events that are usually external to the learner, supplied by the teacher, or text, or other materials with which the learner interacts.

The definition implies that instruction encompasses the whole process of planning, communicating information to the learners and stimulating relevant learning activities. The term *instruction* has been used synonymously with *teaching* (Bruner, 1966). To Eze (2011), teaching is the *how* and the *way* that the curriculum is taught. A teacher can deliver instruction in ways that make it approachable by all learners. Teaching is the personal skills and professional preparation demonstrated by the *who* in the equation, the teacher. The teacher uses the curriculum to design the instruction that, hopefully, causes learners to learn. Sometimes it is the other way around. The definition by Gagne and Briggs (1974) suggests that instruction should be taken to mean all that is done by the teacher during the teaching and learning process 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 (Visser, 2007). Instruction can take place in the absence or presence of the individual called a teacher. This conception of teaching accepts that teaching is part of instruction and instruction is the broader and more encompassing concept. Taken in this sense, the presence of the teacher becomes a pre-requisite for the occurrence of teaching (Schwier, Campbell, & Kenny, 2004).

Pertinent review of literature in science education (Tsai, 1999; Vhurumuku, 2011; Wetzel, 2012; Windschitl, 2004) suggests that the concept *instructional practice* is in itself indefinable. The concept *instructional practice* has been associated with the terms strategy, approach, style, method, skills and technique. The terms approach, strategy technique and

method sometimes overlap. In some instances the terms can be adapted to refer to teaching styles and/or skill. This is also problematic. In this study, the terms are used synonymously, bearing in mind that each one might take an idiosyncratic distinction depending on context. Instructional practice is a summation of what the teacher does and what the learners do during the teaching and learning of investigation. This includes: source of problem for practical investigation(s); the open-endedness of tasks or activities (degrees of freedom given to learners to make decisions; how the teacher gives out instructions and other information; nature of learner–learner interactions; nature of learner– teacher interactions; how learners recorded information; group activities including group discussion, if any; pre- and post-laboratory activities; what was expected of learners' reports; how learners made observations; how learners interpreted data; skills and techniques displayed by the learners.

Instructional practice for science teaching in this case implies teachers being able to craft a large repertoire of teaching methods, strategies, approaches, techniques, styles, and so forth, into their daily practice for learners to experience scientific inquiry. The connection is that what the teacher does in planning and executing instruction is a determinant of learners experiencing scientific inquiry. Instructional practice is about the teacher's use of various methods or approaches or styles or techniques to determine if inquiry is closed or open-ended. At the end of the day, if learners ask/frame research questions, design investigations, conduct investigation, collect data and draw conclusions from investigations, then they have experienced inquiry within the cognitive and epistemological boundaries of school science. Given the above attributes: instructional practice can be defined as: What the teacher does and what the learners do before, during and after Chemistry practical investigation sessions in order for learners to experience scientific inquiry as stipulated by the NCS for Physical Sciences.

2.5.1 Teaching as scientific inquiry

There has been a tendency to treat inquiry teaching as if it were something new and innovative, as well as a recently invented approach to science teaching. But in one form or another, inquiry teaching has been part of the educational landscape since time immemorial

(Bybee & DeBoer, 1994; Deboer, 2001, 2006). Aristotle saw inquiry as a persistent examination of the nature of the mind. Aristotle, the founder of formal logic believed that abstract knowledge was possible but it was *a posterior* (obtained from experience). Thus Aristotle's philosophy is the root of empiricism. To Aristotle, knowledge could be deductively obtained from experience in accordance with the rules of logic. According to Malhotra (1994), Aristotle encouraged the teacher to lead the student systematically. This was the beginning of inquiry teaching. Bybee (2006) refers to *teaching as inquiry* as the pedagogical approaches that model aspects of scientific inquiry. In his description of inquiry teaching, Bybee alludes to the fact that inquiry teaching mirrors scientific inquiry by emphasizing learner questioning, investigation and problem-solving. Just as scientists conduct their inquiries and investigations in the laboratory, at field sites, in the library and in discussion with colleagues, learners engage in similar activities in inquiry-based classrooms (Deboer, 2006).

The NSES is of the view that the term *teaching as inquiry* has no precise operational definition but does contain some specific teaching examples which refer to authentic questions generated from learner experiences and is the central strategy for teaching science (Anderson, 2002). This is rather a broad, process-oriented, definition of teaching as inquiry which includes both the products and processes of science. Because of varied conceptions of teaching as inquiry, it sometimes has led to confusion about what teaching as inquiry is. A couple of questions are raised: Does teaching as inquiry suggest a pedagogy that is modelled after the investigative nature of scientific inquiry or does it suggest a content to be studied, that is, the nature of scientific inquiry? An attempt to briefly give answers to the above questions leads to the literal examination of the terms *inquiry teaching* and *teaching about inquiry*.

The two terms *inquiry teaching* and *teaching about inquiry* do not go hand-in-hand. According to Anderson (2002), just because scientific inquiry is the thing being studied does not mean that inquiry teaching is being practiced. Science educators believe the nature of scientific inquiry can be taught in very non inquiry-oriented ways (Anderson, 2002;

Chambers, 2002; Lederman, 2008b). Anderson asserts that teachers can provide learners with examples of scientific investigations and explain the logic of these studies and show learners how evidence was used to answer the question being raised in inquiry. In addition, teachers can introduce the language of scientific inquiry by describing the differences between theories, hypothesis, evidence, conclusions, observations and inferences. All of these can be accomplished using traditional, teacher-directed methods. However, through use of inquiry-oriented activities, teachers can introduce the methods of science and learners can develop an understanding of the processes of science by engaging in actual scientific inquiries as science is practised by scientists. The truth of the matter is inquiry teaching and teaching about scientific inquiry are not necessarily one and the same thing hence using the term inquiry teaching for both of them often leads to hubbub. This section on definitions is concluded by operationalizing the term *teaching as inquiry* as referring to the use of general processes of scientific inquiry and its teaching methodology.

Prior to the 1960s, the direction of science education in the United States had been centred on the teaching of facts, concepts and principles through didactic expository instruction rather than an inquiry-based approach (Bianchini & Colburn, 2000; Eltinge & Roberts, 1993; Pugliese, 1973; Rakow, 1986b). Teacher-talk and textbooks were the primary sources of science information provided to learners. Laboratory work was used in order to illustrate and confirm science concepts presented in textbooks. In 1962, Joseph Schwab was more concerned with learners developing habits of inquiry and emphasized, instead, using inquiry as a mode of teaching to portray science as inquiry. He described a number of potential instructional approaches in his essay, *The Teaching of Science as Enquiry*—his classic and most comprehensive treatment of the inquiry approach. In Schwab's ideal classrooms,

> … students would be led to dissect the textbook and lectures, to look for evidence for the validity of the claims of others, and to be active in a process of analysis. The teacher's job in such a classroom changed from one of presenting information and explaining concepts to one of teaching learners how to ask questions, how to look for evidence, and how to evaluate the results of their enquiries...[DeBoer, 1991, p. 165].

To Schwab, this was teaching as inquiry. As an instructional approach, teaching as inquiry has been characterized in a variety of ways over the years (Collins, 1987; DeBoer, 1991; Rakow, 1986a) and promoted from a variety of perspectives. Some have emphasized the active nature of learner involvement, associating inquiry with *hands-on* learning, experiential or activity-based instruction, and inquiry-based teaching (Scheppler, Styer, Dosch, Traina, & Kolar, 2009). Others have linked teaching as inquiry with a discovery approach or with development of process skills associated with *the scientific method* (Hackett & Pratt, 1998). Though these various concepts are interrelated, inquiry-oriented instruction is not synonymous with any of them. Novak (1964, p.21) suggests, "Inquiry is the [set] of behaviours involved in the struggle of human beings for reasonable explanations of phenomena about which they are curious". From a science perspective, inquiry-oriented instruction engages learners in the investigative nature of scientific knowledge. Teaching as inquiry involves activity and skills, but the focus is on the active search for knowledge or understanding to satisfy a curiosity. Thus, a focus on teaching as inquiry should always involve collection and interpretation of information in response to wondering and exploring.

Teachers can best practice *teaching as scientific inquiry* when teaching scientific investigations. Garnett, Garnett and Hackling (1995, p.27) describe a science investigation as “a scientific problem which requires the student to plan a course of action, carry out the activity and collect the necessary data, organize and interpret the data, and reach a conclusion which is communicated in some form”. The definition by Garnett et al. (1995) delineates three phases in investigations namely the beginning or planning phase, the doing phase and the concluding phase. An additional phase relating to data processing is found on the *Working Scientifically* strand in Western Australian science curriculum. According to Hackling & Fairbrother (1996), the Western Australian science curriculum contains four sub-strands; planning investigations, conducting investigations, processing data, and evaluating findings. The planning component and the problem solving nature of the task distinguish investigations from other types of laboratory work. The planning phase serves

three main functions: it guides the learners through a sequence of decision-making steps, thus scaffolding their work; by scaffolding learner work it reduces the management load of the teacher; and the questions elicit information from the learners about their thinking and doing, so the written record of learners' work becomes valuable source of data for the teacher to use for formative and summative assessment (Education Department of Western Australia, 1994). As mentioned in Chapter 1, scientific investigations in the South African NCS for Physical Sciences are modelled along these same lines. The problems of these scientific investigations can be real or artificial. A real problem has no known or standard answer, an artificial problem has an answer but the learners do not know it although the teacher does. This distinguishes investigations from other types of laboratory work.

Using scientific investigations to teach about the nature of scientific inquiry is just one of the many ways in which scientific investigations can be utilized in school science. It is important to remember that in school science, scientific investigations can be used for a variety of purposes including; developing an understanding of scientific knowledge and developing science process skills such as manipulation of apparatus, observing, formulating problems and designing procedures. Teaching as scientific inquiry, therefore, is about the teacher organizing investigative activities during which learners are provided with opportunities to engage in sub-processes of inquiry: asking/framing questions; designing investigations, conducting investigations, collecting data and drawing conclusions. In a nutshell, teaching as inquiry is a process of active exploration during which learners use critical, logical, and creative thinking skills to raise and engage in questions of curriculum relevance.

2.5.2 The forms and types of inquiry

In the previous section teaching as scientific inquiry was discussed. It is logical to ask the question what could be a conceptual framework for data analysis for research involving this concept? A brief examination of typical forms and types of inquiry can provide some answers.

Both teacher and learner activities during learning in which scientific investigations are involved can be described as either *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 gleaned from literature on science education and laboratory work associates closed inquiry with verificationistic laboratories with a frequency of such activities as; teacher lecturing to the class or to groups of learners; low levels of learner– learner and learner–teacher argumentation; and having the outcome of experiments known prior to the investigation. Teaching of investigative activities is also described as closed or low-inquiry-oriented if the teacher asks learners to follow step-by-step instructions; answer specific questions; be passive recipients of information; and use teacher and textbook explanations for observed phenomena (Vhurumuku, 2011). Closed inquiry is based on the philosophy that knowledge can be transferred from the teacher to the learner.

The various teaching approaches or styles used in science, such as, demonstrations, guided discovery, problem solving and open-ended investigations can be located along the surfaces of a continuum whose poles are *closed inquiry* oriented to *open ended of inquiry*. In *demonstrations*, the teacher or the learner (s) handle or manipulate of laboratory equipment apparatus and/or materials and make observations mainly for purposes of illustrating some theoretical or practical phenomena. Because in most science lessons demonstrations are largely teacher centred and verificationistic, the extent to which learners can experience inquiry is limited. This is in spite of the fact that during demonstrations, teachers can provide learners with opportunities to think critically by asking questions that encourage thought and use of prior knowledge (Hanson & Wolfskill, 2000). In *guided discovery*, also called guided-inquiry, learners are led to an understanding of scientific 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, learners are led to "discover knowledge or new concepts".

To Domin (1999), *problem solving* differs from discovery in that in problem solving learners make use of the knowledge they have acquired whereas in discovery learners acquire knowledge. While the discovery approaches have learners' 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 learners is kept minimal. In most laboratory situations, the teacher already knows the solution to the problem. The laboratory is seen as a place where learners can learn the scientific processes of problem solving, observation, hypothesizing, manipulation, interpretation, etc. (DeBoer, 1991; Hodson, 1996). Whereas in problem solving the outcome of the experiment or exercise is normally predetermined that outcome is undetermined for more *open-ended investigations*. For both approaches however the procedure for carrying out the experiment is determined by the learners. In open-ended investigations, learners are given greater freedom to ask questions, design and plan experiments and decide on how they are going to record, interpret and communicate results.

2.5.3 Determining levels of practices of scientific inquiry in the classroom

The practice of teaching as scientific inquiry can be described as those activities, approaches and strategies designed and executed by the teacher with the aim of promoting and developing learners' abilities and skills of *doing* inquiry (investigations) as well as their understandings of the NOSI. These practices are intricately linked to what the learners do as a result of the teacher's actions. In this regard, teaching practices are inseparable from *what learners do* in the classroom. In this thesis, the degree or extent to which a teacher practices scientific inquiry is judged by considering the latitude given to learners to: ask or frame questions for investigation; design and conduct investigations; collect their own data; interpret results; and the draw their own conclusions. The wider this latitude is the more *open-ended* the teaching practice and the greater the *extent of inquiry*.

Not all inquiry activities are created equal. This body of scientific research (Schwab, 1964; Herron, 1971; Chinn & Malhotra, 2002; Lederman, 2004; McComas, 2005; Fay, et al., 2007) has clearly established that not all inquiry-related laboratory activities are equivalent. Schwab in 1964 was the first to describe the concept of different levels of inquiry (Bell, Smetana, & Binns, 2005). Later, Herron (1971) identified three levels of openness for inquiry in science investigations. The three levels were level 1 (structured inquiry), level 2 (guided inquiry) and level 3 (open inquiry). The nature, form and extent of inquiry in the common laboratory instructional styles, approaches or practices were aptly captured in the 1970s by Rezba, Auldridge and Rhea (1999) who developed a four level model tool for determining the level of inquiry promoted by a particular investigation based on the work of Schwab and Herron. Known as the Herron's scale, the assessment tool is based on a very simple principle: How much information is *given* to the learners by the teacher or activity (Herron, 1971). In 1986, Hegarty-Hazel adapted the Herron's scale. To characterize the open-endedness of inquiry for the five teachers' practices; this thesis adopted a model by Hegarty-Hazel (1986). The model describes the extent of open-endedness of inquiry along a four scale continuum ranging from: level 0 -confirmation/ exploratory; level 1 -structured inquiry; level 2 -guided inquiry; and level 3 -open-ended inquiry. According to this model, the higher the level of inquiry, the greater the latitude given to the learners to be "in charge" of investigations. The choice for this model for this study is based on the premise that other models (e.g., Banchi & Bell, 2008; Bell, et al., 2005; Lederman, 2009), do not discriminate between level 2 of inquiry (guided inquiry) but instead conflate it. The model by Hegarty-Hazel (1986) has the advantage that it elaborates level 2 by dividing it into levels 2a and 2b, thus simplifying the discrimination between the levels of inquiry. For level 2a, the apparatus are given whereas the apparatus are not given for level 2b. This is crucial as it points to the explicitness of the type of inquiry being practiced in a given classroom. For both levels 2a and 2b, the teacher provides the problem for the investigation but the procedures and answers are open. Thereafter everything else is the similar with other models.

Given the description and arguments on teachers' instructional practices, like other studies (Flick, 2000; Keys & Bryan, 2001), this study focused on this aspect arguing that there are few research studies that actually examine teachers' instructional practices in inquiry classrooms. This study is one among the many aiming to make progress in promoting learner inquiry; since science education needs to develop a better understanding of productive teacher practices in natural classroom settings through rich detailed case studies of instructional practices.

2.6 Learning as scientific inquiry

Learning as scientific inquiry is a philosophy that dates back to Socrates and has its roots in the West. The philosophy is evident in the works of John Dewey, Lev Semenovich Vygotsky, Jean-Jacques Rousseau, Giambattista Vico and Jean Piaget (Benson & Bruce, 2001). By definition, *learning as scientific inquiry* sometimes referred to as *inquiry-based learning* is a form of learning in which the teacher acts as *a guide on the side* rather than *a sage on stage* (Fall, 2011). To Chambers (2003), learning as scientific inquiry is a natural human activity in which the learner obtains meaning from experience. De Jong and van Joolingen (1998) assert, *learning as scientific inquiry* is as an educational activity in which learners individually or collectively investigate a set of phenomena-virtual or real—and draw conclusions about it. De Jong and van Joolingen suggest that learners direct their own investigatory activity, but they may be prompted to formulate questions, plan their activity, and draw and justify conclusions about what they have learned. For the reason that learners are engaged (Anderson, 2002), learning as scientific inquiry has proven to be a powerful tool in the classroom and in keeping wonder and curiosity alive in learners(Campbell, et al., 2010; Chambers, 2003; Minstrell & van Zee, 2000).

Resnick and Nelson-LeGall (1997) assert, learning as scientific inquiry is a strong educational process and tool given that learners come to understand that they are able to acquire knowledge they desire, in virtually any content domain, in ways that they can initiate, manage, and execute on their own, and that such knowledge is empowering. This outcome is believed to justify the time devoted to development of these skills and

dispositions within the context of what is typically a circumscribed topic of investigation. To some, learning as scientific inquiry as an educational tool has disadvantages. As Saunders (1992, p.139) puts it, the disadvantage of learning as scientific inquiry is:

> ... in the investigative or inquiry lab, the learner is much more likely to be immersed in an environment rich with opportunities that evoke disequilibration (confusion & questioning) and hence give rise to the potential for cognitive restructuring (changing one's mind...

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). In such contexts, learning is most likely to occur if there is compatibility of prior and the new knowledge making new knowledge useful for learners. Constructivists (Fosnot, 1996; Osborne & Freyberg, 1985) believe this is not a disadvantage but a strength in that learning as scientific inquiry occurs in contexts in which the new knowledge is useful for learners. Learners ideally also acquire a set of intellectual values—values that deem activities of this sort to be worthwhile in general and personally useful.

As can be seen, this is constructivism or at least a form of it. Learning as scientific inquiry has been associated with constructivism (Libman, 2010; Lorsbach & Tobin, 1992; Tobin & Tippins, 1993; Windschitl, 2004) and both have relevance to Piaget and Vygotsky's theories of learning. Piaget's cognitive constructivism theory and Vygotsky's social constructivism theory have significant relevance to modern learning as scientific inquiry theory. Piaget (1970) believes that children learn through personal interactions with physical events and objects in their daily lives. Learning as scientific inquiry provides

opportunities for learners to experience scientific phenomena and processes directly. These direct experiences challenge deeply entrenched misconceptions and foster dialogue about new ideas, moving learners closer to scientifically accepted explanations. Piaget felt the classroom setting should provide many opportunities and practical activities that challenge a learner's prior conceptions and encourage them to reorganize their personal beliefs and theories. It is essential for learners to investigate their environment and eventually work out problems for themselves for inquiry learning to succeed. Learning is also mediated by the social environment in which learners interact with others. Vygotsky (1978) believed children learn through interactions and dialogues when engaged in socially mediated activities. This belief goes beyond the idea that *two heads are better than one*. As is true for scientists, learners do not construct their understanding in isolation. They test and refine their thinking through interactions with others. Simply articulating ideas to another person helps learners realize the knowledge they feel comfortable with and the knowledge they lack. By listening to other points of view, learners are exposed to new ideas that challenge them to revise their own thinking. Although Vygotsky felt a major social interaction should be between an expert and the learner, the teacher is there to nurture the buds, and help the learners find answers for themselves.

In 1985, Project 2061 was inaugurated by F. James Rutherford (American Association for the Advancement of Science, 1993). Project 2061 is a long-term initiative of the American Association for the Advancement of Science (AAAS) to reform K-12 education (Bybee, 2000). According to Lee (1998), Project 2061 organizes programmes that have made significant statements about learning as scientific inquiry. Rutherford's observations and recommendations presaged in 1964 the place Project 2061 assigns to the nature and history of science and that which it sets for habits of mind. The principal components of inquiry were defined in a chapter on *Effective Learning and Teaching*, prepared by *Science for All Americans* making the general recommendation, "Learning Should Be Consistent with the Nature of Scientific Inquiry," followed by specific advice below:

- Start with Questions About Nature

- Engage Students Actively
- Concentrate on the Collection and Use of Evidence
- Provide Historical Perspectives
- Insist on Clear Expression
- Use a Team Approach
- Do Not Separate Knowing From Finding Out
- Deemphasize the Memorization of Technical Vocabulary (Rutherford, 1989, pp. 147-149).

This description of inquiry has the weakness of being too broad and almost captures all that is described under specific results of learning about the nature of scientific inquiry, gaining historical perspectives, and acquiring good habits of mind (Bybee, 2000). Project 2061 also set in place goals and specific benchmarks for teaching scientific inquiry as content. Bringing this initiative closer home, the South African NCS for Physical Sciences was specific about the activities which learners should engage in during scientific investigations so as to learn scientific inquiry. Five essential features of classroom inquiry spelling out what learners should do include: (a) engaging in scientifically oriented questions; (b) giving priority to evidence, thereby allowing them to develop and evaluate explanations that address scientifically oriented questions; (c) formulating explanations from evidence to address scientifically oriented questions; (d) evaluating their explanations in light of alternative explanations, particularly those reflecting scientific understanding; and (e) communicating and justifying their proposed explanations (Department of Education, 2005). These are the same features of classroom inquiry promulgated by the National Research Council in the year 2000. In formulating questions, accessing and interpreting evidence, and coordinating it with theories, learners are believed to develop the intellectual skills that will enable them to construct new knowledge (Chan, Burtis, & Bereiter, 1997).

The five essential features of classroom inquiry can be used to investigate the extent to which learners are engaged in scientific inquiry. Instruments have been developed to assess both learner and teacher perceptions of classroom inquiry. Campbell et al. (2010)

developed two instruments, the Principles of Scientific Inquiry-Student (PSI-S) and the Principles of Scientific Inquiry-Teacher (PSI-T). These two instruments were both adopted and adapted in this study to determine teacher and learner perceptions of inquiry experiences in science classrooms. This sub-section is concluded by discussing how the one of the instrument (Learner Perception of Classroom Inquiry (LPCI) Questionnaire) was adapted as an analytic tool to elicit the perception of learners' experiences during scientific investigations. The LPCI instrument is an adopted Campbell et al.'s (2010) PSI-S instrument. The response alternatives on the five-point bipolar Likert scale ranging from (1) never occurred (2) seldom, (3) sometimes, (4) often to (5) almost always are allocated scores from 1, 2, 3, 4 to 5, respectively. Scoring is done in reverse for statements representing non-inquiry or closed-inquiry laboratory. Open-ended inquiry is represented by high scores (maximum = 100) and laboratory work which is verificationistic, expository, or closed inquiry is reflected by low scores (minimum = 20). The rankings given to the statements by each class are used to categorize the type of laboratory they experienced into verificationistic, structured, guided inquiry or open-ended inquiry. As an example, learners exposed to more open-ended laboratory work are expected to rank a statement like *I actively participate in investigations as they are conducted* very highly, and those in low-inquiry laboratories to rank a statement like *I am given step-by- step instructions as I conduct investigations* very highly. By so doing perceptions of learner experiences when doing scientific investigations are determined. At the same time, teacher practices when teaching investigations are established.

2.7 Studies on teachers' and learners' conceptions of NOSI

Because of the conflation of NOS and NOSI that exists in the research literature, most of the studies reported here are those which do not separate the two constructs. Very few studies have specifically focused on NOSI only. This is despite the fact that there is a lot of literature on both inquiry and on NOSI.

Research on teachers and learners NOS and NOSI conceptions started in the mid 1950's (Lederman, 1992). This research has fallen into two major strands namely: assessing

teachers' and learners' conceptions of NOS and NOSI; and developing teachers' and learners' conceptions of NOS and NOSI. Generally, this research has revealed that in most parts of the world most secondary school learners' habour naive and inadequate conceptions of both the NOS and NOSI (Abd-El-Khalick & Lederman, 2000a, 2000b; Lederman, 1992; Lederman, 2007a; Rubba & Anderson, 1978). Studies have also shown that many teachers habour naive and inadequate conceptions of both NOS and NOSI (e.g., Abd-El-Khalick, 2002; Kang, Scharmann, & Noh, 2004; Lederman, Abd-El-Khalick, et al., 2002; Linneman, Lynch, Kurup, Webb, & Bantwini, 2003; Sutherland & Dennick, 2002; Zeidler & Lederman, 1989). Results of these studies give an overall picture that the majority of science teachers and their learners view scientific knowledge as immutable truth, possess absolutist viewpoints, have little, if any, formal exposure to NOS and/or NOSI. However, the results of some studies (for example, Liang, et al., 2006; and Miller, Montplaisir, Offerdahl, Cheng, & Ketterling, 2010) show that some learners may harbour informed NOSI conceptions (Abd-El-Khalick, 2006; Abd-El-Khalick & Lederman, 2000b; Abd-El-Khalick, Randy, & Lederman, 1998) whilst others have the transitional conceptions. A transitional conception is when an individual's views of the NOSI are showing development from being naive to being informed.

Studies on developing teachers' and learners' NOS and NOSI conceptions generally support the view that these conceptions can best be developed using explicit rather than implicit approaches (Abd-El-Khalick & Lederman, 2000b; Lederman, 1992; Lederman, 2008b). Curriculum and instructional approaches are described as explicit when the subject content, teaching methodology and learner assessment deliberately aim to develop learners' NOS and NOSI conceptions (Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001; Liang, et al., 2008). Learners are taught about the NOS and NOSI. Their conceptions are formally assessed. This is in contrast to implicit approaches where learners' conceptions are assumed to develop as a secondary product of instruction. There is no deliberate effort to teach and assess learners' conceptions about the NOS and NOSI. It is assumed that by being involved in science (practicing science) learners can develop *adequate* or *desirable* conceptions of the nature of scientific knowledge and the scientific process and enterprise.

Methodologically, there has been a shift in paradigms regarding the approaches used to assess both teachers' and learners' conceptions of the NOS and NOSI. In early studies, (up to the late 1970s) use of quantitative instruments dominated. Examples of such instruments include: the Science Process Inventory (SPI) (Welch & Pella, 1967), Nature of Science Scale (NOSS) (Kimball, 1967-68), and the Nature of Scientific Knowledge Scale (NSKS) (Rubba, 1977). Many of the studies reported in the literature up to the mid 1980's have used these instruments or their adaptations or variations. The use of these convergent types of instruments to assess beliefs or conceptions of NOS and/or NOSI has come under a barrage of criticism (Bezzi, 1999; Chan, 1999a; Haidar & Balifakih, 1999; Lederman, 1992; Lederman, Wade, & Bell, 2000; Rennie, 1998). Rennie (1998), for example, has pointed out that quantitative results have not been of much educational value because statistical figures cannot easily answer questions requiring qualitative answers- issues to do with human thinking and behaviour. This criticism has partly been responsible for the increasing popularity (since the early 1980s) of qualitative methodology in NOS and NOSI studies. Today, while most researchers are using qualitative approaches, some are combining quantitative and qualitative approaches (see, Lederman, 2008b). In this study a combination of quantitative and qualitative approaches was used. What follows is a critical appraisal of some examples illustrating major points highlighted above.

Kang, Scharmann and Noh (2004) investigated the views of scientific inquiry held by 6th, 8th, and 10th grade learners in South Korea. Data was collected through a Likert type questionnaire. The questionnaire consisted of five items that assessed learners' views on five nature of science and scientific inquiry aspects namely; the purpose of science, definition of scientific theory, nature of models, tentativeness of scientific theory, and origin of scientific theory. In responding to the questionnaire, the learners were also required to justify their response to an item. The results of the study showed that on the explored nature of scientific knowledge aspects, the majority of the learners harboured empiricist/absolutist views. These findings were consistent with earlier studies (Cotham & Smith, 1981; Gilbert, 1991; Lederman, 1986a; Lederman, 1986b; Lederman & O'Malley,

1990) which showed that learners harboured naïve views about scientific knowledge. The methodological approach employed in this reported study approaches data interpretation via a deductive framework by evaluating learners' conceptions with what the researchers call a worldly perspective (Aikenhead & Ryan, 1992). Evaluating the *correctness* of learners' conceptions in this way could be problematic because as mentioned in Chapter 1, the philosophical positions of the researchers are likely to colour their interpretation (Southerland, Smith, Sowell, & Kittleson, 2007). Recently Allchin (2011) criticized evaluating NOSI conceptions in the manner Kang, Scharmann and Noh did. Allchin argues that this categorization is too simplistic and treats individuals' NOSI conceptions as fragmented. Thus such kind of assessment is declarative. This study goes beyond evaluating learners' and teachers' conceptions of NOSI as declarative but interpretive. Instead, the study utilizes a multidimension (MD) framework which acknowledges individuals' conceptions as more-or-less independent dimensions. In this manner, the framework utilized by this thesis acknowledges learners' and teachers' NOSI conceptions may not develop coherently and that correlations among dimensions are not ruled out. Of importance is the context in which learners' and teachers' conceptions of the NOSI are evaluated which the study by Kang et al. did not do.

A study by Koksal and Cakiroglu (2010) on examining science teacher's understandings of the NOS and NOSI aspects through the use of knowledge test and open-ended questions in Turkey showed existence of some misunderstandings on the NOS and NOSI. The participants' responses to knowledge test and open-ended questions gave similar pattern in terms of ten aspects of NOS, except for three aspects they were assessed on. Koksal and Cakiroglu found that most of the sampled teachers held what they called traditional views (empiricist or logical positivist, e.g. scientific knowledge is based on evidence and observation) about the nature of science and scientific inquiry. The same study showed that analysis of participants' answers to the open-ended questions showed that majority of the teachers hold naïve views regarding "no universally accepted one way to do science" (73%) and "roles of theories and laws" (68%) aspects whereas they were in transitional position regarding "creativeness and imagination"(41%) aspects of the NOSI. 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. The results of the study showed that science teachers had many naive understandings about the aspects of the NOS and NOSI. They had the most extreme naive understandings regarding relationship between theory and law consistent with findings from other studies (Abd-El-Khalick, 2006; Lederman, 2007; Lederman & O'Malley, 1990). Similar findings were found by Miller, Montplaisir, Offerdahl, Cheng and Ketterling (2010) who in their study of undergraduate students addressing six aspects of the NOS and NOSI showed notably uninformed views of the distinctions between scientific theories and laws. The exploration constituting the present investigation is similar to the study by Koksal and Cakiroglu in that six out of ten aspects of the NOS and NOSI they examined are explored in this study using both teachers and learners.

An international collaborative study that investigated preservice teachers' views on the nature of scientific knowledge development with respect to six elements: observations and inferences, tentativeness, scientific theories and laws, social and cultural embeddedness, creativity and imagination, and scientific methods is the work of Liang et al. (2008). This project, based in the United States, China and Turkey Kingdom, used the survey, Student Understanding of Science and Scientific Inquiry (SUSSI). The survey instrument has a blend of Likert-type items and related open-ended questions (in an effort to address concerns of validity and reliability, and to be sensitive about not imposing the philosophical positions of the researcher onto the scoring criteria of the instrument) was used to gain a fuller understanding of the preservice teachers' views of the nature of scientific knowledge development. This is the same research instrument used in this study adopted from Liang et al. (2008). With regard to their analysis and findings, Liang et al. (2008) showed that even teachers did not possess adequate conceptions of the nature of science and scientific inquiry. The results showed that for Likert type items, the respondents' views were classified as naïve. The findings also confirmed the interdependency between certain NOS and scientific inquiry aspects. However, it must be pointed out that what Liang et al. (2008) are calling NOS and scientific inquiry aspects have been delineated in this thesis as only NOSI

aspects. Liang et al. (2008) reported that the preservice teachers' understanding of the "observation and inference" (theory-laden NOSI) aspect was correlated with their views of the "tentative," the "social and cultural embedded" nature of science, and methodology of science. Participants' views of the NOSI were influenced by their cultures including worldviews. Though this result is consistent with earlier findings (Cobern, 1989; Gallagher, 1991; Lederman & Druger, 1985; Lederman, 1986a; Ogunniyi, 1982), on its own, the instrument used by Liang et al. (2008) and related lines of research described above do not attempt to explicate learner thinking, nor does it help them identify common patterns in the way learners conceive the nature of scientific inquiry. However, their recommendation on further studies involving a variety of methods to assess whether the teachers are able to translate their understanding of the nature of science and scientific inquiry into learning opportunities for learners is among the many recommendations which gave birth to this study.

Philpot (2007) conducted a research project in Georgia, in the United States. An interpretive, qualitative, case study method was used to address the research questions specifically focusing on Science Olympiad learners' understanding of the nature of science and scientific inquiry. Data was collected using the Views of Nature of Science – High School Questionnaire (VNOS-HS) (Schwartz, et al., 2001), semi- structured individual interviews, and a focus group. To solicit understandings of the nature of science and scientific inquiry, the study used the following tenets: understandings of the tentative nature of science and the role of inferences in science, role of human imagination and creativity, the empirical nature of science, or theories and laws. Four of these tenets are explored in this thesis. The main findings of this study were similar to much of the previous research in the field of nature of science and scientific inquiry (Abd-El-Khalick, 2006; Lederman, 2007a; Lederman & O'Malley, 1990) in that the participants had informed understandings of the tentative nature of science and the role of inferences in science, but they did not have informed understandings of the role of human imagination and creativity, the empirical nature of science, or theories and laws. Another finding was that high level science classes and participation in Science Olympiad did not translate into informed understandings of

NOS and scientific inquiry. Philpot (2007) concluded that investigation work with a set procedure and given data tables did not contribute to informed NOS and scientific inquiry understandings, while explicit instruction may have contributed to more informed understandings. Philpot did not clarify the difference between aspects of the nature of science and processes that characterize science. This study describes scientific processes as activities related to the collection and interpretation of data and the derivation of conclusions, whereas aspects of the nature of science are distinctly separate because they are concerned with the values and assumptions underlying these activities. Philpot's findings point to the fact that explicit instruction during investigations may have contributed to more informed understandings as opposed to implicit instruction. This is an interesting finding which this study explores within the South African context depending on teacher practices of inquiry in science classrooms.

2.8 Studies on learner perceptions /experiences of scientific inquiry

Fraser (1998a) asserts that research on learners' perceptions/experiences of scientific inquiry falls within the realm of classroom learning environments research. Studies done on learners' perceptions of their experiences of the nature of scientific inquiry (Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005; Rop, 2003) suggest that some learners see being actively involved in asking and answering scientifically oriented questions as helpful to their conceptions of the nature of scientific inquiry. Some studies (Dillion, 2008; Ergül, et al., 2011; Hofstein & Lunetta, 2004; Hofstein, et al., 2005) found that engaging learners in scientific inquiry help them to improve their performance in science and even develop some skills that enable them to solve their daily science related problems. This is in line with authors (Haefner & Altoona, 2004; McComas, 2008) and curriculum documents (National Research Council, 1996) who assert that engaging learners in authentic science activities helps them to understand the nature of science and scientific inquiry even better. However, there are researchers (Aikenhead, 1973b; Bady, 1979; Bell, et al., 2003; Larochelle, 2007; Lederman, 1992; Lederman & O'Malley, 1990; Matthews, 1998c; Meichtry, 1992; Rubba, et al., 1981) who maintain that learners' experiences of scientific inquiry have nothing to do with their conceptions of the nature of science and scientific

inquiry. A common recommendation among these and other studies has been for educators to provide learners with opportunities to do science through either in-class science projects or extracurricular work with scientists (Bell, et al., 2003). Learners' classroom experiences thus, can be examined through a lens of the nature, form and extent of inquiry woven through the teaching and learning activities. Learners' 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, & McRobbie, 1995; Roth & Lucas, 1997; Tsai, 1998a; Tsai, 1999, 2003b). The perceptions can be taken as reliable indicators or determinants of actual classroom practices. Fraser (1998a) alludes to the use of teachers' and learners' perceptions to assess the classroom learning environment as being more reliable than the independent observer.

During the past five decades, research into learning environments has produced a large variety of instruments. Essentially, learning environment research instruments are questionnaires designed to capture quantitative and/or qualitative data about learners'/teachers' assessments of the "...social, psychological, and pedagogical contexts in which learning develops and which affect students' achievements and attitudes" (Telli, den Brok, Tekkaya, & Cakiroglu, 2009, p. 110). According to Fraser (1998b), the development of instruments designed to measure learners' perceptions of their learning environments started in the 1950s and gained momentum in the early 1970s. Most of the instruments have been developed in the United States and it follows that most of the studies in this field have been done where the instruments have been developed. Gathering data on learners' perceptions of their experiences 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, learners' perceptions of their experiences of scientific inquiry, specifically the instructional practice were obtained through a quantitative questionnaire and semi-structured interviews. A critical appraisal of some examples done in this field is done below.

A study by Rop (2003) investigated high school learners' perceptions of chemistry classroom questioning behaviour and its implications, as it is indicated that "posing questions is one of the vital behaviour associated with scientific inquiry" (p.17). Rop's study was ethnographic and carried out in one of the high school chemistry class in Unites States of America using participant observation, informal interviews and journal notes and extended time on site as methods of data collection. The study found that some learners regularly participate in classroom conversation by asking "Students Inquiry Questions" (SIQs) as a way to "alleviate boredom and engage in intellectual challenges" (Rop, 2003, p. 21). The study came to the conclusion that learners ask interesting questions about the content as they perceive that a classroom without more scientific inquiry based questions is very boring. Learners were found to ask SIQs to challenge themselves to think at higher levels. The study also found that learners ask SIQs "to fill an intellectual hunger to understand subject matter better" (Rop, 2003, p. 21). Thus learners ask SIQs to enable themselves to understand or learn subject matter in deeper ways. Rop (2003) further maintains that such learners do not want to learn for good grade but for better understandings of the NOSI which might help them to go ahead with the scientific knowledge they got hence, perceive that scientific inquiry based question will help them achieve that. Thus, the study findings also confirm that learners in this study purported that the social atmosphere in high schools is loaded with scientific inquiry and that actively engaging in scientific inquiry will develop their understandings of the NOS and NOSI. This finding is consistent with an assumption from the South African NCS for Physical sciences which asserts that by doing inquiry, learners shall come to understand the NOSI. Though this may seem a noble assumption, this study is set to examine this assumption.

Grady, Dolan, Glasson (2010) performed a study whose purpose was to gain insight into the implementation of scientific inquiry in an agriscience classroom. Also of interest was how the tenets of nature of scientific inquiry were reflected in the learners' experiments. Participants included an agriscience teacher and her fifteen students who were conducting plant experiments to gain insight into the role of a gene disabled by scientists. Analysis of the data indicated that the teacher viewed scientific inquiry as a mechanical process with

little emphasis on the reasoning that typifies scientific inquiry. Students' participation in their experiments also centred on the procedural aspects of inquiry with little attention to scientific reasoning. Data sources included classroom observations, conversations with learners, face-to- face interviews with the teacher, and students' work. There was no explicit attention to the nature of scientific inquiry during the experiments, but the practice implied correct, incorrect, and underdeveloped conceptions of the nature of scientific inquiry. The authors believe that conducting the plant experiments in this agriscience classroom could have nurtured students' conceptions of nature of scientific inquiry and more closely reflected the authentic practice of scientists had the teacher been supported with professional development related to nature of scientific inquiry. This is an interesting conclusion which the study by Grady et al. makes. A question is asked, is this the case with the sampled teachers in this thesis? Grady, Dolan, Glasson (2010) did not report of the exact scientific inquiry experiences they sought the learner to obtain. However, the authors were explicit when it came to the three tenets of NOSI (scientific knowledge is theory–laden and subjective, scientific work is socially and culturally embedded and scientific knowledge can be generated through empirical practices) they explored. These three tenets are among the six which this thesis explores. Data sources employed in the reported study are more or less the same with the ones used in this thesis. However, this thesis employs an additional instrument (the Learner Perception of Classroom Inquiry) to elicit learner experiences of scientific inquiry.

In another study, Sadeh and Zion (2009) compared the influence of open versus guided inquiry learning approaches on dynamic inquiry performances among high-school biology students in Israel. In their study there were two groups involved, that is the group experiencing open inquiry and the group experiencing guided inquiry. The data sources included interviews, learners' inquiry summary papers, logbooks, and reflections. Even though, Sadeh and Zion were expecting that learners in open inquiry will outperform the guided inquiry group because they have experienced difficulties and problems that arise during the open inquiry process, their results revealed that there is no difference in learners' performances and on their procedural understanding. This is in line with Furtak (2006)

statement which indicates that learners experiencing different levels of inquiry may similarly develop scientific knowledge and understandings of NOSI. The study recommended that identifying the elements underlying the dynamic inquiry learning process and their benefits to students' learning processes could provide guidance and encouragement for teachers in implementing open inquiry learning and in helping their students experience it. Moreover, teachers' awareness of the elements of dynamic inquiry can also improve the teaching of guided inquiry. On contrary, findings in a study by Fay, Grove, Towns, & Bretz (2007) clearly show that not all instances of inquiry are equivalent. That is they do not necessarily imply or describe the same learning opportunity for learners. Fay et al. further indicate that there are varying degrees of freedom in the learners' experiences which result in different learning opportunities. Unlike the study by Sadeh and Zion which compares two types of inquiry practices in a science classroom, this study is exploratory and non-causal and is after establishing learner experiences of scientific inquiry they go through in the learning of scientific investigations.

Another widely cited study that probes learner perceptions of scientific inquiry was conducted in Korea. Kim, Fisher, and Fraser (1999) conducted an investigation of the extent to which a new general science curriculum, reflecting how constructivist views influenced the classroom learning environment in grade 10 Science. The Constructivist Learning Environment Survey (CLES) was selected for the investigation and translated into Korean. Other objectives of this study were to determine whether: the Korean version of the CLES is valid and reliable; differences between learners' perceptions of their actual and preferred learning environment; and associations between learners' perceptions of the constructivist learning environment and their attitude to science. The Korean-language version of the CLES was found to be valid and reliable and grade 10 learners did perceive a more constructivist learning environment than grade 11 learners who had not been exposed to the new curriculum. The findings were that efforts of curriculum reform had produced some positive effects. Learners tended to prefer a more positive environment than what was perceived to be present and statistically significant relationships were found between classroom environment and student attitudes. Although the study by Kim, Fisher and Fraser

(1999) investigated attitudes, this thesis does not foray into the construct of attitudes. However, the associations between learner experiences of scientific and conceptions of the nature of scientific inquiry are explored. Robust statistics employed by Kim, et al. (1999) are also done in this study. After translating the CLES into Korean language, validity and reliability issues were tested. In this study, after adopting the LPCI instrument, validity and reliability issues were also tested through piloting. The study by Kim, et al. (1999) recommends that qualitative studies are needed to enhance our understanding of the results obtained from quantitative studies like theirs. This thesis took aboard the recommendation and was modelled along mixed methods research.

The last study to be reviewed in this section is by Krajcik, Blumenfeld, Marx, Bass, Fredricks & Soloway (1998) who investigated what middle school learners do, where they have problems and difficulties they experience in their first encounters with inquiry learning. In their study, they detail how learners: ask questions; design and plan investigations and procedures; construct apparatus and carry out their work; analyse data and draw conclusions; and present the findings which according to Asay and Orgill (2010), and Park, Rogers and Abell (2008) is considered to be full inquiry. The findings point out that, middle school learners are capable of conducting inquiry in their classrooms. That is, they are thoughtful in designing investigations, planning procedures and organizing the collection of data. Krajcik et al. also found that teacher's questioning were crucial in encouraging learners to be thoughtful about the important aspects of inquiry. These results are consistent with findings from Marx, Blumfeld, Krajcik, Fishman, Soloway, Geier & Tal, 2004; Kipnis & Mamlok-Naaman, 2005). The exploration constituting the present investigation is similar to the study by Krajcik et al. in that focus is on scientific inquiry processes like framing questions, designing investigations, conducting investigations, collecting data and drawing conclusions. Though, Krajcik et al. studied middle school learners, it can be argued that middle school learners may behave in a similar manner with high school learners and with appropriate assistance from their teachers when engaged in scientific inquiry may perform better.

2.9 Studies on teacher practices when teaching through inquiry – including when teaching investigations

Several studies have reported on teacher inquiry practices (Carnes, 1997; Crawford, 2000; Keys, Kang, & Lyon, 2001; Keys & Kennedy, 1999). According to Keys and Bryan (2001), an important source of information on teacher practices has come from the writings of teachers themselves. Most often several elementary teachers participating in research groups with the focus of exploring their own practice have contributed book chapters or even entire books describing how they perceive of and implement inquiry (Gallas, 1995; Iwasyk, 1997; Kurose, 2000; Nissley, 2004; Oliver, 2005; Pearce, 1993; Reardon, 1993; Whitin & Whitin, 1997). One major finding emerging from these studies is that these teachers overwhelmingly practiced inquiry-based instruction as arising from learners' authentic questions. Their inquiry teaching narratives include rich descriptions of activities they used to help learners generate questions, or how they used discussion to shape learner's natural questions into topics for investigation. Research tells us that mostly elementary teachers have been observed to have learners generate portions of their investigations, such as raising questions, selecting variables, or interpreting data, while using all class instruction to guide the rest of the process (Flick, 1995; Fradd & Lee, 1999; Keys & Kennedy, 1999). Keys & Kennedy reported that an experienced fourth-grade teacher seized opportunities for inquiry spontaneously when she allowed learners to deviate from planned instruction to pursue authentic questions. Gallas (1995) devoted time not only to question posing, but also to extensive discourse on young children's questions in which various theories and supporting evidence are posed. It is clear that these teachers value learner questioning as central to the inquiry experience. We perceive three major areas of research on inquiry-based practices that need further research. Though studies on teacher practices when teaching through inquiry are abound, the most reported studies are for elementary teachers. Keys and Bryan (2000) recommend more studies similar to those described above from middle school and high school levels. It is argued the sociocultural context of middle school and high school will provide both broader opportunities and, at the same time, more perceived constraints for implementing inquiry in the classroom.

A recent study that investigated the effect of explicit, reflective inquiry activities on middle school learner's understandings of Knowledge of Inquiry (KOI) was the work of Bartels, Lederman and Lederman (2012). This project, based in the United States, Chicago used the instrument Views about Scientific Inquiry (VASI) and interviews to track learners' understandings of KOI throughout the school year. The teachers then taught these labs while making audio recordings of the classes and the researchers ensured that teachers were explicitly teaching KOI. The knowledge of inquiry (KOI) instrument follows the Schwartz, Lederman, & Lederman (2008) presentation as; 1) Scientific investigations all begin with a question, but do not necessarily test a hypothesis, 2) There is no single set and sequence of steps followed in all scientific investigations, 3) Inquiry procedures are guided by the question asked, 4) All scientists performing the same procedures may not get the same results, 5) Inquiry procedures can influence the results, 6) Research conclusions must be consistent with the data collected, 7) Scientific data are not the same as scientific evidence, 8) Explanations are developed from a combination of collected data and what is already known. These eight themes represent consensus regarding key components of learners practicing scientific inquiry in a science classroom and underscore the importance of both learning and teaching as scientific inquiry. By the conclusion of the study, learners improved their understanding of KOI for the aspects that were explicitly taught. The exploration constituting the present investigation represents a stepping off point and is different to the study by Bartels et al. in that it involves both learner and teacher conceptions and the researcher did not participate in co-planning meetings on the scientific investigation to teach. Although Bartels et al., (2012) audio-recorded their classes to insure that teachers were explicitly teaching KOI, this study video-recorded teacher investigation classes so as to determine instructional practices taking place. This was done to ascertain the level of inquiry practised in these teachers' classes. Another interesting finding from the Bartels et al.,'s (2012) study was that the teaching about inquiry can be realistically infused into instruction complementing content objectives in an engaging manner without taking much instructional time. Is it the case within South African Physical Science classrooms, in particular Chemistry classrooms? The answer to this question constitutes rationale for exploring teacher practices through inquiry in this study.

Another study is by McNeill and Krajcik (2007) who examined what instructional practices teachers engage in when they introduce scientific explanation and whether these practices influence learners' ability to construct scientific explanations during a middle school Chemistry unit. They conducted their research with 13 teachers from the Michigan State, in the United States. Each teacher's enactment of the focal lesson on scientific explanation was videotaped for four different instructional practices on scientific explanation. One of the findings was that when teachers introduce scientific explanation, they vary in the practices they engage in as well as the quality of their use of practices. They also found that teachers' use of instructional practices can influence student learning of scientific explanation and that the effect of these instructional practices depends on the context in terms of what other instructional practices teacher uses. These results are consistent with those of previous research that has found that teacher modeling of scientific inquiry practices can encourage learner success in these same practices (Crawford, 2000; Tabak & Reiser, 2008). McNeill and Krajcik recommended that future research should also look more closely at the interactions between the teacher and learner, instead of simply focusing on the role of the teacher as they did in their study. Building off the recommendation by McNeill and Krajcik (2007), this study looks at the interactions between teachers and learners when teachers are teaching practical investigations. The other way in which the current exploration differs in the McNeill and Krajcik's study is that their study only focused on explanation and did not specifically examine other teacher practices like allowing learners to frame research questions, design investigations, conduct investigations, collect data and draw conclusions which this study explores.

Windschitl (2004) conducted a multi-case study in which 14 preservice secondary science teachers developed their own empirical investigations—from formulating questions to defending results in front of peers. The purpose of the study was to find out how the teachers conceptualized inquiry, how these conceptions are formed and reinforced, how they relate to work done by scientists, and if these ideas about inquiry are translated into classroom practice. Findings indicate that participants shared a tacit framework of what it

means to *do science* which shaped their investigations and influenced reflections on their inquiries. Some facets of the participants' shared model were congruent with authentic inquiry; however, the most consistent assumptions were misrepresentations of fundamental aspects of science: for example, that a hypothesis functions as a guess about an outcome, but is not necessarily part of a larger explanatory system; that background knowledge may be used to provide ideas about what to study, but this knowledge is not in the form of a theory or other model; and that theory is an optional tool one might use at the end of a study to help explain results. These ideas appear consistent with a *folk theory* of doing science that is promoted subtly, but pervasively, in textbooks, through the media, and by members of the science education community themselves. Windschitl (2004) found that all participants held degrees in science and were part of a highly regarded master's program in secondary science teaching yet, most of them subscribed to a model of inquiry that was mainly a technical procedure (albeit complex, i.e. followed the scientific method) rather than a theoretically grounded exploration. Is this the case with the sampled teachers in this thesis? Unlike the sample used by Windschitl (2004), the sample for this thesis is that of practicing teachers who have recently completed an in-service course in science education and have been learnt about teaching as scientific inquiry. In presenting results Windschitl (2004) gave a detailed report on the sub-processes like asking/framing questions, designing investigations, conducting investigations, collecting data and drawing conclusions. This thesis follows that same format in the reporting of results on teacher practices and employs assertions to report qualitative data findings.

Another study on teacher practices when teaching through inquiry was conducted by Windschitl (2002) who examined how preservice teachers' inquiry experiences, in a science methods course, influenced and were influenced by their conceptions of inquiry. The study also assesses how these experiences were associated with eventual classroom practice. Six preservice secondary teachers were observed during a 2-month inquiry project and then followed into the classroom as they began a 9-week teaching practicum. Data revealed that participants' pre-project conceptions of the inquiry process were related to the conduct and interpretation of their own inquiry project, and that the project experience

modified the inquiry conceptions of those participants who already had sophisticated understandings of scientific investigations. Windschitl (2002) recommended that independent science investigations be part of preservice education and that these experiences should be scaffolded to prompt reflection specifically about the nature of inquiry. Though this study focuses on pre-service teachers, it is reported here because true to the spirit of inquiry, this study generated as many questions as it answered. Most importantly, the study found that the participants who eventually used guided and open inquiry during their student teaching were not those who had more authentic views of inquiry or reflected most deeply about their own inquiry projects, but rather they were individuals who had significant undergraduate or professional experiences with authentic science research. This finding is interesting in the sense that this thesis as part of its endeavours want to establish whether by practicing open-ended inquiry, a teacher holds informed conceptions about the nature of scientific inquiry.

2.10 Studies focusing on investigating relationships among learners' and teachers' conceptions of NOSI and teacher instructional practices

Over the past two decades a number of studies have examined learners' and teachers' conceptions of NOSI within the context of teacher instructional practices (Lucas & Roth, 1996; Martin, 1999; Ryder & Leach, 2000; Ryder, Leach, & Driver, 1999; Tomkins & Tunnicliffe, 2001; Tsai, 1999, 2003b). Links between learners' views of the NOSI and their laboratory learning have been demonstrated (Tiberghien, Veillard & Le Marechal et al., 2002; Tsai, 1999). To a very large extend, learners' experiences and actions during scientific investigations are influenced by the instructional setting and teachers' conceptions of the scientific process and enterprise (Adyniz, Baksa & Skinner, 2010; Gibson & Chase, 2002; Hodson, 1993; Tiberghien et al., 2002). One finding recurring in most of these studies is that learners revealed that the translation of NOSI conceptions into instructional practice was constrained by such factors as: teachers viewing NOSI conception as less important than other curriculum goals, teachers discomfort with their own NOSI conceptions, teachers' preoccupation with management and routine chores, and lack of resources and experience for teaching the NOSI (Duschl & Wright, 1989; Gess-

Newsome & Lederman, 1995b; Lederman, 1999, 2007b). Accepting that the interaction between NOSI conception and instructional practice is a complex one, Abd-El-Khalick et al. (1998) recommended that development of preservice teachers NOSI understandings and learning to teach about the NOSI should be done separately. Their study however did not specifically examine the interaction between teachers NOSI conceptions and their practice of inquiry in laboratory instruction. What follows is a critical appraisal of some examples of studies done in this field.

Adyniz, Baksa & Skinner (2010) investigated scientific inquiry experiences in authentic settings and their influences of high school learners' conceptions of the nature of science and nature of scientific inquiry. Adyniz et al. (2010) collected data through an open-ended questionnaire. They found that most of the participating learners have some conceptions of NOSI as they were able to differentiate between evidence and data; observation and experimentation. The participating learners also showed an understanding that scientists use multiple methods when solving problems. They also held a sophisticated understanding about the tentative nature of science. These results are consistent with an earlier study by Lederman (2007b) but are different from the study by Liang et al. (2006). Adyniz et al. (2010) and Lederman (2007b) argue that the naive views of NOSI held by learners originate from their lack of experiences in conducting scientific inquiry. They claimed that this happens because high school science laboratories focus only on demonstrations and experimentation aspects of the scientific inquiry, and fail to provide a context for high school learners to understand how the scientific knowledge gets generated and validated. The exploration constituting the present investigation is different from the study by Adyniz et al. in two ways. First, the current study uses a completely different instrument (Campbell, et al., 2010) which is closed to specifically examine learners' perceptions of the nature and extend of laboratory inquiry vis-a-vis their conceptions of the NOSI. Interviews and classroom observations are used to corroborate responses to the closed instrument. Secondly, the students who took part in the present study were 16-year-old high school (Grade 11) learners in a different culture.

In another study, Khishfe (2008) investigated the influence of two different explicit instructional approaches on improving high school learners' understanding of the nature of science and scientific inquiry. In one group (integrated), the nature of science and scientific inquiry was explicitly taught as an integrated component of a unit on global climate change. In the other group (non-integrated), the nature of science and scientific inquiry was taught as a group of explicit activities about global warming, dispersed across the content. Based on the VNOS framework, Khishfe investigated five aspects of the nature of science and scientific inquiry: tentativeness of scientific knowledge, empirical nature of science, role of creativity and imagination in science; distinction between observation and inference; subjective nature of scientific knowledge. The results showed improvements in learners' views of the nature of science and scientific inquiry regardless of which instructional treatment they received. Comparing the groups did not provide conclusive evidence in favour of a specific instructional method. The 7th grade learners' thinking regarding the tentativeness of scientific theories moved from 17% having an informed view (i.e., theories can change) before explicit nature of science instruction to 44% after the instruction. This suggests that explicit instruction in the nature of scientific knowledge can promote a more sophisticated understanding among learners of the tentative nature of scientific knowledge. The author provided quotes to help the reader compare and contrast how learner thinking changed as a result of the explicit nature of science and scientific inquiry instruction. The following quotes capture the concrete way learners' perceived scientific knowledge before the explicit instruction:

> ...They [scientists] haven't actually seen it [the atom] with their eyes…then they are not certain until after they actually see it, maybe in 100 years or less"; "There's got to be a dinosaur preserved frozen…should explore Antarctica." (Khisfe, 2008, p.15)

The quotes that were provided to reflect the more informed learner views after explicit instruction suggest that learners had a better grasp of the revisionary aspects of scientific knowledge, despite simultaneously holding narrowly empirical notions of science, such as "seeing" leads to the certainty of scientific knowledge. The authors used the following quote to emphasize this point: "People used to think the

Earth was flat but we know it's not flat; we have seen pictures of the earth." (Khisfe, 2008, p.16)

Similar findings were reported by Khishfe and Lederman (2006). Learners' thinking regarding the tentativeness of scientific theories moved from 0% having an informed view before explicit nature of science instruction to 42% after instruction in one treatment group, and similarly from 0% to 24% after instruction in another treatment group in the study. Khishfe and Lederman (2006) provided similar quotes to typify naïve and more informed learner thinking. For instance, naïve thinking is illustrated by the following: "No, they [scientists] are not certain [about atomic structure] unless they were able to see it front of them" (Khisfe, 2008, p.19). This is contrasted with the following quote used to characterize a more informed notion of science after explicit nature of science instruction: "Yes, some scientific knowledge may change. In the future a new discovery might be found and change some of the information they've found" (Khisfe, 2008, p.19).

However, in both studies little effort is made to report what changed in learners' thinking, nor to identify the common reasons they attribute as to why scientific knowledge has the capacity to change or even categorize the range of ideas learners tend to have regarding the tentativeness of scientific knowledge. With regard to their analysis and findings, the two studies should have at least addressed learners' views maybe from a constructivist perspective, using existing notions to explicitly create learning experiences that enable learners to construct new and more sophisticated levels of critical thinking and reasoning. Furthermore, regardless of the fact that the author (s) provided some quotes and some dialogue excerpts from learner interviews to support the categorization of naïve, intermediary or informed views for each aspect; there is little to no explication of the qualitative different types of responses learners provided on the questionnaire, nor did the researchers report variations in thinking beyond naïve, intermediary or informed views during the semi-structured follow-up interviews based on context. The studies by Khisfe and Lederman (2006) and Khisfe (2008) are presented here because as a stepping off point. This current study investigates teacher and learner conceptions in relation to instructional

practices and in the process makes reference to some misused terms such as laws are proven theories filling the gap left by the reported studies.

Lederman (1999) reports a multi- case study in which an open-ended questionnaire eliciting views related to teachers' conceptions of the nature of science and scientific inquiry was administered to teachers. This was followed by structured and unstructured interviews, classroom observations and analysis of instructional materials to investigate the relationship between teachers' conceptions of the nature of science and scientific inquiry and classroom practices. The study also elucidated those factors that impede or enhance the relationship. The questionnaire focused on the complexities of tentativeness in scientific knowledge, and specifically on (a) the use of human creativity and imagination in the development of scientific knowledge, (b) the subjectivity resulting from scientists' background experiences, knowledge, and scientific paradigms, (c) the difference between scientific theory and law, (d) the importance of both observation and inference to the development of scientific knowledge, and (e) the empirical basis of scientific knowledge. One of the findings of this study was that although the teachers possessed good understandings of nature of scientific inquiry, classroom practice was not directly impacted. Lederman concluded that there was no clear relationship between teachers' conceptions of NOS and/or NOSI and classroom practice. Overall, the study was consistent with emerging findings about the relationship between teachers' conceptions and classroom practice as well as the research indicating the importance of explicit instructional attention to NOS and/or NOSI (Bady, 1979; Brickhouse, 1989; Brickhouse, 1990; Lederman & Druger, 1985; Lederman, 1986a; Lederman & Zeidler, 1987; Zeidler & Lederman, 1989). However, this same body of research suggests these efforts of the translation of teachers' conceptions of NOSI into classroom practice have been met with limited success since teachers cannot teach what they do not understand (MacDonald & Rogan, 1990). This lack of consensus is a concern and this study sees it as an issue worth investigating much to the disagreement with Herron (1969) who stated, anything as complex as the nature of scientific knowledge or scientific inquiry is capable of being seen from a variety of viewpoints.

In their study, Marchlewicz and Wink (2010) examined how undergraduate students' views of scientific inquiry shift after introduction of the Activity Model of Inquiry in a general Chemistry course. They used essay prompts, pre- and post questionnaire and interviews to get learners views. The questionnaire (the Views of Nature of Science questionnaire Form-C by Lederman, Abd-El-Khalick, et al., 2002) that students completed probed their understandings of the "empirical, tentative, theory-laden, creative and imaginative, and social and cultural embeddedness nature of scientific knowledge, as well as, the myth of a universal scientific method, the difference between scientific laws and theories, and learners' overall view of science" (Marchlewicz & Wink, 2010, p. 309). These were considered to be the tenets of NOSI in the present study and the rationale given for this claim was mentioned earlier in this Chapter. The results reveal that there are some shifts from a naïve view to a more informed view of nature of scientific inquiry for some learners. It can be argued that such learners whose views shifted from being naive to more informed have a better understandings of the NOSI. Even though Marchlewicz and Wink (2010) did their study with undergraduate students, their findings were similar to some researchers who did their studies with high school learners (Cuevas, Lee, Hart, & Deaktor, 2005; Domin, 1999) and primary school learners (Ackerson & Donnelly, 2010). These findings are inconsistent from a study by Abd-El-Khalick, Bell and Lederman (1998) who found that even when teachers had an adequate understanding of the NOSI, that understanding did not necessarily influence classroom practice. The exploration constituting the present investigation is different from the study by Marchlewicz and Wink (2010) in two ways. First, the current study uses a completely different instrument (Liang, et al., 2008) to specifically examine learners' conceptions of the nature of scientific inquiry and vis-a-vis their perceptions or experiences of scientific inquiry elicited using the an instrument by Campbell et al. (2010). Secondly, the students who took part in the present study were 16-year-old high school (pre-university) learners in a different culture.

This section is concluded by reporting a study by Sampson & Grooms (2008) who used a new instructional model called an *argument-driven inquiry* (ADI) to determine its impact on learners' conceptions of the nature of professional scientific inquiry (NOPSI) and the

nature of school scientific inquiry (NOSSI) using the views of scientific inquiry (VOSI) questionnaire before and after an eighteen week intervention. The intervention consisted of fifteen lessons that were designed using the argument-driven inquiry model. An analysis of learner responses to VOSI items before and after the invention indicates that the instructional model did affect some change on learners' views of NOPSI but not to the degree expected or desired. The results also suggest that the ways learners conceptualize key aspects of science or struggle to articulate their ideas about science seem to act as a barrier to the development of an appropriate understanding of NOPSI. Despite an explicit and authentic approach to instruction meaning that science teachers made the nature of scientific inquiry in professional science clear to students (Abd-El-Khalick & Lederman, 2000a; Khishfe & Abd-El-Khalick, 2002) while at the same time engaging them in realistic scientific practices inside the classroom (such as inquiry, argumentation, writing, and peer review) so that the nature of scientific inquiry made sense in the context of their own work (Kuhn & Reiser, 2006; Sandoval & Reiser, 2004), these learners' conceptions of the nature of science changed very little. This is consistent with findings from the study by Abd-El-Khalick, Bell and Lederman (1998). The current study does not have an intervention but instead utilizes semi-structured interviews and classroom observations; and it will be interesting to find out if these findings hold to the South African context. There seems to be a critical factor that is missing. Sampson & Grooms (2008) propose, based on the results of their study, that more focused attention must be paid to the development of learners' declarative knowledge and the difficulties that learners face when asked to articulate their ideas. This study deviates from this recommendation since it does not involve an intervention but instead focuses on the functional (interpretive) analysis of learners' ideas.

2.11 Conclusion

This chapter provided an overview of the science education research literature related to the nature of scientific inquiry. It explained that a central and reoccurring element of science education reform efforts posits inquiry and the understanding of the nature of scientific inquiry as essential cogs that extend beyond the mere development of process skills. Such skills include; observing, inferring, classifying, predicting, measuring, questioning,

interpreting and analyzing data. Precipitating concepts that form the conceptual framework were reviewed from a historical, philosophical, pedagogical exploratory and analytical manner. A review of research that focuses on curricular and assessments efforts aimed at improving learner and teacher views of the NOSI suggests that scientific inquiry includes the traditional science processes, but also refers to the combining of these processes with scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge. The findings of specific research related to this study, including the particular aspects of nature of scientific inquiry this work addresses, were reviewed in detail. The following chapter describes the research design and methodology, including the sample of teachers and learners and the instruments used to collect data and data analysis procedures.

CHAPTER THREE

Research methodology

3 Introduction

This study employed mixed methodology. During the last twenty years, most of the reported research on the nature of science and scientific inquiry including on scientific investigations has been combining quantitative and qualitative methods (Lederman, 2007a). This combination has been based on the conviction that mixing quantitative and qualitative research can provide richer understandings of the phenomenon being studied (Gall, Borg, & Gall, 2007). There are also prospects of the combination raising more intriguing questions for future research. Mixed methods research is a strategy that involves combination of quantitative and qualitative research techniques, methods, approaches, and concepts in a single study (Johnson & Onwuegbuzie, 2004). It is an attempt to legitimize the use of multiple approaches in answering research questions; providing the researcher with significant latitude to make choices. Mixed methods research has been described as inclusive, pluralistic, complementary, expansive and creative (Gall, et al., 2007). Quantitative techniques, methods, approaches and concepts can be used to investigate constructs and their measures whilst at the same time qualitative techniques, methods, approaches, and concepts are used to discover additional constructs that are relevant to the study's goals.

According to Johnson and Onwuegbuzie (2004), the practice of mixed research includes the use of induction (or discovery of patterns), deduction (testing of theories and hypotheses), and abduction (uncovering and relying on the best of a set of explanations for understanding one's results). It is argued that mixed-methods approach increases both the validity and reliability of research results, as it involves triangulation and cross-checking. Mixed methodology was chosen for the study being reported here for the reason that neither quantitative nor qualitative methods on their own can capture the trends and details of a

situation. When used in combination, quantitative and qualitative methods complement each other and allow for a more robust analysis, taking advantage of the strengths of each (Greene, Caracelli, & Graham, 1989; Miles & Huberman, 1994; Tashakkori & Teddlie, 1998). Additionally mixed methodology is currently popular with researchers working on NOSI including investigations (see, e.g., Abd-El-Khalick, 2006; Koksal & Cakiroglu, 2010; Schwartz, et al., 2008). Moreover understanding phenomenon fully necessitates using all approaches available. For these reasons, the present study combined quantitative and qualitative data collection procedures.

In this Chapter, a review of the literature on the methodology and instrumentation that have been used in studies of teachers and learners' nature of scientific inquiry (NOSI) conceptions is first discussed. This is followed by a description of the methodological framework, research design, the data collection procedures, the sampling, and the data analysis frameworks used in this study. A reflective overview of the relevant features of validity and reliability relevant to this study follows. In the subsequent section, a review of methodological approaches and instruments in studies on teachers' and learners' NOSI conception is presented. Finally, the detailed methodology including instruments and data collection procedures is presented.

3.1 A review of the methodological approaches and instruments used to study teachers and learners' NOSI conceptions

3.1.1 Quantitative approaches

As mentioned in Chapter 1, the concepts NOS and NOSI have been conflated. It was pointed out that that NOS aspects are those that relate to the product of inquiry, i.e. the scientific knowledge itself; whereas NOSI relates to the processes of inquiry-the "how" the knowledge is generated and accepted. Early studies on both NOS and NOSI employed mainly quantitative methods; especially in the 1960s and early 70s (e.g., Billeh & Hasan, 1975; Carey & Stauss, 1970; Kimball, 1967-68; Miller, 1963; Welch & Pella, 1967). Thereafter qualitative research became popular (see, e.g., Aguirre, Haggerty, & Linder,

1990; Bloom, 1987; Cobern, 1989; Shapiro & Martin, 2010) and gained in momentum during the 1980's. Arguments were levelled against the use of quantitative approaches to study human behaviour and thinking. One of these arguments has been that quantitative results have not been of much educational value because statistical figures cannot easily answer questions about human behaviour and thinking (Rennie, 1998). Naturally, research on the NOS and NOSI could not escape this shift in methodological paradigm and the criticisms levelled against the use quantitative approaches. Inevitably, during the last 15 or so years mixed methodology has become fashionable (see, e.g., Abd-El Khalick, 2001; Akerson, Abd-El-Khalick, & Lederman, 2000; Cobern, 2000; Gess-Newsome, 2002).

The use of quantitative approaches including convergent type instruments to assess beliefs or conceptions of NOS and NOSI has come under a barrage of criticism (Abd-El-Khalick & Lederman, 2000b; Bezzi, 1999; Chan, 1999b; Haidar & Balifakih, 1999; Lederman, 1992). Lederman et al. (2000) point out that these convergent instruments label respondents' views as adequate or inadequate without clarifying the basis on which such labelling 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, 1999b; Lederman, et al., 2000). This limits the usefulness of convergent instruments in assessing gains in NOSI conceptions that might arise as a result of instructional intervention. Additionally, the NOSI 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). Currently the use of interviews combined with open-ended written responses is the most popular. According to Lederman et al. (2000), interviews serve as a better choice to assess conceptions of the NOSI as they give respondents a better chance to elaborate on their views, giving the researcher a deeper interpretation of the response.

Review of literature done on studies of learners' and teachers' conceptions of the NOSI shows 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 (Abd-El-Khalick & Lederman, 2000b; Lederman, 1992; Lederman, et al., 2000). Studies reported in the literature up to the early 1980's have used these instruments or their adaptations or variations. Examples of such studies include the Kelton and Griffith (1986) and Lederman and Druger (1985). Essentially, most of these studies retain the features of previous forced-choice instruments (many used over the past six decades), such as the Science Attitude Questionnaire (Wilson, 1954), the Test on Understanding Science (Klopfer & Cooley, 1961), the Science Process Inventory (Welch & Pella, 1967), the Nature of Science Test (Billeh & Hasan, 1975), the Conceptions of Scientific Theories Test (Cotham & Smith, 1981), and the Views on Science-Technology-Society instrument (Aikenhead, Ryan, & Fleming, 1989).

Objectively scored instruments have also been developed (e.g., Lombrozo, Thanukos, & Weisberg, 2008; Scharmann & Harris, 1992; Scharmann, Smith, James, & Jensen, 2005) to quantitatively assess teachers' and/or learners' NOSI. A Likert-type instrument was developed by Tsai and Liu (2005a) to measure views about the nature of scientific knowledge. The instrument is based on the Nature of Scientific Knowledge Scale (NSKS) developed by Rubba (1976). It has 48 items. Respondents choose from a five-point Likert scale ranging from Strongly Disagree, Disagree, Neutral, Agree, to Strongly Agree, with scoring on half the items done in reverse. The NSKS covers six NOS tenets, namely; (1) Amoral (scientific knowledge itself cannot be judged good or bad i.e., it provides people with many capabilities, but does not provide instruction on how to use them, (2) Creative (scientific knowledge is partially a product of human creative imagination), (3) Developmental (scientific knowledge is tentative), (4) Parsimonious (scientific knowledge attempts to an interrelated network of laws, theories, and concepts) to achieve simplicity of explanation as opposed to complexity), (5) Testable (scientific knowledge is capable of empirical test), and (6) Unified (the specialized sciences contribute to an interrelated network of laws, theories, and concepts). The NSKS employs a five-point Likert scale.

Responses for each NSKS items are scored 5, 4, 3, 2, or 1 for “strongly agree”, “agree”, ‘neutral”, “disagree”, or “strongly disagree” respectively. Scores are reversed for each negative item.

For the NSKS the scales of Amoral, Parsimonious, and Unified, however, are not covered in the consensus list of international science standard documents. Some researchers have subsequently modified the NSKS [M-NSKS] (Meichtry, 1992) by eliminating the scales of Amoral and Parsimonious. The concerns raised by Lederman, Wade and Bell (2000) as threats of validity for this instrument centre around its high number of items and half of them being just negatively worded versions of the rest.

A convergent instrument 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 (e.g., Aikenhead, et al., 1987; Aikenhead & Ryan, 1992; Bradford, Rubba, & Harkness, 1995; Fleming, 1988; Haidar & Balifakih, 1999). The problem with this instrument is that some VOSTS items appeared redundant, and/or had ambiguous positions and overlapping meanings (Chen, 2006). Researchers also pointed out that respondents might have combinations of views that would not be reflected in the multiple-choice format (Chen, 2006; Lederman & Abd-El Khalick, 2002; Lederman, Abd-El-Khalick, et al., 2002; Lederman, Schwartz, Lederman, Matthews, & Khishfe, 2002).

Recently, two multi-dimensional Nature of Scientific Knowledge assessment tools were developed by Tsai and Liu (2005a) and Chen (2006), respectively. Tsai and Liu's instrument, use a 5-point Likert scale, and was designed for assessing High School students' epistemological views of science (SEVs). It has its roots in Pomeroy’s (1993) instrument. The development of SEVs was based on both the existing literature and interview data

collected by the researchers. The SEVs instrument consists of five subscales: the role of social negotiation in science, the invented and creative reality of science, the theory-laden exploration of science, the cultural impact on science, and the changing features of science. Chen (2006) also reports the development of a nature of scientific knowledge assessment tool, the Views on Science and Education Questionnaire (VOSE), built on selected VOSTS items by incorporating a 5-point Likert scale. Chen modified and clarified certain ambiguous VOSTS statements based on the interviews of both American and Taiwanese preservice secondary science teachers. The latest version of VOSE was administered to 302 college students majoring either in Natural Science or Language Arts at two research universities in Taiwan. Both instruments demonstrated satisfactory validity and reliability when tested with samples in Taiwan.

The instruments described above are common in that they consist of multiple-choice or Likert-type questionnaires and are scored objectively. They have the advantages of studying large numbers of subjects and easy data analysis. Well-made quantitative instruments have the added advantage of being more reliable than most qualitative procedures (Aikenhead, et al., 1989; Vhurumuku, et al., 2004). Beginning late 1990's, these instruments have been criticized on the basis of their questionable ability to measure what they actually purport to measure, i.e. for lack of validity (lack validity) (see, e.g., Lederman, Wade, & Bell, 1998). Chan (1999a), points out that the researcher who develops the questionnaire or multiple- choice item has a different background to the respondents (teachers or learners). As mentioned earlier (Chapter 3), this produces the likelihood of respondents interpreting items in ways different from the intentions of the researcher resulting in respondents being ascribed to views which are not theirs but artifacts of the instrument. Another major criticism about the traditional true/false or Likert-type questionnaires is that they often fail to detect both the subjects' perceptions and interpretations of the test items or their underlying reasons for making a choice (Liang, et al., 2006). Use of quantitative methods and instruments is seen as being unable to unravel how factors such as questionnaire or multiple- choice item developed by a researcher that

has a different background to the respondents could influence the views of the respondents (Lederman, 1992).

In an effort to address concerns of validity and reliability, and to be sensitive about not imposing the philosophical positions of the researcher onto the scoring criteria of the instrument, Liang et al. (2008) developed the Student Understanding of Science and Scientific Inquiry (SUSSI) instrument. This instrument has a dual response format that integrates a forced response Likert scale type of question with open-ended written responses. Although the SUSSI makes progress in addressing the aforementioned concerns, it still simply results in an evaluative judgment of "naïve" or "informed" similar to the VNOS approach developed by Lederman and O' Malley (1990) if used on its own. None of the instruments described above attempt to explicate learner thinking. They also do not identify common variations in the way learners conceive the nature of scientific inquiry.

The criticisms mentioned in the foregoing paragraphs have partly been responsible for the increasing popularity of qualitative methodology in nature of science and scientific inquiry studies. However, 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 (Louden & Wallace, 1996).

3.1.2 Qualitative approaches

As already noted a methodological shift towards qualitative studies came in around the 1980's as a result of paradigm shift in science education research methodology the world over. In order to avoid the ambiguity of language singled out as a demerit of the quantitative approach, nature of science and scientific inquiry studies after the late 1980s shifted from being more quantitative to more qualitative in nature, utilizing more flexible tools, such as; the Images of Science Probes (ISB) (Driver, Leach, Millar, & Scott, 1996), small group discussion (Solomon, 1992), situated-inquiry interviews (Ryder & Leach, 2000; Welzel & Roth, 1998), critical incidents (Nott & Wellington, 1996), reviews of lesson plans and documents, field observations of classrooms and teachers, concept maps,

case studies, in-depth interviews, and interviews combined with surveys or open-ended questions.

Commenting on the use of critical incidents, Lederman and Lederman (2005) describe their use to assess teachers' conceptions of the nature of science and scientific inquiry as a significant departure from the usual paper and pencil assessments. This sentiment is in agreement with Nott and Wellington (1996) who note that teachers do not effectively convey what they know about the NOS and NOSI in "direct response to abstract, context-free questions" of the sort, 'What is science?' Instead, Lederman and Lederman (2005) created a series of *critical incidents* that are descriptors/scenarios of actual classroom events. An example of where such a scenario is applicable is when a laboratory activity or demonstration does not yield the desired data. A teacher then has to respond to three questions which constitute a critical incident. These are: 1) what would you do? 2) What could you do? 3) What should you do? How the teacher responds to the three aforementioned questions is believed, to communicate what the teachers believe about the NOSI.

Generally, it is believed that qualitative approaches can achieve greater validity than quantitative methodologies (Cohen, Manion, & Morrison, 2000). Qualitative approaches 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. Aikenhead (1988) investigated the problem of ambiguity harboured by different response formats: written paragraph, semi structured interview, and empirically derived multiple-choice items. He found that paragraph responses worked better than the other two but the ambiguity was still high because subjects often lacked the skill to present their thoughts well. Semi-structured interviews offered the most accurate data, but were time-consuming. Interviews serve as a better choice to assess learners' conceptions of the NOSI as they give learners a better chance to elaborate on their views, giving the researcher a deeper interpretation of the response (Lederman, et al., 2000). Interviews can be

structured, unstructured or semi-structured (Opie, 2004). Of late, the use of interviews has increased in popularity (Lederman, 2008a). Recently, Lederman, Lederman, Kim & Ko (2006) used interviews in a study linking teachers' knowledge and practice related to the nature of science and scientific inquiry.

As can be seen from the review of qualitative methods described so far, data collection can be done in a variety of ways including interviewing and asking respondents to give written answers to questions. One of the most popular pencil and paper tool is the Views of the Nature of Science questionnaire (VNOS), which is an open-ended questions test developed by Lederman, Abd-El-Khalick, Bell, and Schwartz (2002). There are several forms of VNOS (Form A, B, C, D, and E). Several versions of this instrument or their adaptations or variations have been used by the researchers to focus on middle school learners[VOSI-M, E, 2,3] (Lederman, Abd-El-Khalick, et al., 2002; Lederman & Lederrman, 2007), high school learners [VOSI-1,4, Sec] (Lederman & Lederrman, 2007; Schwartz, et al., 2001), scientists [VOSI- Sci] (Schwartz, et al., 2004), preservice teachers (Schwartz, 2007), in-service teachers (Akerson, Hanson, & Cullen, 2007; Lederman, 2006b), early elementary learners [CVS] (Lederman & Lederman, 2005; Lederman, 2008b) and elementary learners [VOSI-E] (Ko & Lederman, 2005). Items in these instruments ask teachers to explain scientific activities in their classroom. Researchers then use a rubric to identify when teachers explicitly mention one of the seven identified aspects of the nature of scientific knowledge. All VNOS instruments consist of open- ended questions accompanied by follow-up interviews. The lengthy time required by learners to complete the survey instruments and complexity of language used in the questionnaires present the challenge to respondents with limited knowledge of nature of scientific knowledge and writing skills (Liang, et al., 2005). Most often, learners who are not equipped to fully express their own ideas in an open-ended format tend to respond in a few words or simply leave certain items blank. This limits the potential of the VNOS instruments as both accurate and informative classroom assessment tools as anticipated.

Other instruments have been developed to be more descriptive in explaining learner achievement in the nature of scientific knowledge such as Scientific Inquiry Capabilities and Scientific Discovery (Zachos, Hick, Doane, & Sargent, 2000). Although the objective pencil and paper assessments have been altered to include more descriptive options, there is still a need for improved assessments of both the teachers' and learners' NOS and NOSI understandings. Significant efforts have been made to modify and/or develop instruments aimed at increasing validity and minimizing the chance of mis-interpretation of learners' perceptions over the last decade. It appears that the open-ended questionnaires accompanied with interviews would yield valid and meaningful assessment outcomes. However, it may not be appropriate as a standardized tool in large-scale assessments (Liang, et al., 2005). On the other hand, previous research suggested that empirically derived assessment tools would significantly reduce the ambiguity caused by the problem of language. This has led to the development of the *Student Understanding of Scientific Inquiry* (SUSI) instrument by Liang et al. (2005), which combines both quantitative and qualitative approaches to assess learners' views about how scientific knowledge develops. The combination of various data collection techniques is currently in fashion for nature of science and scientific inquiry studies. Tao (2003) has recommended a combination of traditional Likert-type instruments with interviews. This study is aligned with this trend and in addition makes use of Science Probes.

3.2 A review of the methodological approaches and instruments used to study instructional practices

Research focusing on describing and determining levels of scientific inquiry in the science classroom falls broadly into what is called learning environment research (Fraser, 1998). This research has utilized various approaches and techniques to capture the extent or level of practice of scientific inquiry. Some of these approaches are; use of learners and/or teacher perceptions, laboratory class observations and interviewing teachers and learners.

3.2.1 Use of learners' perceptions

Research into determining levels of inquiry in science classrooms can be traced back to Murray (1938), who uses the terms *alpha press* and *beta press* in a similar manner to the *low inference* and *high inference* measures of later researchers (Patrick, Ryan, & Kaplan, 2007). Low inference measures itemize specific phenomena (e.g. the number of learner questions), and high inference measures and are concerned with perceptions relating to classroom events (e.g. the degree of teacher preparedness) (Fraser, 1986). Alpha press describes the environment as assessed by a detached observer (researcher) and beta press to describe the environment as observed by those within that environment (teachers and learners) (Fraser, Fisher, & McRobbie, 1996). These ideas were extended by Stern, Stein and Bloom (1956) to include perceptions of the environment unique to the individual (called private beta press) and perceptions of the environment shared among the group (called consensual beta press). Hence, even in the early studies of human environments, it was recognized that the perceptions of persons from different perspectives could lead to different interpretations of that environment.

Interest in the study of learning environments in classrooms was rekindled and is attributed to the pioneering independent contributions of two American researchers, Herbert Walberg and Rudolf Moos in the 1960s (Fraser, 1998a). The pioneering work of Walberg and Moos built upon the ideas of Lewin (1936) and Murray (1938) presented several decades before (Fraser, 1998a; Fraser & Walberg, 1991). Walberg (1976) developed the learning environment inventory (LEI) to assess students' perceptions as part of the research and evaluation activities of Harvard Project Physics (Sebela, 2003). Moos (1974) developed questionnaires to assess nine separate human environments (including hospital wards, families and work settings), with one of these being the classroom environment scale (CES) (Fraser & Walberg, 1991). The scope of the field of learning environments is covered in books (Fraser, 1986; Fraser & Walberg, 1991; Goh & Khine, 2002), literature reviews (Fraser, 1998a) and articles published in Springer's *Learning Environments Research: An International Journal* since its inception in 1998. Descriptions of students' perceptions of

the learning context appear in sociological studies starting in the climate of student unrest of the late 1960s, during which period it first became popular to consider learning from the students' perspective (Entwistle, 1997a).

The field of learning environment research has made available a variety of research instruments in the last five decades. As mentioned before, the original instruments were the Learning Environment Inventory (LEI) and the Classroom Environment Scale (CES) (Fraser, 1998b). Over the years, these instruments were gradually refined to suit specific environments, which allowed researchers to select instruments most suitable for their chosen fields of study. The *Science Laboratory Environment Inventory* (SLEI) (Fraser, et al., 1995), the *Chemistry Laboratory Environment Inventory* (CLEI) (Wong & Fraser, 1995), the *Questionnaire on Chemistry-Related Attitudes* (QOCRA) (Wubbels & Brekelmans, 1998; Wubbels, Brekelmans, & Hooymayers, 1991; Wubbels & Levy, 1993) for instance, were designed for studying science laboratories at senior high schools and universities. Basically the instruments determine the nature of the classroom environment through eliciting teachers' and/or learners' perceptions of the environment. According to Campbell, Abd-Hamid and Chapman (2010), several teacher and learner instruments exist. Examples are the *Constructivist Learning Environment Survey* [CLES] by Taylor et al. (1997); the *Constructivist Online Environment Survey* [COLLES] by Taylor and Maor (2000); and the *Science Teacher Inquiry Rubric* [STIR] by Beerer and Bodzin (2004). The CLES (Taylor, et al., 1997) was developed to assist researchers and teachers to assess the degree to which a particular classroom's climate is consistent with a constructivist epistemology, and to assist teachers to reflect on their epistemological assumptions and reshape their teaching practice. The CLES has 36 items with five response alternatives ranging from almost never to almost always. It assesses learners' perceptions of the constructivist nature of their classroom-learning environment. The instrument has since been used in studies assessing the science classroom-learning environment (Aldridge, Fraser, & Sebela, 2004; Johnson & McClure, 2004).

The COLLES is used to examine learners' perceptions of online learning environment in light of social constructivist pedagogical principles. The 24-item, Likert-type COLLES instrument is a popular measure for examining online learning environments for a least two reasons. Firstly, it measures the online learning environment along constructivist categories, which makes it in line with the dominant pedagogical philosophy for online instruction. Secondly, the COLLES instrument is freely an open source course management system included in additional modules making it most popular and particularly convenient for online instructors to use COLLES in their teaching and research. The instrument has since been used in studies assessing the online social constructivist learning environment (Sthapornnanon, Sakulbumrungsil, Theeraroungchaisri, & Watcharadamrongkun, 2008) as well as studies that has the potential to generate a measure of learners' perceptions of both their preferred and actual on-line classroom environment (Johnson, McHugo, & Hall, 2006).

Another instrument, the Reformed Teaching Observation Protocol (RTOP) was created by the Evaluation Facilitation Group (EFG) of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) (Yager, 2009). It is an observational instrument designed to measure "reformed" teaching. The Reform Teaching Observation Protocol (RTOP) has proven highly worthwhile in the study of science classrooms in middle and high schools, colleges and universities. The RTOP is criterion-referenced, and observers' judgments are not supposed to reflect a comparison with any other instructional setting than the one being evaluated. It can be used at all levels, from primary school through university. The instrument contains twenty-five items, with each rated on a scale from 0 (not observed) to 4 (very descriptive). Possible scores range from 0 to 100 points, with higher scores reflecting a greater degree of reform. RTOP scores predict improved student learning in science classrooms at all levels. Analysis of the RTOP suggests that it is largely a uni-factorial instrument that taps a single construct of inquiry. Campbell, et al. (2010) suggest that for effective results, it has to be used along with other instruments possibly the Learner Perception of Classroom Inquiry (LPCI).

Although the RTOP can be used to describe science-learning environments, it does little to capture learners' perceptions of the nature and extent to which learners are engaged in the principles of scientific inquiry. For assessing and determining the nature and extent to which learners are engaged in the principles of scientific inquiry from both teacher and learner perspectives, Principles of Scientific Inquiry-Student (PSI-S) instrument developed by Campbell, et al. (2010), becomes a more useful tool. It can be used to place learners' perceptions of laboratory and science classroom experiences along a continuum ranging from the lowest level of inquiry, level zero (0) (verificationistic), level 1 (guided inquiry), levels 2a and 2b (open-guided inquiry) to level 3 (open inquiry) as discussed in Chapter 2. In its original form, the instrument is based on five categories (each with four items) namely framing of research questions, designing investigations, conducting investigations, collecting data and drawing conclusions. The response alternatives for the items are based on a five-point Likert scale with responses ranging from almost never to Almost always. The activities are ranked according to how often they occur. Learners' rankings are then used to determine the extent to which learners are engaged in the principles of scientific inquiry in the laboratory or classroom. This is the instrument used in the current study.

3.2.2 Classroom/laboratory observations

There have been many observational studies specifically designed to describe specific educational phenomena. The last quarter of the twentieth century saw several hundred different observational systems being developed and used in classrooms (Good & Brophy, 2000). According to Good and Brophy there have similarly been hundreds of studies that have used classroom observation systems since the 1970s. Several laboratory class observation instruments have also been developed to characterize the nature of teaching and learning during laboratory work (Dolan & Grady, 2010; Kanari & Millar, 2004). For example, Dolan and Grady (2010) developed a classroom observation matrix using a modified version of Chinn and Malhotra (2002) instrument for categorizing student complexity of reasoning during teaching through laboratory inquiry. The instrument yields qualitative data. Newton, Driver, & Osborne (1999) developed an instrument called, Science Lesson Observation System (SLOS) that captures how teachers organize their

laboratory classes, the nature of learner activities and the kind of teacher- learner interactions occurring during lessons.

Another instrument designed for classroom observation is the Classroom Observation Schedule (COS), a modified version of the Scharmann and Smith's (2001) instrument. The COS was used in a study by Varley, Murphy and Veale (2008) in assessing teacher classroom practices in South African science classrooms. It focused on their teachers' actions. Among other things, the schedule assessed; classroom management, the time spent "on-task", and the classroom instruction strategies the teacher used in the teaching, and the frequency and types of questions asked. In one sense, the observation was unstructured allowing the situation to "speak for itself". However, in another sense the observations were structured since certain aspects of the teaching and learning processes in the classroom had been identified and were focused on.

A variety of similar laboratory observations schedules, for example, the Contemporary teacher classroom performance observation instruments pack have also been used in the United States of America (Lavely, Berger, Blackman, Follman, & McCarthy, 1994). All schedules discussed above have the common feature of looking at the nature of classroom interactions but fall short by failing to capture the nature and extent of inquiry. This is not surprising since most observations schedules are normally based on a predetermined and predefined theoretical focus. As Good (1988, p. 337) puts it, "one role of observational research is to describe what takes place in classrooms in order to delineate the complex practical issues that confront practitioners". These observations can be structured or unstructured.

In structured observations, the observer looks for specific instances, events, and behaviours, as guided by predetermined criteria (for example, using a checklist) (Gall, Borg, & Gall 1996; Riley, 1990). The researcher or researchers can also record what happens in the classroom, simply by manually taking notes. Use of observation schedules is known as structured observation (Gall, et al., 2007). When the nature of the instruction comes out

from the data analysis, it is known as unstructured observation (Gall, et al., 2007). The observer simply captures the lesson as it is without necessarily following a checklist (Cohen, et al., 2000). In reality the observation is guided broadly by the research focus or question. There is really no such thing as observing everything and hoping to get a research question out of it.

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. This study utilizes this type of observation. Several elements are common to most observational systems(Stallings & Mohlman, 2002). These include:

- a purpose for the observation
- operational definitions of all the observed behaviours
- training procedures for observers
- a specific observational focus
- a setting
- a unit of time
- an observation schedule
- a method to record the data and
- a method to process and analyze data

(Stallings & Mohlman, 2002, pp. 469-471)

The above-mentioned elements also apply to other techniques of capturing what occurs in the classroom including video recording. Some researchers have made use of video recording of laboratory classes (Bianchini, Johnston, Oram, & Cavazos, 2003; King, Shumow, & Lietz, 2001; Sherman & MacDonald, 2008). According to Plowman (1999), the advantages of video-based data to a study are its permanence as a record, its retrievability, and availability to other researchers to check the findings and reinterpretation. Digital video adds to the value of video-based data collection, with the ability to annotate clips, find them easily, select clips for future use, and edit the video. For example, Mousley (1998) coded relevant snippets of video and linked them to a

spreadsheet. Included on the spreadsheet were notes of the clips' origins, categorizations, and short descriptors. She subsequently made transcriptions that provided an easily and searchable resource for revisiting later, and a basis for careful data analysis. Plowman (1999) also carefully labelled and logged videos to help future searching and emphasized the flexible nature of the data with the ability to go back and review material repeatedly. She did, however, acknowledge the problem of video being relatively inaccessible and even in digital format, it needs to be viewed and coded in real time.

3.2.3 The Research Methodology

According to Guba and Lincoln (1994), 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. Figure 3.1 summarizes the methodological framework used in this study.

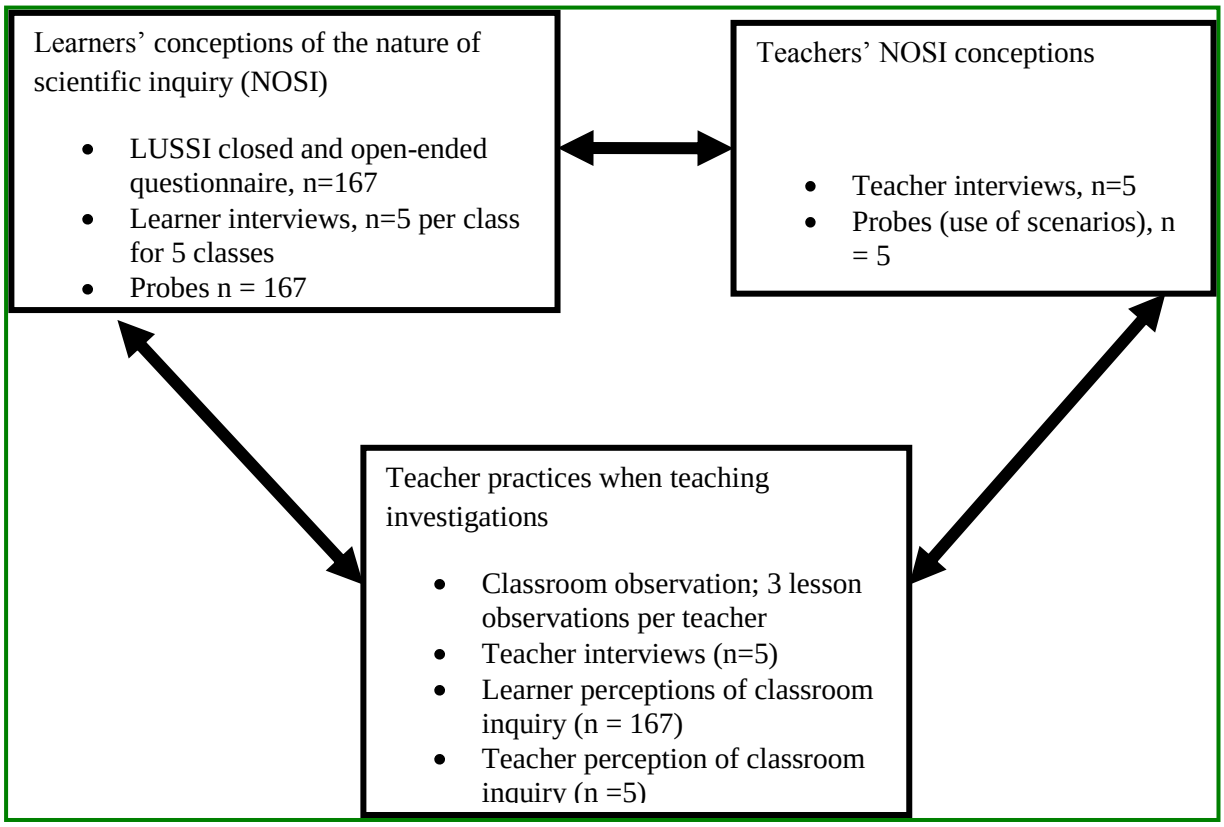

Figure 3.1: A summary of the methodological framework

As Figure 3.1 shows, data was collected on three variables namely; learners' conceptions of the NOSI, teachers' conceptions of the NOSI, and teacher practices when teaching investigations. The interest was not only to find out about the nature of each of these variables but also to unravel the interactions among the variables. Following Hollway (1984), this study can be described as having two features of an exploration. First, the determination of teachers' and learners' NOSI views was inherently exploratory since the real nature of the conceptions was unknown at the beginning of the investigation. Secondly, the search for interactions among the variables or aspects of the variables (learners' conceptions, teachers' conceptions and instructional practices) was also exploratory. The study was also correlational in its treatment of the relationship between learners' conceptions of the NOSI and their perceptions of levels of inquiry in classroom practices; and teachers' conceptions of the NOSI and their perceptions of levels of inquiry in

classroom practices. This study also involved interpretational analysis (Guba & Lincoln, 1994). Interpretational analysis is about getting meaning out of the data.

To get learners' NOSI conceptions, three instruments were used, which are: a Learners' Understandings of Science and Scientific Inquiry (LUSSI) closed and open-ended questionnaire (Appendix A); learner interviews; and probes (Appendix B). To determine teachers' NOSI conceptions, teacher interviews and probes were used. The same Probe instrument given to the learners is the one that was given to teachers. To determine teacher practices when teaching investigations, four instruments were used, namely: classroom observation schedule; teacher interview schedule; a learner perception of classroom inquiry (LPCI) questionnaire (Appendix C) and a teacher perception of classroom inquiry (TPCI) questionnaire (Appendix D).

3.3 The Research Design

As already alluded to, a semi-naturalistic mixed-method triangulation embedded approach was employed in this study. The mixed-methods sequential explanatory design was informed by the methodological framework described above. Although this design was chosen for the study, it is important to appreciate that it also has its own problems. According to Ivankova, Cresswell and Stick (2006), despite its popularity and straightforwardness, this mixed methods design is not easy to implement. Examples of certain methodological issues that were considered in advance in the study included: the priority or weight given to the quantitative and qualitative data collection and analysis; the sequence of the data collection and analysis; and the stage/stages in the research process at which the quantitative and qualitative phases were connected and the integration of results (Creswell, Plano Clark, Gutmann, & Hanson, 2003; Morgan, 1988). While quantitative data was gathered to give a general picture of the phenomena under investigation, the centre of the methodological approach was interpretive (Guba & Lincoln, 1989; Tobin & Fraser, 1991) as this allowed for greater insights into teachers' and learners' NOSI understandings.

This approach represents one of the traditional models of a mixed-methods triangulation design. The mixed-methods sequential explanatory design consisted of two distinct phases: quantitative followed by qualitative (Creswell, et al., 2003). For the study being reported here, quantitative (numeric) data was first collected and analyzed. Qualitative (text) data was then collected and analyzed. This helped explain, or elaborated on, the quantitative results obtained in the first phase. The second, qualitative phase built on the first, quantitative phase, and the two phases were connected in the intermediate stage in the study (Ivankova, et al., 2006).

The rationale for this approach was that the quantitative data and their subsequent analyses provided a general understanding of the teachers' and learners' NOSI conceptions in relation to teacher instructional practices. The qualitative data and their analyses refined and explained statistical results by exploring participants' views in more depth (Creswell, 2003; Moghaddam, Walker, & Harre, 2003; Tashakkori & Teddlie, 1998). As mentioned earlier, the strengths and weaknesses of this mixed-methods design have been widely discussed in the literature (Creswell, 2003, 2005; Creswell, Goodchild, & Turner, 1996; Green & Caracelli, 1997). Some of the advantages mentioned include straightforwardness and opportunities for the exploration of the quantitative results in more detail. For this study the approach taken was found useful because teachers' and learners' NOSI views were inherently unknown at the beginning of the investigation. To Morse (1991), such a design presents limitations such as lengthy time and feasibility of resources to collect and analyze both types of data to one's study. As such, it was possible to overcome and address these assumed "shortcomings" through assimilating subjective bias into the research process which contributed to and strengthened the research instead of crippling it (Mama, 1995; Seedat, 1992).

The model shown in Figure 3.2 summarizes the sequence of the research activities followed in the study being reported here. It indicates the importance of the phase by capitalizing the term QUALITATIVE. The figure shows all the data collection and analysis procedures, and lists the products or outcomes from each of the stages of the study. It also shows the

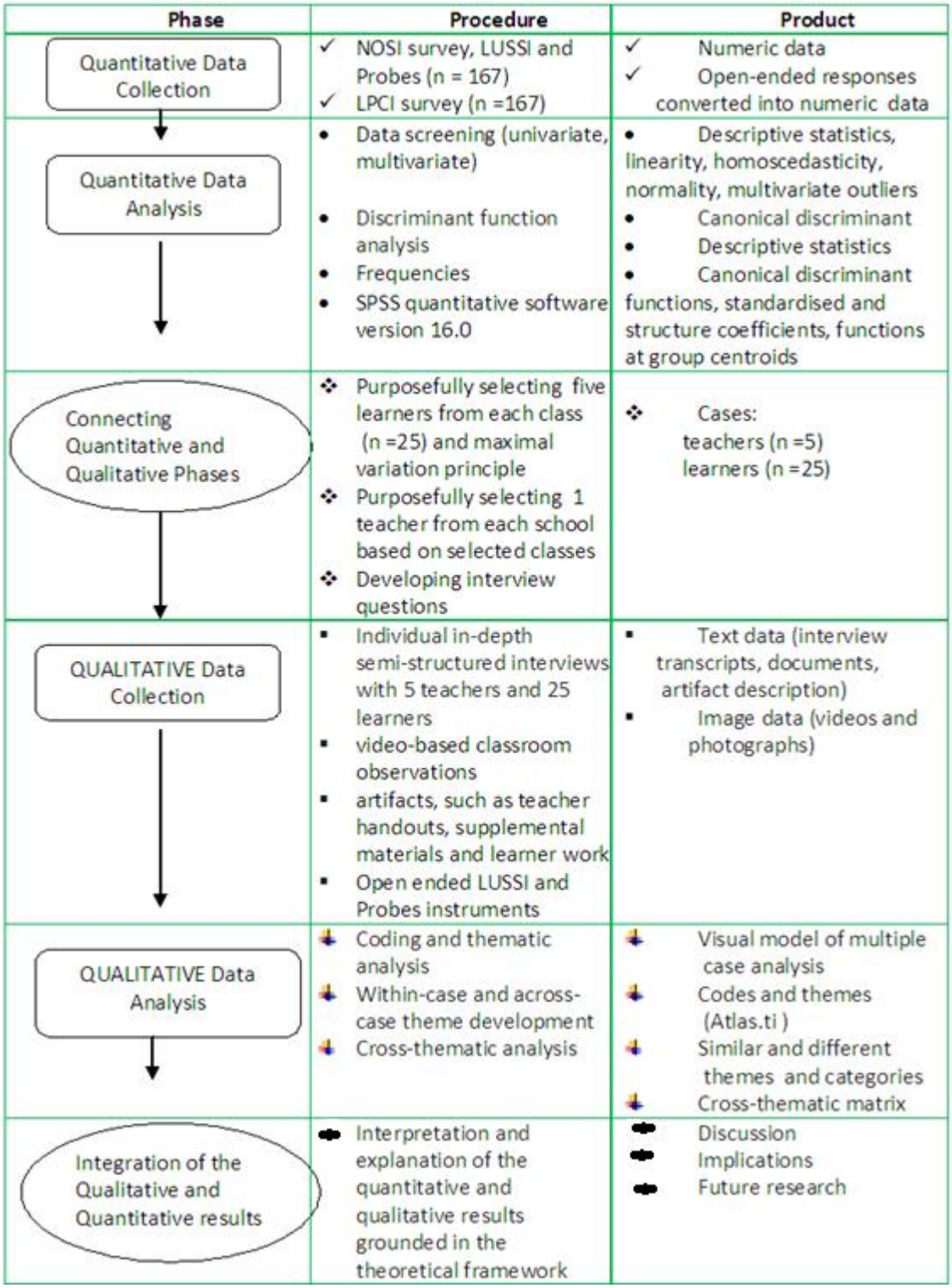

Figure 3.2: Visual Model for Mixed-Methods Sequential Explanatory Design Procedures employed in the study

connecting points between the quantitative and qualitative phases and the related products, as well as the integration or mixing of the results of both quantitative and qualitative phases. This sequence was followed for this study.

3.4 Research instruments: development, validity and reliability

The importance of providing checks and balances to maintain acceptable standards is a necessary component of any research inquiry. In this section, issues around validity and reliability relevant for the study are raised and discussed. An overview of validity and reliability for the mixed method approach is apposite.

3.4.1 Validity and reliability

Validity and reliability are fundamental concepts that are treated differently in both quantitative and qualitative research. Since mixed method research utilizes both quantitative and qualitative research strands, an overview of validity and reliability as defined and operationalized in both research strands is appropriate. Joppe (2000, p. 1) provides the following explanation of what *validity* is in quantitative research; "*validity* determines whether the research truly measures that which it was intended to measure or how truthful the research results are". If an instrument is designed to measure learners' NOSI conceptions for example, does it actually measure understanding and not opinions or beliefs? In other words, does the research instrument allow one to hit 'the bull's eye' of one's research object? Miller (2009) defines validity as the extent to which the instrument measures what it purports to measure. Similarly connected to Joppe's definition of validity, Bashir, Afzal and Azeem (2008) say validity determines whether the research truly measures that which it was intended to measure or how truthful the research results are. Insofar as the definitions of validity in quantitative research are concerned two issues are pertinent: Firstly, whether the means of measurement are accurate and secondly, whether they are actually measuring what they are intended to measure.

Joppe (2000, p. 1) defines reliability as:

> …the extent to which results are consistent over time and an accurate representation of the total population under study is referred to as reliability and if the results of a study can be reproduced under a similar methodology, then the research instrument is considered to be reliable.

Embodied in this citation is the idea of replicability or repeatability of results or observations. Brink (1991, p. 176) identifies three types of reliability referred to in quantitative research, which relate to: (1) the degree to which a measurement, given repeatedly, remains the same (2) the stability of a measurement over time; and (3) the similarity of measurements within a given time period (p. 176). Czaja and Blair (1996) adheres to the notions that consistency with which questionnaire [test] items are answered or individual's scores remain relatively the same can be determined through the test-retest method at two different times. This attribute of the instrument is actually referred to as stability. If we are dealing with a stable measure, then the results should be similar. A high degree of stability indicates a high degree of reliability, which means the results are repeatable. Joppe (2000) detects a problem with the test-retest method which can make the instrument, to a certain degree, unreliable. She explains that test-retest method may sensitize the respondent to the subject matter, and hence influence the responses given. Researchers cannot be sure if there is no change in extraneous influences such as an attitude change, for example, that occurs. This could lead to a difference in the responses provided.

3.4.2 Types of validity

Validity in quantitative research

There are many different types of validity, which include; *face validity*, *content validity*, *construct validity*, *criterion-related validity* (or *predictive validity*), *factorial validity*, *concurrent validity*, *convergent validity* and *divergent* (or *discriminant validity*) (Miller, 2009). For the instruments used in this study, the types of validity of concern are mainly the first three.

Face validity is defined as the extent to which casual, subjective inspection of an instrument's items indicates that they cover the content that the instrument claims to measure (Gall, Gall, & Borg, 2003). *Face validity* is about looking at the operationalization and seeing whether "on its face" the instrument seems like a good translation of the construct (McGartland & Kimberly, 2005; Miller, 2009). In this study the constructs are conceptions of the NOSI and teacher inquiry practices. Face validity refers to what the instrument superficially appears to measure. Simply put, face validity means the validity at face value. According to Golafshani (2003), 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. In this study, face validity of instruments was determined by the respondents to each instrument and a panel of experts working in the same university where the researcher was registered. However, the criteria of validity in research go beyond 'face' and 'appearance' and closely related to face validity is content validity.

Content validity refers to the extent to which a test or instrument measures a representative sample of subject-matter content, for example the coverage of the content of a syllabus (Cohen, et al., 2000). To Miller (2009), it pertains to the degree to which the instrument fully assesses or measures the construct of interest. The construct means concept, notion, or hypothesis, which forms the basis for the researcher to make decisions about data collection and sampling designs, consistent with the construct (Bashir, et al., 2008). In the case of determining conceptions of the NOSI, *content validity* addresses the question of whether the instrument's items actually capture (are relevant to) the constitutive tenets (as discussed under the theoretical framework in Chapter 1) of the NOSI. Both the LUSSI and the Probes questionnaire instruments used in this study cover all the tenets. In other words, *content validity* is essentially about checking the operationalization against the relevant content domain for the construct. It is usually established by consensus among content experts. Miller (2009) is of the opinion that development of a content valid instrument is typically achieved by a rational analysis of the instrument by raters (ideally 3 to 5) familiar with the construct of interest. Specifically, raters review all of the items for readability, clarity and

comprehensiveness and come to some level of agreement as to which items should be included in the final instrument. A team of experts working in the same university where the researcher is registered and some teachers in schools were used for piloting content validated the instruments used in this study.

Construct validity is the third type of validity of relevant concern that relates to the instruments used in this study. Construct validity is the degree to which an instrument measures the trait or theoretical construct that it is intended to measure (Miller, 2009). The extent to which an instrument or test score (outcome of measurement) is a measure of what is understood as 'creativity' is referred to as construct validity (Ryu & Smith-Jackson, 2005). The creativity of an instrument or test is made up of a large number of individual instrument items. In this case, this refers to items on all instruments used in this study. In this sense, creativity is not something which can be directly observed but must be inferred from other observable behaviour. Creativity is equated to a 'construct' which Lincoln and Guba (2000) define as 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. In simple terms, construct validity examines the fit between the conceptual definitions and operational definitions of variables.

Construct validity can also be described in terms of the correlation between the *intended* independent variable (construct) and the *proxy* independent variable (indicator, sign) that is actually used such as learners' response to the LUSSI instrument. Here correlation is assumed between for example getting a high score on the LUSSI instrument and harbouring informed views of the NOSI. The existence of the construct is established by inference. Other schools of thought (e.g., Angoff, 1988; Cronbach & Quirk, 1976; Li, 2003) argue that construct validity cannot be expressed in a single coefficient; there is no mathematical index of construct validity. Rather the nature of construct validity is qualitative. They recommend two types of indicators: reflective indicator (the effect of the construct) and formative indicator (the cause of the construct). When an indicator is expressed in terms of multiple items of an instrument, *factor analysis* is used for construct validation. Factor

analysis is a statistical procedure used to uncover relationships among many variables (Gorsuch, 2003; Stanek & Buonaccorsi, 1995). The traditional factor analysis has been developed through decades of study on the relationship of latent variables and the observed data as an approach to demonstrate construct related validity. This study utilized adapted instruments of which factor analysis (exploratory factor analysis to be precise) had been performed on three of the Likert-type instruments. Suffice to mention that validity can only be estimated and is not determined with outmost precision.

Validity in qualitative research

For *qualitative research, validity* has a plethora of meanings. The reason being qualitative researchers are of the view that the term validity is not applicable to qualitative research, but at the same time, have realized the need for some kind of qualifying check or measure for their research. As a result, many researchers have developed their own concepts of validity and have often generated or adopted what they consider to be more appropriate terms, such as, quality, rigor and trustworthiness (Davies & Dodd, 2002; Lincoln & Guba, 1985; Seale, 1999; Stenbacka, 2001). The traditional method of judging the rigor of a research inquiry is by the use of several of the following six strategies: prolonged engagement, triangulation, peer debriefing and support, member checking, negative case analysis, or auditing (Guba & Lincoln, 1989; Lincoln & Guba, 2000; Padgett, 1998). Researchers, who frame their studies in an interpretive model, think in terms of trustworthiness as opposed to the conventional, criteria of internal and external validity, reliability, and objectivity (Denzin & Lincoln, 1994; Lincoln & Guba, 2000; Padgett, 1998).

While the term validity is essential criterion for quality in quantitative paradigms, in qualitative paradigms the terms Credibility, Neutrality or Confirmability, Consistency or Dependability and Applicability or Transferability are to be the essential criteria for quality (Lincoln & Guba, 2000). Credibility in quantitative research depends on instrument construction, but in qualitative research, “the researcher is the instrument" (Patton, 2002, p. 14). Thus, it seems when quantitative researchers speak of research validity and reliability,

they are usually referring to a research that is credible while the credibility of a qualitative research depends on the ability and effort of the researcher. Although reliability and validity are treated separately in quantitative studies, these terms are not viewed separately in qualitative research. Instead, terminology that encompasses both, such as credibility, transferability, and trustworthiness is used. In the same vein, Denzin and Lincoln (1994) are of the opinion that four factors namely credibility, confirmability, dependability and transferability, should be considered in establishing the trustworthiness of findings from qualitative research.

Credibility refers to the confidence one can have in the truth of the findings and can be established by various methods (Golafshani, 2003). Three credibility methods are triangulation, member checking and negative case analysis. Triangulation is defined to be "a validity procedure where researchers search for convergence among multiple and different sources of information to form themes or categories in a study" (Creswell & Miller, 2000, p. 126). Triangulation is a way of corroboration that allows the researcher to be more confident of the study's conclusions. In this study, with respect to triangulation, data from multiple sources through multiple methods (i.e. interviews, classroom observation, and open-ended questions), non-participant observation, and document reviews was employed. *Confirmability* refers to the quality of the results, in other words the degree to which qualitative data and their interpretations can be authenticated. The techniques used for establishing credibility such as data triangulation, investigator triangulation, and member-checking are important for building confirmability. According to Denzin & Lincoln (1994) *dependability* refers to the stability of the findings over time and confirmability to the internal coherence of the data in relation to the findings, interpretations, and recommendations. An audit trail can be used to accomplish dependability and confirmability simultaneously (Lincoln & Guba, 1985; Padgett, 1998). The audit trail for this study included detailed notes regarding data collection, data analysis, and any modifications made. Transferability or applicability means, in essence, that other researchers can apply the findings of the study to their own. To provide for applicability the study presents the findings with "thick" descriptions of the participants, the data collection

procedures, the analytic procedures, and the emergent patterns. The current study invested in these ways to improve and demonstrate validity.

3.4.3 Reliability

Reliability procedures in quantitative research

Reliability procedures are designed to find out whether the items in the test measure the same thing (Ary, Jacobs, & Razavieh, 1996). These are so-called internal consistency measures 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 (Leong & Austin, 2006; Miller, 2009). 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 (Nunnally & Bernstein, 1994). They help in describing the extent to which the same trait or attribute is being measured. This study utilized adopted instruments of which high inter-item coefficients (e.g. Cronbach alpha) had been performed in three of the Likert-type instruments. This is not to say validity and reliability is the same thing. An instrument can be reliable without being valid (Lincoln & Guba, 2000). However, when an instrument is valid it is most likely to be reliable. Patton (2002) concurs that reliability is a consequence of the validity in a study.

Reliability procedures in qualitative research

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)

(Bogdan & Biklen 1992; Gall, et al., 2007). Stenbacka (2001) views reliability as having the purpose of 'generating understanding' in the qualitative approach to research. Issues of reliability have been questioned in qualitative research (Bashir, et al., 2008). Evaluating the quality of studies is one of the reasons that make the concept of reliability irrelevant in qualitative research. Stenbacka (2001) believes the concept of reliability is even misleading in qualitative research. He goes on to say if a qualitative study is discussed with reliability as a criterion; the consequence is rather that the study is no good. That aside, Bashir et al., (2008) argue that to ensure reliability in qualitative research, examination of trustworthiness is crucial.

To be more specific with the term of reliability in qualitative research, Lincoln and Guba (1985, p. 300) use "dependability", which closely corresponds to the notion of "reliability" in quantitative research. They further emphasize "inquiry audit" (p. 317) as one measure which might enhance the dependability of qualitative research. This can be used to examine both the process and the product of the research for consistency (Hoepfl, 1997). In the same vein, Clont (1992) and Seale (1999) agree that the term dependability is consistent with reliability in qualitative research. The consistency of data will be achieved when the steps of the research are verified through examination of such items as raw data, data reduction products, and process notes (Campbell, 1996). This consistency and accuracy help demonstrate a high level of reliability.

3.5 Sampling and participants

3.5.1 Schools

Purposeful and convenience sampling was used to identify research sites (Patton, 1990) for this study. Five schools (one from each district, n=5) located in and around Johannesburg (within 90km radius) in the Gauteng Province of South Africa, were purposively and conveniently sampled from a total of 18 Gauteng's administrative districts. From a possibility of ten schools that place emphasis on Mathematics, Science and Technology the five schools were selected for their proximity and accessibility to the researcher. All five

schools are public schools with two of them located in historically disadvantaged poverty-stricken backgrounds. The two schools are mainly designated for blacks and located in townships. Townships are historic settlements designated for blacks and characterised by poor socio-economic conditions and poor education structure and resources. The other three schools are former model C schools. Of the three, two are city schools and one is a suburban boarding school. Former model C schools had the best facilities, best teachers and best educational opportunities for learners and to this day some schools enjoy these priviledges. However, the three schools sampled for this study now accommodate white, coloured and black learners. However, for this study, the selected schools can be described as generally uniform in terms of availability of teaching and learning resources for Physical Science and class sizes. Each of the selected schools had at least one science laboratory for use in Physical Science teaching. The average class size for Grade 11 at each of the schools was approximately 33. Each of the Grade 11 classes at the selected schools was taught by a qualified teacher. This implies that the other criterion for selection was that schools were functional. By functional, it means the teaching of investigations was actually taking place in the five schools. This meant lack of external resources like the laboratory, laboratory equipment, and books was not cited as a major problem.

3.5.2 Learners

One Grade 11 class randomly chosen by the participating teacher at each of the five sampled schools participated in the study giving a total of 167 learners. As noted, the average class size for Grade 11 at each of the schools was approximately 33. All the 167 learners completed the LUSSI, LPCI and Probes questionnaires. For the interviews, five learners from each school, who had also completed the three instruments as mentioned before were purposefully sampled (ensuring gender balance) to take part in the semi-structured interviews, giving a total of 25 learners. At least for each school the same number for boys and girls was almost the same. The selection was based on the responses by the learners to the LUSSI, LPCI and Probes questionnaires. These learners were selected because they appeared to have given the most comprehensive answers in the open-ended

sections of the LUSSI and Probes instrument whilst some of these learners' responses to the open-ended responses needed further probing.

Learner numbers by gender were as follows: 108 out of 167 learners (65 %) were females and 59 out of 167 learners (35 %) were males. Of the 25 interviewed learners, fifteen (60 %) were females and ten (40 %) were males. The average age of the learners was 17 years (age range 16 to 18 years). In addition to Physical Science, all the learners were also studying at least six subjects, including two compulsory official South African languages - a first and second language - and three elected subjects (depending on the curriculum focus of the school). Life Orientation is a non-optional subject which was being done by all the 167 learners. Fifty-five out of 167 learners (33 %) were at two city schools, sixty-eight out of 167 learners (41 %) were at two township schools and forty-four out of 167 learners (26 %) were at one suburban boarding school in Gauteng, Johannesburg.

3.5.3Teachers

Table 3.1: Summary of demographic variables for the five interviewed and observed teachers.

Teacher code	Name	Qualifications	Type of School	Teaching experience
T1	Ranelo	B.Sc. (Hons.), B. Ed., S.T.D	Township	18yrs
T2 (Female)	Hedwick	M.Sc., B.Sc. (Hons.),B.Ed.	City	22yrs
T3	Jairos	B.Sc. (Hons.), B.Ed., Dip.Ed.	Suburban Boarding	15yrs
T4	Johnny	B.Ed., Cert.Ed., ACE	City	20yrs
T5	Booi	B.Sc. (Hons.), B.Pedagogics, S.T.D	Township	16yrs

Five teachers, one from each of the five selected schools formed the study sample. The five teachers, pseudo-named, Ranelo, Hedwick, Jairos, Johnny and Booi Johnny were chosen

for the study for two major reasons. First from a possibility of ten schools in 18 Gauteng's administrative districts that place emphasis on Mathematics, Science and Technology, they are the ones who were judged to be the most experienced, and also appeared to be cooperative and willing to participate in the study. Second, they also willingly agreed to re-sequence their content so as to be teaching investigations with Grade 11 classes during the period of the study. The teachers involved in this study were the Grade 11 Physical Science teachers of the sampled learners. Thus at each school, the study involved a Physical Science Grade 11 teacher and about 33 learners. All five teachers were interviewed about their NOSI conceptions and laboratory instructional practices. Three practical investigation sessions (a pre-laboratory, laboratory and post-laboratory session) for each of the five teachers were observed.

Of the five teachers only one is female (Hedwick). She held a Master of Science degree, a Bachelor of Science Honours degree both from the University of Witwatersrand, and a Bachelor of Education degree from formerly the Johannesburg College of Education (JCE) now the School of Education, University of Witwatersrand. Three of the male teachers held a Bachelor of Science Honours degree from the University of Witwatersrand. One of these three teachers (Jairos) held a Bachelor of Education degree and a Diploma in Education both from the University of Zimbabwe. In addition to the Bachelor of Science Honours degree, one (Ranelo) of the other two male teachers, held a Bachelor of Education degree from the University of Johannesburg and teaching qualifications (S.T.D) from teachers' colleges. The other (Booi) held a Bachelor of Pedagogics degree from the University of Johannesburg and teaching qualifications (S.T.D) from teachers' colleges which have long since been closed. The last male teacher (Johnny) had a Bachelor of Education degree and a Certificate of Education from the University of Zimbabwe and an Advanced Certificate in Education (ACE) from the University of the Witwatersrand.

All teachers had been exposed to the History and Philosophy of Science and Scientific Inquiry as part of their training. The NOSI, as mentioned before (Chapter 2) has its roots in the philosophy of science. All the five teachers had high school teaching experience

ranging from fifteen to twenty-two years and had regularly gone for in-service training to upgrade their qualifications. All sampled teachers were teaching Physical Science at Further Education and Training (FET) level, that is, Grades 10, 11 and 12 and either Mathematics or Natural Science at General Education and Training (GET) level, that is, Grades 8 and 9. Only the female teacher had a teaching load of 24, 40-minute periods per week because she was a Head of Department (HOD). The other four teachers had on the average a total teaching load of 36, 40-minute periods per week. Table 3.1 summarizes the demographic variables for the interviewed teachers who for ethical reasons are given the indicated pseudonyms.

3.6 Instruments

In this section the instruments used to gather data in this study are discussed. These instruments are: the Learners' Understanding of Science and Scientific Inquiry (LUSSI); Probes, Learner Perception of Classroom inquiry (LPCI), and Teacher Perception of Classroom inquiry (TPCI) questionnaires, semi-structured interview schedules, and classroom observation schedules.

3.6.1 Learners' Understanding of Science and Scientific Inquiry (LUSSI) Questionnaire

To get learners' conceptions of the NOSI the LUSSI questionnaire was used. A Student Understanding of Science and Scientific Inquiry (SUSSI) instrument developed by Liang et al. (2006) was adopted and renamed the Learners' Understanding of Science and Scientific Inquiry (LUSSI) Instrument (see, Appendix A). The LUSSI instrument was specifically chosen for this study for several reasons. First, the instrument has been used successfully in educational contexts similar to South Africa, i.e. Taiwan and China. Second, a study using this instrument has never been done on the African continent; and thirdly, the data obtained by the instrument is comparatively easy to analyze and prone to statistical analysis. The original version of the SUSSI instrument comes from a combination of two instruments, the VOSTS (Aikenhead & Ryan, 1992), and VNOS- Form C (2002). Known as the SUSSI, the first draft of this instrument was developed in 2004 (Liang, et al., 2006). Minor syntactical

changes were made to the SUSSI instrument. For example, in the SUSSI, the word *student was* replaced by the word *learners* in the LUSSI instrument. This was done for consistency purposes. The thesis focuses on learners and not students and as such it was felt that wording had to be changed to be in tandem with the focus of the thesis. The LUSSI questionnaire (Appendix A) comprises a questionnaire in two parts. The instrument blends Likert-type items and related open-ended questions to assess learners' conceptions of selected NOSI tenets.

Items on the LUSSI questionnaire cover the six NOSI tenets chosen for this study, which are: observations and inferences in science; scientific laws versus theories in science; change of scientific theories in science; social and cultural influence on science; imagination and creativity in scientific investigations; and methodology of scientific investigations. For each NOSI tenet, the closed-ended part asks learners to indicate their views on a five point Likert scale ranging from *strongly agree to strongly disagree*, similar to the instrument developed by Pomeroy (1993). The respondents are required to explain their views in the open-ended part of the question. For Likert-type items, learners indicated their responses by ticking (√) in appropriate boxes. The first part for each of the six tenets has four items that represent both the most common naïve ideas and informed views consistent with standard documents and current nature of scientific knowledge literature (American Association for the Advancement of Science, 1993; National Research Council, 2005, 2006). For each item the second part, the open-ended question also solicited learners' views on the targeted NOSI aspects and required learners to explain their answers with the aid of examples. In a way it specifically asked learners to give their views on the targeted NOSI aspect. An extract (Table 3.1) illustrates one of the NOSI items in the questionnaire. In this case, the NOSI tenet was the methodology followed by scientists during investigations and how scientific knowledge is discussed and created.

Table 3.2: An extract from the LUSSI instrument showing an example of a NOSI item

Item		SD	D	U	A	SA
A	Scientists use a variety of methods to conduct scientific investigations					
B	Scientists follow the same step-by-step scientific method					
C	When scientists use the scientific method correctly, their results are true and accurate.					
D	Experiments are not the only means used in the development of scientific knowledge.					

Where: SD = strongly disagree; D= disagree; U= uncertain; A = agree; SA = strongly agree

The tenets are organised in the following manner in the instrument: (1) observations and Inferences in science; (2) scientific laws versus theories; (3) change of scientific theories; (4) social and cultural influences on science; (5) imagination and creativity in scientific investigations; and (6) methodology of scientific investigations. Exploration of learners' conceptions of the NOSI is reported in some studies of learners' NOSI conceptions (Lederman, 2008a; Miller, et al., 2010; Schwartz, et al., 2008) and was seen as appropriate in this study. The Learners' Understanding of Science and Scientific Inquiry (SUSSI) instrument has been globally tagged as a valid and meaningful instrument which has been used as either a summative or formative assessment tool in small and/or large scale studies and used to track learners' growth and promote evidence-based practice in determining learners' conceptions of NOSI (Liang, et al., 2008).

To validate the instrument, a version was administered to 90 Grade 11 learners from two classes at one High School purposively and conveniently sampled (the school was not part

of the sample for the main study), in Gauteng. After completing the instrument, 10 learners were again purposively selected based on their responses to the LUSSI (five from each class). These learners were selected because they appeared to have given the most comprehensive answers in the open-ended sections of the LUSSI. Among other issues, the researcher saw it necessary to check on learners' understandings of the complexity of the English language used in the questionnaire. This is because South Africa has eleven major official indigenous languages. For most Grade 11 South African learners who formed the population of the study, English is a second language if not third or fourth after Afrikaans, IsiXhosa, Zulu, or Tswana. First they were interviewed, individually (in the absence of the other learners and also ensuring that the learners did not mix to share answers) and later as a group about whether or not they had difficulties with understanding the complexity of the language in the questionnaire. The researcher went on to ask the learners individually to explain how they interpreted statements from the questionnaire. The ten learners were also asked to comment on what they thought the instrument was designed to measure. It came out that the learners understood that the questionnaire sought to elicit their views on what science is, based on what they did during practical investigations. Their class teachers were also asked to comment on how they make of the questionnaire.

Face validity and content validity and construct were further evaluated by a panel of six experts (three Professors, two doctoral students, and one Masters' student) at the same university where the researcher was registered. They were given the instrument to comment on its face value and the relevance of the content and constructs included in the questionnaire instrument. The instrument was also given to twenty-five (25) postgraduate science (physics, chemistry and biology) students doing a BSc Honours course in science education. They were asked to comment on its face validity. All participants who were asked to face validate the LUSSI instrument gave it a thumps up regarding this validity aspect.

Repetitive testing which can be done through the test-retest method assumes that there is no substantial change in the construct being measured between the two occasions of testing.

Implementing this type of testing using the LUSSI instrument within a shorter time gap would produce a higher correlation and the longer time gap would produce a lower correlation. This is because the two observations are related overtime hence the closer in time one gets the more similar the factors that contribute to error. Since this correlation is the test-retest estimate of reliability, considerable different estimates could be produced depending on the interval. Repetitive testing was however not conducted with the LUSSI instrument because teachers could not afford to further let go more of their precious teaching time considering their packed schedule for the year. The researcher is aware of how this is a threat to validity issues.

3.6.2 Probes

The Probes questionnaire was used to corroborate learners' conceptions of the NOSI. To Jääskö and Mattelmäki (2003), probes provide contexts for respondents to reflect on their NOSI conceptions and for this reason they were chosen for this study. Probes have been used to investigate understandings of the NOSI in several studies (see, for example, Ibrahim, et al., 2009; Lederman, 2008b). Exploration of both teachers' and learners' conceptions of the NOSI using probes is reported in some studies of teachers and learners' nature of scientific knowledge conceptions (Lederman, 2008b; Miller, et al., 2010; Schwartz, et al., 2008). The use of probes was seen as appropriate for this study.

Each probe presents a scenario followed by a number of different options, which are presented in the form of conversations. This instrument (Appendix B) comprises a questionnaire in two parts. The written instrument consists of 6 probes related to NOSI aspects. The probes were adapted from three instruments the VOSTS (Aikenhead & Ryan, 1992), the VNOS-Form A (Lederman & O'Malley, 1990) and VNOS- Form C (Lederman, Abd-El-Khalick, et al., 2002). All probes in the questionnaire have a common style and are based on the same context which involves conceptions of the NOSI.

Figure 3.3 illustrates one of the NOSI probes in the questionnaire. In this case, learners' ideas on the use of human "imagination" and "creativity" in the creation of scientific

knowledge are being elicited. The respondents are requested to select only one of the alternatives provided, which is deemed to be most appropriate. They are also asked to provide a detailed justification for their choice. The explanations for their decisions provide insight in the underlying reasoning on which their actions are built. By providing the option "I have a different idea" or "I have another view which I will explain" for all probes, respondents are encouraged to formulate alternative choices (with rationale) on the issue discussed in the probe.

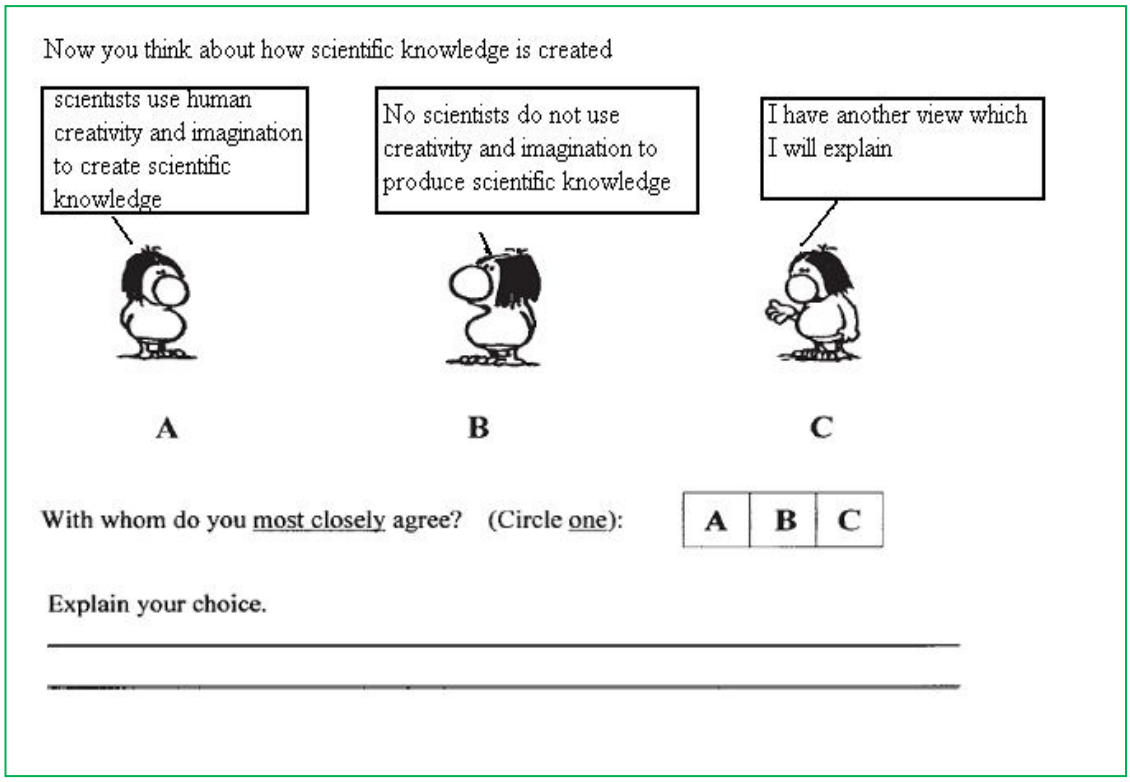

Figure 3.3: Example of a NOSI probe

One probe was used for each of the six NOSI tenets chosen for this study. Review of pertinent literature (Ibrahim, et al., 2009), shows that previous studies carried out with similar target groups showed that the use of real-life figures and names can lead to prejudice towards the selection of an option. Consequently, to improve construct validity of the responses, cartoons were used and labelled by letters to present the various options for

each question, as they do not refer to any aspect of gender, race and culture. The vocabulary was chosen to be simple and the words were reduced to a minimum. Respondents were asked to complete the set of written probes individually and in no strict sequence.

The same learners who validated the LUSSI and LPCI instruments were used to validate the Probes questionnaire. The researcher wanted to ascertain if the instrument items had same meaning the researcher had in mind when designing the tool. The instrument was also given to three Professors, two doctoral students and one Masters' student at the same university where the researchers was registered for face, content and constructs validation. The instrument was further given to twenty-five (25) postgraduate science (physics, chemistry and biology) students doing a BSC Honours course in science education for face and construct validation. All these respondents were working in the field of scientific inquiry. These experts and post graduate students were given the instrument for peer reviewing it so as to improve the instrument's content validity and construct validity to some extent.

3.6.3 Learner Perception of Classroom Inquiry (LPCI) Questionnaire

To determine learner perceptions of the extent of inquiry during investigations the LPCI questionnaire was used. The Principles of Scientific Inquiry-Student (PSI-S) instrument (Campbell, et al., 2010) was adopted and named the Learner Perceptions of Classroom Inquiry (LPCI) instrument (see, Appendix C). The instrument was renamed because to determine extent of inquiry the researcher used learner perceptions as measured through their scores to the LPCI. Essentially the instrument measures learner perceptions of the extent to which they experience inquiry during science lessons. The instrument consists of 20-items separated into five parts (each with four items), each representing a category of the practice of scientific inquiry namely; asking questions/framing of research questions, designing investigations, conducting investigations, collecting data and drawing conclusions. The response alternatives for the items are based on a five-point Likert scale with responses ranging from *almost never* to *almost always*.

By adding the scores to each instrument item, a total score is obtained for each learner for the whole instrument giving learner rankings. Learners' scores are then used to determine the extent to which they are engaged in the principles of scientific inquiry in the laboratory or classroom. Examples of items on the questionnaire are:

A1. I formulate my own questions which can be answered by investigations;

B1: I am given step-by-step instructions before I conduct investigations;

C4: I have a role as investigations are conducted;

D1: I determine which data to collect; and

E4: I justify their conclusions.

The instrument had been found to be internally consistent with high reliability estimates after both Cronbach alpha reliability tests estimates and exploratory factor analyses were performed on it (Campbell, et al., 2010) with 130 secondary school science learners from one Western State, in the USA. Campbell et al. (2010) provide reliability evidence through a Cronbach alpha value of 0.85 for the entire instrument and validity evidence through factor analysis and expert content analysis (p. 23). While the validity of the instrument items was ascertained (Campbell, et al., 2010), there was need to corroborate the analysis as well as the content and construct validity of the instrument in the South African context.

The instrument was validated by the same group of learners who validated both the Learner's Understanding of Science and Scientific Inquiry and Probes' instruments. Discussions were held with the learners about their interpretation of the meanings of the item statements. Readability concerns for the LPCI were addressed by this validation process. Before the instrument was used in the study, an estimate was made of the correlation between group items and its internal consistency. Three colleagues – two university Professor, one doctoral student and one Masters' student all working in the field of scientific inquiry at the same university the researcher was registered were given the LPCI instrument to validate.

3.6.4 Teacher Perception of Classroom Inquiry (TPCI) Questionnaire

To determine teacher perceptions of the extent of inquiry a teacher was practising, the researcher used the TPCI questionnaire. The teacher instrument (Appendix D) was similar to the learner questionnaire with the only difference being the syntax. Syntactical changes were made to the statements to suit the teacher. For example, "I formulate questions which can be answered by investigations" (statement A1 of the learner questionnaire) was changed to read: "Learners formulate questions which can be answered by investigations". In this instance, "I" representing the learner is replaced by the word "learners". Some other examples of statements on the instrument are as follows (with the statement number in square brackets), ''Learners are given step-by-step instructions before they conduct investigations" [B1], "Learners conduct their procedures" [C2], "Learners determine which data they should collect" [D1] and "Learners justify their conclusions" [E4].

The instrument required the teachers to indicate how often they allowed what the item statement said in their classroom/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. As was the case with the learner questionnaire the content and construct validity of the instrument was established through the consensual judgment of the same three colleagues described in the preceding learners section above.

The instrument was given to two teachers in the school which was used to validate the other instruments. These are the teachers who were teaching the two Grade 11 classes. The same experts and postgraduate students who validated the LUSSI, LPCI and Probes instruments are the same people who validated the TPCI questionnaire. The validation was done the same way the LPCI was validated as explained in section 3.6.3.2

3.6.5 Learner Semi-structured Interview Schedule

For purposes of getting a deeper understanding of the nature of scientific inquiry as well as corroborate probes and open-ended Likert instrument (LUSSI) responses, interviewing of

sampled learners (n = 25) was done using the semi-structured format (Merriam, 1998). An initial batch of nine questions was administered to a sample of ten Grade 11 Physical Science learners from two classes (five from each class) at a school in Gauteng, Johannesburg which was not part of the study sample. The learners were purposively selected based on their responses to the LUSSI instrument which they had completed earlier. After analyzing the responses the researcher interviewed the ten 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 learners problems of understanding and interpretation. The remaining six questions elicited learners' views on selected aspects of the following broad issues: scientific laws versus theories; change of theories; imagination and creativity in science; social and cultural embeddedness of science; the scientific method in science; and observations and inferences in science. The six questions used were:

1. Do you think laws and theories serve different roles in science? Explain your answer.
2. Do scientific theories change with time after having been developed by scientists? Elaborate on your response.
3. From what you do during Physical Science practical investigations, what can you say about the use of imagination and creativity in science?
4. Where do you think scientific knowledge comes from?
5. What can you say about the methods scientists use in their investigations or experiments?
6. From what you do in Physical Science practical investigations, what can you say about scientific observations?

Interviewing was done around a set of these six core questions. The structuring of the core questions was informed by the literature (Kirschner, Sweller, & Clark, 2006; Liang, et al., 2006; Ryder & Leach, 2000; Saunders, Cavallo, & Abraham, 1999). Five of the questions asked in the open-ended section of the LUSSI (questions 1, 2, 3, 5 and 6, Appendix A) were also asked in the interview (questions 1, 2, 3, 5 and 6 above). The six questions

formed the basis for the learner probing and other questions were also asked as a way of following up to get clarifications or to get a deeper understanding. Additional questions asked as part of the probing, for example, was "In your opinion explain how the teaching of scientific laws and theories at high school level is important?" This question was asked as a follow up to question 1 above. Questioning was not done in the same sequence for all the interviewed learners.

During the same interview, learners were also asked questions about the extent to which they experienced inquiry during science lessons. The theoretical guideline was assessment of learners' perceptions of the nature of inquiry. Learners were asked questions related to what actually happens in the laboratory when conducting investigations. Questions elicited learners' views on selected aspects of the following broad issues: the source of the investigative problem; framing investigative questions; conduct investigations; designing investigations; data collection; and drawing conclusions. The five questions used were:

1. Who frames the investigative questions?
2. How do you design your investigations?
3. How do you conduct the actual investigation?
4. How is data collected during investigations? and
5. How are conclusions drawn from investigations?

The questions were designed to serve the purposes of corroborating learners' responses to the LPCI instrument, getting a deeper understanding of learners' perceptions of the extent to which they experience inquiry during science lessons and eliciting teacher practices the teachers engaged in when teaching practical investigations.

3.6.6 Teacher Semi-structured Interview Schedule

Teachers were interviewed for the purposes of:

(i) Corroborating responses from the Probes and TPCI; and
(ii) Getting a deeper understanding of teachers' NOSI understandings and laboratory instructional practices.

In order to get information about teachers' NOSI understandings 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. Do you think what you do in the Physical Science laboratory with your learners is similar to what is done in scientific laboratories?
2. How do scientists build scientific knowledge?
3. Why do scientists do experiments?
4. Do you think laws and theories serve different roles in science? Explain your answer.
5. Are scientific observations theory- free?
6. Do you think scientific theories change with time after having been developed by scientists? Explain.
7. Will the knowledge we know in Physical Science today one day change?
8. From what you do during Physical Science practical investigations, what can you say about the use of imagination and creativity in science?
9. Where do you think scientific knowledge comes from?
10. Why do scientists do experiments?
11. Is scientific knowledge culture free?
12. How is scientific knowledge validated?
13. What can you say about the methods scientists use in their investigations or experiment?

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 Grade 11 practical investigations?
2. What is your philosophy of teaching investigations?
3. Do you think the way you teach Physical Science practical investigations helps learners understand what science is all about?

3.6.7 Laboratory Class Observation Schedule

Grade 11 Physical Science practical investigation sessions were observed for the purposes of triangulating information from the TPCI, LPCI as well as the information obtained from both teachers' and learners' interviews. In addition, classrooms were observed to describe in detail, teachers different teaching practices that supported learners' scientific inquiry, specifically in regards to the ways that the teachers identified, interpreted, evaluated and responded to their learners' scientific inquiry. This was done to learn about the general practice of inquiry, the inquiry settings and learner engagement in the methodological processes of inquiry (Dolan & Grady, 2010) of the teachers' classrooms. Each Grade 11 class from each school met with their teacher for three lessons (pre-laboratory, laboratory and post-laboratory) to do work related to the Chemistry practical investigation.

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, proceedings were video-recorded (by an assistant) and the researcher sat at the back of the laboratory and took detailed notes of the proceedings. The observations were structured with criteria as shown below. The capture of lesson proceedings were guided by a deliberate effort to examine the following issues (Abraham, 1982; Scharman & Smith, 2002):

(i) source of problem for practical investigation(s).
(ii) how the teacher give out instructions and other information

(iii) nature of learner-learner interactions
(iv) nature of teacher- learner interactions
(v) how learners recorded information
(vi) group activities if any
(vii) pre and post laboratory activities
(viii) what was expected of learners' reports
(ix) how learners made observations
(x) how learners interpreted data
(xi) skills and techniques displayed by the learners
(xii) lesson introduction and lesson closure
(xiii) the open-endedness of tasks or activities (degrees of freedom given to learners to make decisions)

In one sense, classroom observation was unstructured allowing the situation to "speak for itself". However, in another sense the observation was structured since certain aspects of the teaching and learning processes in the classroom had been identified and were focused on.

3.7 Data Collection Procedure

First, the instruments were piloted. After the instruments were validated, learner questionnaires (LUSSI, Probes and LPCI) were administered. Teacher questionnaire (Probes and TPCI) were second to be administered. Classroom observation followed administration of teacher questionnaires. As classroom observations were taking place, quantitative (numeric) data was being analyzed. After classroom observations, learner interviews for sampled learners commenced. This was followed by teacher interviews. After concluding learner and teacher interviews, qualitative (text) data was then analyzed. This helped explain, or elaborated on, the quantitative results obtained in the first phase. Qualitative data built on the quantitative data, and the two types of data were connected during the interpretation and explanation of the results in the study.

3.7.1 Ethics Clearance and research permission

The researcher applied to Wits University Human Research Ethics Committee (Non-medical) for ethical clearance to conduct the research. The research proposal, which outlined the procedures, clear information to the participants, informed consent forms and copies of all the instruments to be used accompanied the application. The application also included copies of relevant letters and associated forms for each of the parties involved in the study. The committee approved the conduct of this study, in Protocol number 2010ECE04C of 19 April 2010 (see Appendix E, p.347).

After being granted ethical clearance by the Wits University Human Research Ethics Committee (Non-medical), the researcher then applied to the Gauteng Department of Education (GDE) for ethical clearance to conduct the research in schools under their jurisdiction. Again, the research proposal, which outlined the procedures, clear information to the participants, informed consent forms and copies of all the instruments to be used accompanied the application. Permission was granted by the Gauteng Department of Education (GDE). Appendix F has the information about the confirmation of the permission from the GDE. Permission was also obtained from parents, the science teachers and the Principals of the schools for their learners to take part in this research. All the above-mentioned people, together with the learners, were given full knowledge of the purpose, nature and duration of the study. Pseudonyms were used in this study to ensure anonymity (Kanari & Millar, 2004, p.753).

3.7.2 Administration of learner questionnaires

The three learner questionnaires namely: The LUSSI, Probes and LPCI were administered over a period of three days at 5 schools. Before visiting the schools to administer the three questionnaires, the researcher made prior arrangement in person both verbally and in writing with the schools' principals and the teachers involved in the study. At each school the sampled learners sat in one classroom- the laboratory and completed the three questionnaires. On the first day, the LUSSI was administered in the presence of the

researcher so as to respond to any queries raised by the respondents. On the average learners took 30 minutes to complete the LUSSI questionnaire. On the second day, the Probes questionnaire was administered and it took on average 25 minutes for learners to complete it. The LPCI was completed last on the third day and learners took on average 15 minutes to complete it. Before completing the questionnaires, learners were verbally reminded that their ideas about science were sought in two of the questionnaires-the LUSSI and the Probes. The learners were reminded that their responses to the LPCI were based on what they did during Physical Science practical investigations. As can be seen from the appendices all questionnaires also had written instructions to this effect. The learner questionnaires were administered on different days for each of the five schools. Each completed questionnaire was given a learner and school code (for example A1 meaning school A, learner 1), ensuring that different questionnaires completed by the same learner got the same code.

3.7.3 Administration of teacher questionnaires

The researcher made an appointment with the teachers before each administration through a telephone conversation. In each of the teachers' laboratory office, the researcher gave the Probes questionnaire to the teachers to complete first in his presence. The researcher responded to any queries raised by the respondent. Teachers took on average about 25 minutes to complete the Probes questionnaire. Second, the researcher then distributed the TPCI instrument to the teachers which on average took 15 minutes to complete. Both teacher questionnaires were administered on the same day and for each teacher. It took about 40 minutes to complete both questionnaires. However, teacher questionnaires were administered on different days from the administration of the learner questionnaires. This was seen as necessary to avoid using too much of the teachers' time and teacher fatigue. For each teacher, the Probes and TPCI questionnaires were given the same code as done with learner questionnaires.

3.7.4 Learner Interviews

The researcher in person conducted all learner interviews. Selection of interviewed learners was purposive in that the researcher selected those learners whose responses in the other instruments such as the LUSSI, LPCI and probes questionnaires needed further probing because they either lacked clarity or they showed an informed view which the researcher wanted to confirm. The interviews took place in the laboratory after school or during lunch time. Learner interviews were held after all the post-laboratory sessions had been observed. This gave the researcher the opportunity to probe learners with what he had observed in practical-related and practical investigation sessions in mind. For each school, interviews were completed in one day. The purpose of the interview was explained to the learners. It was also made known to the learners that the interviews were to be tape-recorded. During the interview, the researcher also took notes of the learners' answers. The learners were given assurance that the interviews were 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 learner'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 learner's life and schoolwork. This was seen to have the effect of opening up the learner and informalizing the conversation. On the average each learner interview took between 20 and 25 minutes. The researcher did the verbatim transcription of all the tape-recorded interviews on his own. The researcher then went on to word-process the handwritten transcription.

3.7.5 Teacher Interviews

Teacher interviews were conducted after learner interviews. Each teacher's interview was conducted after the post-laboratory session observation. Interviews were conducted in each teacher's office in the laboratory. It was also made known to the teachers that the interviews were to be tape-recorded. The teachers preferred to have only one interview due

to time constraints. On the average each teacher interview took between 40 and 45 minutes. The researcher handwrote all responses to questions. Responses were transcribed verbatim and word- processed by the researcher.

3.7.6 Lesson observations

Three of the five teachers were observed teaching the same practical work content areas whilst two were observed teaching different practical work content areas. Before each practical investigation-related session observation, the teacher in question informed the researcher (almost a week in advance) and gave the researcher a copy of the planned work that was to be done. The teacher also briefed the researcher on the approach he/she was going to use. The researcher sat at the back of the class taking field notes for all pre-laboratory and post-laboratory sessions while a hired assistant (a colleague in the Mathematics division) would do the video- recording. For the practical investigation lesson, the teacher in question informed the researcher (about two days in advance) and gave a copy of the practical work. In all five teachers' classes, the practical investigation immediately followed the pre-laboratory session. Post-laboratory sessions were conducted after the teachers had finished marking learners' laboratory reports. All five teachers also provided the marking scheme by which they were going to assess the learners' laboratory 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 3.3 gives a summary of the practical work content areas that were covered by each of the five teachers for those laboratory-related sessions that were observed. The observation was done consecutively, that is, one lesson after the other except for the post-laboratory sessions which were conducted after the teachers had completed marking learners' reports and the period varied from teacher to teacher.

Table 3.3: Observed practical investigation related-sessions shown by title of content

Teacher Code	School	Pre-Lab. / Lab. / Post-Lab.	Practical investigation-related content areas
T1	A	Pre-Lab.	Real and ideal gases, Kinetic molecular theory
		Lab.	Practical investigation based on Boyle's Law
		Post-Lab	Revision of practical on Boyle's Law and calculations based on Boyle's Law.
T2	B	Pre-lab.	1.Solving Oxidation and Reduction practice problems
		Lab.	1.The Reduction of Copper Oxide with Hydrogen gas 2.Interpreting results of an investigation of the displacement reactions of the halogens
		Post-Lab.	Revision of practical on reduction of Copper Oxide by Hydrogen gas
T3	C	Pre-Lab.	Introduction to the practical (Charles' Law)
		Lab.	Practical based on Charles' Law
		Post-Lab	Revision of practical on Charles' Law
T4	D	Pre-Lab	Real and ideal gases, Kinetic molecular theory
		Lab.	Practical investigation based on Boyle's Law
		Post-Lab.	Revision of practical on Boyle's Law and calculations based on Boyle's Law.
T5	E	Pre-lab.	Kinetic molecular theory (re-visited), real and ideal gases
		Lab.	Practical investigation based on Boyle's Law
		Post-lab	Revision of practical on Boyle's Law and calculations based on Boyle's Law.

3.8 Data Analysis and Presentation

Both quantitative and qualitative approaches were used to analyze the data. This was done to generate the most rigorous description of the participant's conceptions of the nature of scientific inquiry and learners' perceptions of the extent to which they were engaged in scientific inquiry. Quantitative data analysis was done using both descriptive and inferential statistics. For qualitative data, inductive analysis was utilized (Hatch, 2002; McMillan & Schumacher, 2006; Miles & Huberman, 1994). Through this process, particular pieces of evidence lead to meaningful wholes. Inductive analysis involved coding and categorization of data, observing patterns and themes, and making reasoned conclusions. Coding began with reading the data in each data set and identification of frames of analysis (Hatch, 2002). Frames of analysis are levels of specificity within which the data was examined.

Qualitative data was analysed using Atlas.ti version 6.2, a tool for indexing data. The software aided analysis of learner and teacher interviews, LUSSI and Probes' open-ended responses. The software was used to uncover and systematically analyze complex phenomena hidden in text. The program provided tools that enabled the researcher to locate, code, and annotate findings in primary data material as well as to weigh and evaluate their importance and as such to visualize complex relations between them.

Quantitative data analysis was performed with the Statistics Package for the Social Sciences (SPSS) software version 16 for Windows. Descriptive statistics such as frequencies, means, and standard deviations were computed to summarize the participant's responses to questionnaire assessments. The same software was utilized for the drawing of graphs for data presentation. All statistical correlation tests are two-tailed and alpha was set at .05. However, some Regression analysis tests are one-tailed and alpha was set at either .05 and/or .10. The Independent samples t-test was employed to determine whether there was a difference between being male or female and scores obtained on the LUSSI and LPCI. Tests for correlations between learners' scores on the LUSSI and scores on the LPCI were done using the Pearson correlation coefficient. The Multivariate Inferential Statistical

Test, Multivariate analysis of variance (MANOVA) was used to test the significance of group differences for open-ended LUSSI responses and LPCI responses and alpha was set at .05. Cronbach's alpha was used to determine the reliability or internal consistency of the LPCI instrument. The Pearson correlation coefficient was used to perform Crude item analysis.

3.8.1 Learner questionnaires

3.8.1.1 Learners' Understanding of Science and Scientific Inquiry

For the LUSSI, scoring closed learner responses was done as follows: *strongly agree* = 1, *agree* = 2, *not decided* = 3, *disagree* = 4 and *strongly disagree* = 5 (Liang, et al., 2006). Items representing naive conception of science (negative Likert items) were scored in reverse. These items are: 1B, IC, 2D, 3B, 3C, 4A, 4D, 5C, 5D, 6B, and 6C (Appendix A). A low total (minimum score = 24) score meant agreement with naive views of science and scientific knowledge and a high total score (maximum score = 120) meant views that were informed. Liang et al. (2006; 2008) and Miller et al. (2010) have used this scoring technique. The results reported in the current study do not separate certainty of scientific knowledge and the nature of scientific inquiry (which includes nature of scientific enterprise and scientists according to the definition already given). Computation of scores was only done along the lines of naïve and informed views.

Learner open-ended responses were scored using the SUSSI rubric provided by Liang et al. (2009) (personal communication, see Appendix A2), categorizing responses as informed (3), transitional (2), naïve (1), or not classifiable (0) as developed by Liang et al. (2009) (See Appendix A1) with the scores in brackets. The LUSSI open-ended scoring rubric is based on the multidimensional framework. The six (6) dimensions were then conceptualized as a continuum ranging from positivist/empiricist to constructivist/relativist perspectives (see, eg., Bell, 2006; Crowther, et al., 2005; Lederman & Lederman, 2005; Lederman, 2007a; McComas, 1996). Learner responses were classified as not classifiable, naive views, transitional views or naive views. This involved continuous readings of

responses and meaning-making so as to determine the relevant category. Positivist/empiricist views were labelled as naive or inadequate views, whereas the constructivist/relativist views were labelled as informed or adequate. This was done with the understanding that being an empiricist does not mean one is naïve as is depicted in most NOS and NOSI literature.

The researcher (author) and a post-doctoral research fellow registered in the same centre and university with the researcher first analyzed the data from LUSSI open-ended responses separately following Liang et al.'s (2009) SUSSI open ended scoring rubric. Discussions were then held concerning the categorizations and classification of the NOSI views. This was done for validating the coding purposes and checking inter-rater reliability. Once the categorization was agreed upon, the same codes were utilized in probes' questionnaire and interview analysis. Atlas.ti version 6.2 (a computer software program, mostly used in qualitative data analysis) was utilized for analysis. Use of the same codes (the meaning applied to a quotation for analysis) in Atlas.ti version 6.2 enabled labelling of phrases to be consistent and frequencies determined. All quotations belonging to each code were given as a print out. Tables and figures were then generated from the codes which enabled learners' responses to be classified into different categories.

3.8.1.2 Probes

To analyze data from probes' open-ended responses, the researcher read through sets of transcripts making preliminary notes regarding patterns that emerged from individual participants. This followed a model used by Ibrahim, et al. (2009) and Campbell, Lubben, Buffler and Allie (2005) since the structure of the probes used were similar. However, the coding was not exactly the same as done by Campbell, Lubben, Buffler and Allie (2005) in their monograph on teaching scientific measurement at the University of Cape Town. For this study, a *hybrid model* was produced after fusing the Ibrahim, Buffler and Lubben's (2009) coding model with that of Liang et al.'s (2009) rubric for scoring SUSSI open-ended responses. This was done purposefully and intentionally because probes were used to corroborate LUSSI open-ended responses. Thus, some aspects of grounded theory

analytical procedures (Strauss & Corbin, 1998) especially interpretive analysis (see, e.g. Gall, et al., 2003) were used to inductively analyze the participants' probes' open-ended responses. The data collected from the sets of open-ended probes' responses were coded using the hybrid model. These procedures involved (1) the simultaneous collection and analysis of probes data and (2) comparative methods of analysis whereby participants' responses were compared among one another and within each participant, and (3) the integration of a theoretical framework that guided the study. The *multidimensional framework* was used to categorize NOSI conceptions of the participants when all responses from the other instruments were considered for each participant.

For the hybrid model, dimensions from the LUSSI instrument were used to develop the coding patterns. The transcribed probes data were read looking for patterns, relationships and other themes within the dimensions. Entries were coded according to patterning identified while keeping a record of what entries went with which element of the patterns. In other words, the data was read and then chunked based on common language. The frequencies of responses for each probe were tallied and clusters of responses showing similar types of reasoning were identified, for example, LT0, LT1, LT2, LT3, LT4, LT5 and so forth for the probe category responses on laws and theories in science. The accompanying ascending numbers represent a continuum of positivist/empiricist views labelled as inadequate to constructivist/relativist views labelled as adequate. Underlying reasoning was then identified for each learner by writing the category codes for each probe response and this enabled understandings of the nature of scientific inquiry to be determined for each learner's response. Examples of illustrative codes for the probe on ways scientists validate new knowledge from the Probes questionnaire include: WSVNK0 for no response; WSVNK1 for not able to code reason given; WSVNK2 for scientists do not require accurate record keeping, peer review and replicability; WSVNK3 for scientists require accurate record keeping, peer review and replicability with no further elaboration or examples given; WSVNK4 for scientists review and ask questions about the results of others so as to validate discoveries with reasoning; and WSVNK5 for communication and peer review impact what and how science progresses.

3.8.1.3 Learner Perception for Classroom Inquiry

The response alternatives on the five-point bipolar Likert scale ranging from (1) never occurred (2) seldom, (3) sometimes, (4) often to (5) almost always were allocated scores from 1, 2, 3, 4 to 5, respectively. As was the case with the analysis of lesson observations, scoring was done in reverse for statements representing non-inquiry or closed-inquiry laboratory. Reverse scoring was done for the following items: A1, A2, A3, A4, B2, B3, B4, C1, C3, C4, D1, D2, D3, D4, E1, E2, E3 and E4. Total scores were obtained for all the 20 items in the instrument and for each of the five sections. Open-ended inquiry is represented by high scores (maximum = 100) and laboratory work which is verificationistic, expository, or closed inquiry is reflected by low scores (minimum = 20). The rankings given to the statements by each class were used to categorize the type of laboratory they experienced into verificationistic, structured, guided inquiry or open-ended inquiry. As an example, learners exposed to more open-ended laboratory work were expected to rank statement C3 ‘‘I actively participate in investigations as they are conducted’’ very highly, and those in low-inquiry laboratories to rank statement B1 ‘‘I am given step-by- step instructions as I conduct investigations’’ very highly.

3.8.2 Teacher questionnaires

3.8.2.1Teacher Perception for Classroom Inquiry

Scoring was done in the same way as the LPCI. The response alternatives on the five-point bipolar Likert scale ranging from (1) never occurred (2) seldom, (3) sometimes, (4) often to (5) almost always were allocated scores from 1, 2, 3, 4 to 5, respectively. As was the case with the analysis of the LPCI and lesson observations, scoring was done in reverse for statements representing non-inquiry or closed-inquiry laboratory. Reverse scoring was done for the following items: B1 and C2. Total scores were obtained for all the 20 items in the instrument and for each of the five sections. Open-ended inquiry is represented by high scores (maximum = 100) and laboratory work which is verificationistic, expository, or closed inquiry is reflected by low scores (minimum = 20). The rankings given to the

statements by each teacher were used to categorize the type of laboratory the teacher practised into verificationistic, structured, guided inquiry or open-ended inquiry. As an example, teachers exposing learners to more open-ended laboratory work were expected to rank statement C3 ‘‘Learners actively participate in investigations as they are conducted’’ very highly, and those exposing learners to low-inquiry laboratories to rank statement B1 ‘‘Learners are given step-by- step instructions as they conduct investigations’’ very highly.

3.8.2.2Teacher Probes’ questionnaire

The same instrument completed by learners is the one that was completed by the teachers. Analysis of the probes’ questionnaire is the same as explained in section 3.9.1.2 (learners’ probes).

3.8.3 Teacher and Learner Interviews

Analysis for both learner and teacher interviews was done using a more or less rough combination or “hybridization” of the processes of analytic induction (Murcia & Schibecci, 1999), sequential analysis (Harwell, 2000), and interpretational analysis (Gall, et al., 1996) as done by Vhurumuku, Holtman, Mikalsen and Kolsto (2006). However, sequential analysis was used differently in this study because a qualitative analysis software, Atlas.ti version 6.2 was employed. Analytic induction involved continued reading of learner and teacher responses to unveil common patterns. Using Atlas.ti, version 6.2, learners’ responses were treated as a family and teachers’ responses were treated as another family. Clusters of common responses were placed into similar categories. The emerging patterns were then used to develop categories. Responses were then classified on the basis of the formed categories. Frequency counts were made for each category (see, Appendix H). According to Harwell (2000), sequential analysis is a slight variation 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. However, in this study, interpretations for each response to a question were written as *memos* and *comments* (if the researcher is to use Atlas.ti

language). Memos and comments are methods used to record one's ideas and observations about codes, quotations, and the Hermeneutic Unit (HU).

Formed comments and memos were reduced to clusters based on the responses. Cluster phrases emerged from the responses. The reading and re-reading was continued and clustering and sub-categories formed and this was enabled by merging of codes and quotations where necessary. Responses were quantified using frequency counts in primary document tables (see, Appendix H). Since Atlas.ti version 6.2 indexes all quotations under a specific code, cluster or category, statements exemplifying clusters or categories were then selected or picked from a list. In sequential analysis after clustering and categorization another person looked at the data relating to each possible cluster. From the discussion concerning the evidence of the existence of a cluster, adjustments to the categorization was made and final categorization done on the basis of consensus. Interpretational analysis was about getting meaning out of the data. The researcher asked the question: What does this mean? Meaning was found by going beyond the face value of words or phrases. Insight was required.

In analyzing learners' responses to open-ended and interview questions the following sequence[6] was followed.

1. All responses to each open-ended or interview question were continuously read through and phrases and sentences making reference to the nature of scientific inquiry and teacher practices of scientific inquiry underlined.

2. Each response to each protocol was read through and the sub-category in which the learner's was expressing the identified NOSI aspect (phrase or sentence) classified as

[6]The data analysis sequence followed in the current study was largely based on the analysis done by Vhurumuku, Holtman, Mikalsen and Kolsto (2006) in their analysis of Zimbabwean High School Chemistry students' responses to interview questions. They were studying laboratory work-based Images of the Nature of Science. Details on the 'hybridisation' analysis can be found in Vhurumuku, Holtman, Mikalsen and Kolsto (2006). An Investigation of Zimbabwe High School Chemistry students' Laboratory Work-Based Images of the Nature of Science. *Journal of Research in Science Teaching*, 43 (2) 127-149.

based on the learner's Grade 11 Chemistry practical investigation 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 and this was done in Atlas.ti version 6.2 to capture the main ideas expressed by the learners. For example the code 'teacher frames research question' was assigned to represent the idea the teacher framed research questions which learners would attempt to answer during practical investigation.

4. Atlas.ti version 6.2 then quantified responses as frequency counts. Each NOSI issue raised by the learner was counted as a frequency. Using Atlas.ti version 6.2, learners' probe responses, LUSSI open-ended responses and interview responses were loaded as different primary documents and were further grouped as different families and this enabled the response to be counted only once in each family for that learner even if the learner raised it several times e.g. in probes and LUSSI open-ended and interview responses.

5. For each of the formed categories a comment was written to capture the general ideas expressed by the learners for that category. For example the category 'imagination and creativity in scientific investigations' consisted of learners' views, which generally ranged from naive to informed views. The naive view, for example, said "Imagination and creativity are not used during investigations because they are in conflict with objectivity".

6. The categorized responses were sorted out according to the broad NOSI aspects explored by the protocol items namely: roles of laws and theories in science, the nature of scientific observations in science, methods used to conduct investigations in science, ways of validating new knowledge in science, the creation of scientific knowledge, the purpose of practical investigations in science.

7. Atlas.ti version 6.2 grouped teacher and learner quotations under each formed category hence the required quotations (statements), which could be used to illustrate and exemplify the formed categories and the interactions between learners' NOSI views and participation in instructional practices, could be selected from a group.

As a tool for indexing data, use of Atlas.ti version 6.2 aided analysis of learner and teacher interviews. The software was used to uncover and systematically analyze complex phenomena hidden in text. The program provided tools that enabled the researcher to locate, code, and annotate findings in primary data material as well as to weigh and evaluate their importance and as such to visualize complex relations between them.

3.8.4 Classroom observations

Lesson observations data were analysed using a scoring rubric developed from an adaptation and modification of the PSI-S instrument of Campbell et al. (2010). Three researchers (two doctoral students and a Masters' student working in the field of scientific inquiry), who had been previously trained on the instrument, all working in the field of scientific inquiry, independently watched the fifteen videotaped lessons, three for each teacher, and produced scores for each teacher's practice, for each of the five sections of the Campbell et al. instrument.

The Campbell et al. (2010) instrument was adapted in this study as instrument for data analysis. Some slight changes were made to the instrument and method of scoring. First, some syntactical changes were made to the statements. For example, statement A1 (see, Appendix C) was changed from ''I formulate questions which can be answered by investigations'' to ''Teacher formulates questions which can be answered by investigations''. In this instance, teacher replaces ''I'', which stands for the learner. Second, researchers were required to score according to how often a given activity occurred in the teacher's laboratory lessons by responding to each of the 20 statements on a bipolar Likert scale ranging from (1) never occurred (2) seldom, (3) sometimes, (4) often to (5)

almost always. In scoring, each item response was allocated 1, 2, 3, 4 or 5 from Never Occurred to Almost Always, respectively. Scoring was done in reverse for those statements representing non-inquiry or closed-inquiry laboratory. Examples of such items are A1, A2, A4, B1, B2, C1, C2 and D1. A high score (maximum = 100) is taken to mean that the nature of instruction in that laboratory is generally perceived as open-ended inquiry and a low score (minimum = 20) means laboratory work is verificationistic or closed inquiry. Reverse scoring was done for the following items: A3, B3, B4, C3, C4, D2, D3, D4, E1, E2, E3 and E4. The scores were used to place instructional practice along a continuum ranging from verificationistic/closed/expository to open-ended inquiry.

The researcher adopted the model by Hegarty-Hazel (1986) to characterize the openness of inquiry for the five teachers' practices. The model describes the extent of open-endedness of inquiry along a four-scale continuum ranging from: level 0-confirmation/exploratory; level 1-structured inquiry; level 2-guided inquiry; to level 3-openended inquiry as described in Chapter 2. According to this model, the higher the level of inquiry, the greater the latitude given to the learners to be "in charge" of investigations. The level is determined by the scores obtained for a particular lesson. Total scores were obtained for all the 20 items in the instrument and for each of the five sections.

Inter-rater reliability coefficients were calculated for each of the five sections using STATA (an Integrated Statistical Software package for data analysis, management and graphics). The following Kappa (κ) coefficients were obtained: asking questions/framing research questions (0.947); designing investigations (0.939); conducting investigations (0.971); collecting data (0.956); and drawing conclusions (0.971) (see, Appendix J). This was taken to signify consensus among the three researchers.

3.9 Conclusion

In this chapter, the description of the research design, the data collection procedures, the sample, and the data analysis framework were given. The data analysis and interpretation were fashioned from literature on contemporary studies on the nature of scientific inquiry (NOSI) and instructional practices. For the reason that the thematic presentation rather than monographic format was adopted for this thesis, the description of methodology given detailed 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 was given. The next chapter outlines results from the pilot study.

CHAPTER FOUR

Results from the pilot study

4 Introduction

This chapter describes and discusses some of the results from the pilot study. The major results presented are from the quantitative validation of two instruments adopted for use in the main study. These instruments are: the Learners Understanding of Science and Scientific Inquiry (LUSSI) and the Learner Perceptions of the Classroom Inquiry (LPCI). The major focus is on validation of the closed items on these two questionnaires. Whilst it would be interesting to examine the pilot study results on learners' NOSI conceptions and perceptions of classroom inquiry, this chapter will not report the results on this. These results have already been presented and published elsewhere (see, preliminary pages). Basically the discussion centres on how the face, content, criterion and construct validity of each instrument was corroborated and ascertained. Insights obtained for the main study are fleshed out and probed.

Wiersma (1991, p. 427) defines a pilot study as:

> A study conducted prior to the major research study that in some way is a small-scale model of the major study: conducted for the purpose of gaining additional information by which the major study can be improved -for example, an exploratory use of the measurement instrument with a small group for the purpose of refining the instrument.

Commenting on the importance of piloting, Henk (1987, p. 66) says: "There is no question that the methodology of an investigation can be enhanced considerably by conducting pilot studies". In deciding to do a pilot several issues were taken into consideration.

This study adopted two instruments namely; the LUSSI, and the LPCI questionnaires. While these two instruments have been successfully used in the USA, Taiwan, China and

Turkey, it was important to ascertain their validity within the South African context. This is so because the contexts in which an instrument is administered can affect both its validity and reliability (Wiersma, 1991). Establishing the validity of the two instruments was done to provide greater confidence in the interpretation and reporting of results in the main study. It was also important to check the reliability of measures, and provide guidance about the sample sizes for the main study. The pilot also helped in shaping the sampling procedure and techniques for the main study. Additionally, it was seen necessary to check on learners' understandings of the language used in the questionnaire; considering that for most Grade 11 South African learners, English is a second language if not third or fourth. South Africa has eleven official languages including; Afrikaans, IsiXhosa, Zulu, and Tswana.

For this study, the feedback from the pilot study helped provide ways to improve how the instruments were to be administered in the main study. The pilot also helped checking whether the instruments were suitable for South Africa Grade 11 learners. This entailed making decisions about adopting the instruments as they were or adapting the instruments and suiting them to South African context. In sum, piloting of the already validated instruments assisted in deciding the instruments' suitability for the main study.

Generally, the major result to come out of the pilot study is that: the items in each of the questionnaires were a correct and comprehensive reflection of the concepts the questionnaire intended to measure. In other words the construct validity of each instrument was corroborated. Both instruments were found to measure what they are purported to measure. For both instruments' attributes such as; ease of use, clarity, and readability were also established. However this being the case, it was found that for the LUSSI questionnaire the tenet *change of scientific theories* did not statistically correlate with the other tenets items in the instrument.

4.1 Validation of the LUSSI instrument

As already mentioned, piloting was done to check on the face, content, criterion and construct validity of each instrument. Face and content validity were determined through interviewing as discussed in Chapter 3. Criterion and construct validity were ascertained using Regression analysis. Regression analysis can be applied to establish both criterion and construct validity (Macarolu, et al., 1998; Miller, Meier, Muehlenkamp, & Weatherly, 2009; Miller, 2009). It was conducted for the LUSSI Likert-scale scores. Descriptive statistics was used for the LUSSI open-ended responses. Regression analysis explains how certain events predict an outcome by measuring how the predictive variables agree or disagree when they are combined together. In so doing, Regression analysis explains phenomenon, which is the goal of research. For this reason, it has been used as a method to validate research instruments by several researchers (e.g., Heppner, Kivlighan, & Wampold, 1992; Meyer, Meyer, Knabb, Connell, & Avery, 2011; Sullivan & Karlsson, 1999). In Multiple Regression Analysis, correlation coefficients are calculated. These are equivalent to validity coefficients.

4.1.1 Validation of Likert items

For construct validity, the measured correlation is between the *intended* and *proxy independent variables*. A proxy independent variable is a variable an individual uses because one thinks it is correlated with the variable one is really interested in. It has no direct measurement or produces poor measurements. On the other hand, the intended independent variable identifies correlations between multiple independent variables thus explaining which independent variable has what contribution in predicting the dependent variables. For example, in this study, correlation is assumed between getting a high score on the LUSSI instrument and having informed views of the NOSI. For criterion validity, an independent variable can be used as a predictor variable. The criterion is the dependent variable. The correlation coefficient between them is called validity coefficient. In this case, each tenet representing the idea or doctrine about the scientific knowledge and scientific process is an independent variable and the total score of the instrument is the

dependent variable. Standard Multiple Regression Analysis was used to perform the two afore-mentioned validity processes. Results are presented below.

4.1.2 Construct and criterion validity results

In addressing construct and criterion validity of the LUSSI questionnaire, the question asked was; how well did the Likert-items of the six tenets predict learners' NOSI conceptions? Tables 4.1 provide data to address this question.

Table 4.1: LUSSI- Likert-type responses correlations (n = 90)

		ASC1	ASC2	ASC3	ASC4	ASC5	ASC6	SC Total
ASC1	Pearson Correlation	1	.177	.302**	.113	.152	.092	.586**
	Sig. (2-tailed)		.098	.004	.295	.157	.392	.000
ASC2	Pearson Correlation	.177	1	-.103	-.272*	.069	.194	.290**
	Sig. (2-tailed)	.098		.340	.010	.523	.070	.006
ASC3	Pearson Correlation	.302**	-.103	1	.159	.154	.131	.526**
	Sig. (2-tailed)	.004	.340		.140	.152	.224	.000
ASC4	Pearson Correlation	.113	-.272*	.159	1	-.017	.056	.367**
	Sig. (2-tailed)	.295	.010	.140		.875	.605	.000
ASC5	Pearson Correlation	.152	.069	.154	-.017	1	.289**	.638**
	Sig. (2-tailed)	.157	.523	.152	.875		.006	.000
ASC6	Pearson Correlation	.092	.194	.131	.056	.289**	1	.568**
	Sig. (2-tailed)	.392	.070	.224	.605	.006		.000
SC Total	Pearson Correlation	.586**	.290**	.526**	.367**	.638**	.568**	1
	Sig. (2-tailed)	.000	.006	.000	.000	.000	.000	

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
SC = sum of construct based out of a possible 20
ASC = average of the construct with the highest value being 5.
Where; ASC1 = observations and inferences; ASC2 = change of scientific theories; ASC3 = scientific laws versus theories; ASC4 = social and cultural influence on science; ASC5 = imagination and creativity in scientific investigations; and ASC6 = methodology of scientific investigations.

Table 4.1 shows that five of the six variables correlate substantially (that is, r is between 0.367 and 0.586) with the dependent variable-SC Total. One of the variables, ASC2 'change of scientific theories' has a correlation of 0.290 with SC Total which is not significant because it is less than 0.3. Tabachnick and Fidell (2001) suggest that a variable should have correlation between 0.3 and 0.7 for it to be significant; hence construct two 'change of scientific theories' was dropped when running Multiple Regression Normality plot analysis. In other words, the construct 'change of scientific theories' is an outlier hence was not considered for the data set on regression analysis as suggested by Tabachnick and Fidell (2001). Still from Table 4.1, no correlation is above 0.7 therefore five of the six variables were retained for the analysis. Collinearity diagnostics was performed on the five variables that had significant correlation with the dependent variable as part of the multiple regression procedure. This was done to pick up problems with multicollinearity that may not be evident in the correlation matrix. The results are presented in Table 4.2.

Table 4.2: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	2.139	.510		4.195	.000		
	ASC1	1.206	.092	.378	13.159	.000	.892	1.121
	ASC3	.858	.098	.254	8.762	.000	.875	1.142
	ASC4	.779	.079	.272	9.848	.000	.965	1.036
	ASC5	.994	.065	.443	15.405	.000	.890	1.124
	ASC6	1.190	.095	.357	12.516	.000	.906	1.104

a. Dependent Variable: SC Total

Where; ASC1 = observations and inferences; ASC3 = scientific laws versus theories; ASC4 = social and cultural influence on science; ASC5 = imagination and creativity in scientific investigations; and ASC6 = methodology of scientific investigations.

From Table 4.2, two values are given, Tolerance and VIF [Variance inflation factor]. Tolerance is an indicator of how much of the variability of the specified independent variables in the model is not explained by the other independent variables in the model and is calculated using the formula $1-R^2$ for each variable. Pallant (2005) suggests that if the

value is very small (less than 0.10), it indicates that the multiple correlation with other variables is high, suggesting the possibility of multicollinearity. VIF is just the inverse of the tolerance value (1 divided by Tolerance). VIF values above 10 would be a concern here, indicating multicollinearity. As shown on Table 4.2, the tolerance value for each independent variable is between 0.875 and 0.906 which is way above 0.10; attesting that the multicollinearity assumption was not violated. This is also supported by VIF values, which are between 1,036 and 1.142 which are well below the cut-off of 10. These results are not surprising, given that Pearson's correlation coefficient between these five independent variables with the dependent variable - SC Total was between 0.367 and 0.586 (see Table 4.1).

The variance in which learners' conceptions of the NOSI could be explained by scores on the six NOSI tenets of the LUSSI was also used to further determine construct and criterion validity of the LUSSI questionnaire. Using Regression analysis, the two types of validity can be ascertained at the same time. The Model Summary box (Table 4.3) helps address variance issues regarding learners' NOSI conceptions.

Table 4.3: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Dimension1	.969[a]	.940	.936	.46402

a. Predictors: (Constant), ASC6, ASC4, ASC1, ASC5, ASC3
b. Dependent Variable: SC Total

Looking at the Model Summary box (Table 4.3), the given value under the heading *R Square* is 0.940. This tells how much of the variance in the dependent variable (SC Total) is explained by the model (including the five variables). Expressed as a percentage, it means the model (which includes the five variables) explains 94.0 per cent of the variance in SC Total. However, a sample of 88 can be considered not very big so the R square value in the sample tends to be rather an optimistic overestimation of the true value in the population hence the Adjusted R square statistics 'corrects' the value to a better estimate of

the true population value. In this case, this becomes 93.6 per cent. This is quite a respectable result when comparing to some of the results that are reported in literature.

Beta values under Standardized Coefficients (Table 4.2) help in determining which of the variables included in the analysis contributed to the *prediction* of the dependent variable. 'Standardized' means that values for each of the different variables were converted to the same scale for comparison. Construct ASC 5 'Imagination and creativity in Scientific Investigations' had the largest beta value, 0,443. This meant that this variable makes the strongest unique contribution to explaining the dependent variable, when the variance explained by all other variables in the analysis is controlled for. The beta value for ASC 1 'Observations and inference' was slightly lower indicating that it made a less contribution. All five variables made a significant unique contribution to the prediction of the dependent variable as suggested by Pallant (2005) because their *Sig.* values (see Table 4.2) are all less than 0.05. Actually they have the same Sig. value which is 0 meaning they are significant.

Assumptions like outliers, normality, linearity, homoscedasticity and independence of residuals were checked using two different ways. These are: inspecting the Normal Probability Plot of the regression standardized residuals and the residual scatterplot. These were requested as part of the analysis. Figures 4.1 and 4.2 illustrate how these assumptions were checked.

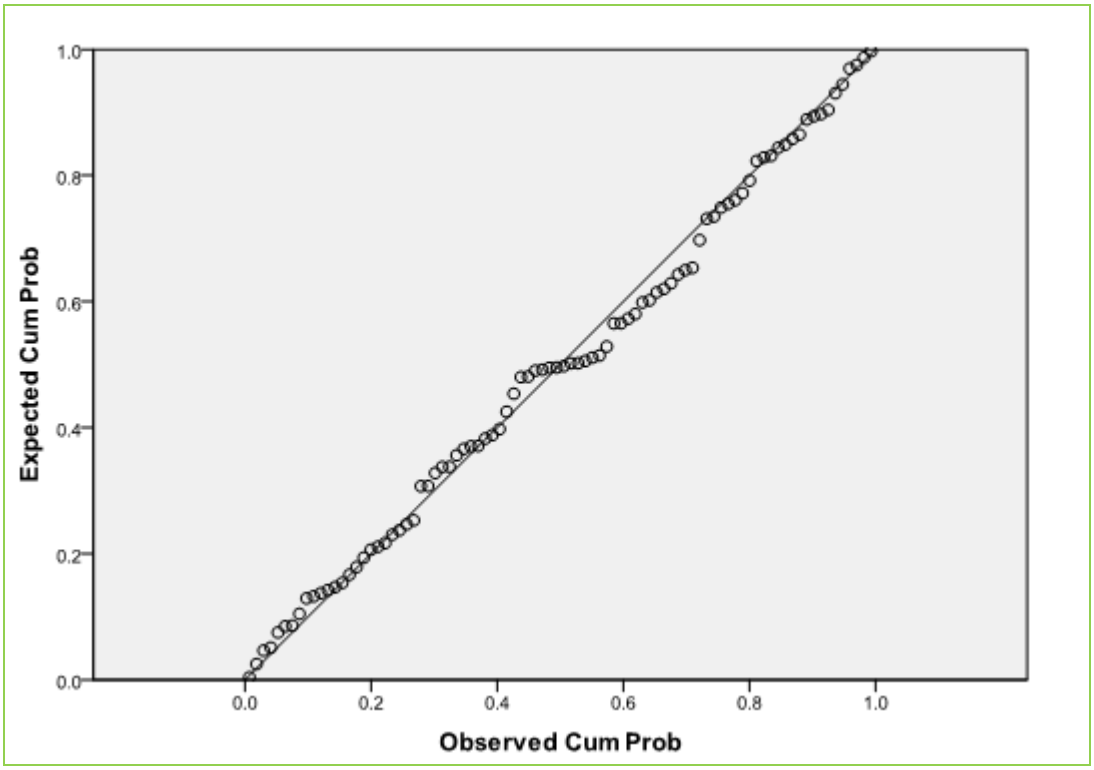

Figure 4.1: Normality P-P Plot of Regression Standardized Residual

In the Normal Probability plot, Figure 4.1 is evidence enough that the points do lie in a reasonably straight line from bottom left to right. This suggests there are no outliers and other assumptions like normality and linearity are not violated. Figure 4.2 below gives a scatterplot of the standardized residual analysis.

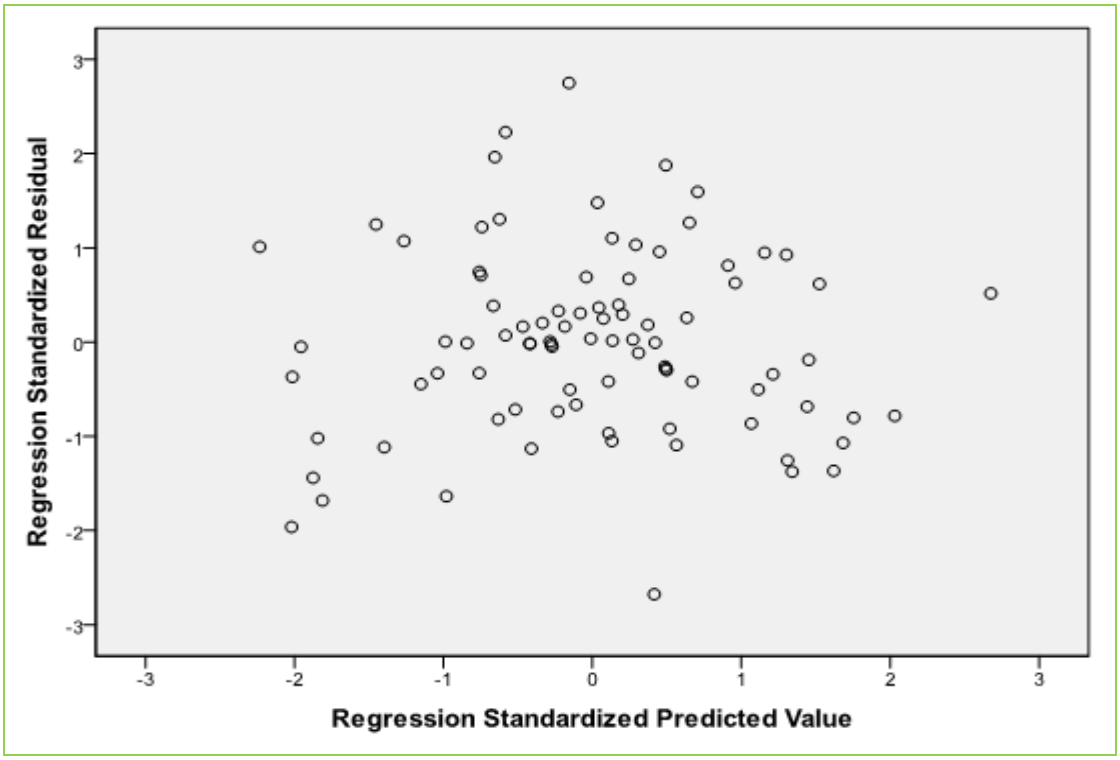

Figure 4.2: Scatterplot of the standardized residual analysis

In the Scatterplot of the standardized residuals (see, Figure 4.2), the residuals are roughly rectangularly distributed, with most scores concentrated in the centre (along the 0 point). There is no clear or systematic pattern to the residuals (e.g. curvilinear, or higher on one side than the other). Figure 4.2 shows that there are no deviations from a centralized rectangle suggesting that there is no violation of the assumptions. The presence of outliers can also be detected from the Scatterplot. Tabachnick and Fidell (2001) define outliers as cases that have a standardized residual (as displayed in Figure 4.2) of more than 3.3 or less than -3.3. From Figure 4.2, it is evident that there are no outliers and this suggests once again that there is no violation to the assumptions.

4.1.3 Face and content validity

Data regarding learners' validation of the LUSSI could not be collected because of logistical reasons. For example, there was a teachers' strike the day interviews were scheduled to take place. Unfortunately, the interviews could not be rescheduled as learners

got busy with their end of year examinations. The researcher is aware that such logistical reasons are a threat to validity. The results reported here are therefore based only on the inputs of six professional science educators, three Professors, two doctoral students and a Masters' student, who were available to discuss validity issues surrounding the LUSSI with the researcher. Four of the science educators had this to say during interviewing:

Expert 1(Professor 1): The instrument asks questions which are related to how scientific knowledge is produced. It talks of observations and inferences as well methodology of scientific investigations which are critical if a learner has to know how science works. A good tool for soliciting views on science. One can actual check if the learner knows what he or she is saying by completing the open-ended section.

Expert 2 (Professor 2): The items covered in the instrument are clear. There is an issue of scientific laws and theories. Learners cover this starting in grade 10 through to Grade 12. Learners must know the difference between the two. It is interesting to see that you have items on the tentativeness of scientific theories. I for see you will get interesting results on this aspect. There is also the issue of the social and cultural milieu of science which learners talk about in their day to day lives. Generally the instrument is good and the language is not that philosophical.

Expert 3(Professor 3): To me the instrument is all about how scientific knowledge is generated. The methods used the validation and the influences on its production. The design of the instrument is good. It consists of closed and open-ended section. The learners will have to justify their choice for a given item and one can determine the conceptions of the learner regarding that aspect based on the learners' response.

Expert 4 (Master's student): You will get interesting findings through use of this instrument I assure you. The way the items are structured and arranged is not leading at all. There is no hint from the way the items are arranged. They are just mixed. The language is simple. If someone is informed on how scientific knowledge develops, it will not take that person time to complete this instrument. At most 30mins because of the open-ended sections which are there for justification I suppose.

Two of the doctoral students had this to say:

> Doctoral Student 1: In completing the instrument, I did not encounter any difficulty at all. I understand you want to give this to Grade 11 learners. My learners will complete this instrument with ease. I always talk to them about scientific laws and theories, the scientific method and observations when we do practical investigations. Ya…ah, they will complete this with ease.

> Doctoral Student 2: What I can say is that the language is simple. The structure of the instrument is also good for me. The Likert items are easy to complete. Then comes need for justification through use of examples. There is nothing new to my grade 11 learners. They will complete the instrument without problems.

4.1.4 Internal consistency

The internal consistency of the items chosen for this study was determined using the Cronbach alpha. The Cronbach alpha values for each subscale were calculated and found to be as follows; Observation and Inferences ($\alpha = 0.61$), Tentativeness ($\alpha = 0.56$), Scientific theories and laws ($\alpha = 0.48$), Social and cultural embeddedness ($\alpha = 0.64$), Creativity and Imagination ($\alpha = 0.89$) and Methodology of Scientific Investigations ($\alpha = 0.44$). Some of the Cronbach alpha values appear to be very low but according to Hatcher and Stepanski (1994), for social studies, a Cronbach alpha as low as 0.55 can still be recognized and accepted for statistical consideration. Considering there is only a small number of items in each subscale, the results indicated that the instrument achieved a satisfactory level of internal consistency. An overall Cronbach alpha value of 0.74 was obtained. The actual SUSSI questionnaire responses used in the production of the instrument produced an overall Cronbach alpha of 0.69 (Liang, et al., 2006) for the whole instrument.

4.2 Validation of the LPCI instrument

In validating the LPCI instrument, criterion and construct validity were ascertained using Regression analysis. Regression analysis was conducted for the LPCI Likert-scale scores. Reasons for utilizing Regression analysis for this instrument are the same as those given for the validation of the LUSSI instrument. As discussed in Chapter 3, content validity was determined through interviewing professional science educators and face validity was determined through interviewing of both professional science educators and learners. What follows are results from the validation process. First, quantitative data is presented followed by qualitative data.

4.2.1 Validation of Likert items

Standard multiple regression analysis was applied to establish how much of the variance the dependent variable (Total Score, which represents sum of construct based out of possible 20) could be explained by the independent variables (five inquiry sub-processes). In this instance, Regression analysis gives an indication of the relative contribution of each independent variable in determining learners' perceptions of the levels of inquiry. All the five inquiry sub-processes are independent variables which can be used as predictor variables. The total score is the criterion variable which is also known as the dependent variable. The correlation coefficient between them is called *validity coefficient*. In this case, each category (subscale) representing the practice of scientific inquiry is an independent variable and the total score of the instrument is the dependent variable. This gives the extent to which learners experience inquiry during science lessons.

For construct validity correlation was assumed between for example getting a high score on the LPCI instrument and experiencing *open-ended* inquiry. Multiple regression analysis was used to explain how much of the variance the dependent variable (SC Total, which represents sum of construct based out of possible 20) could be explained by the independent variables namely: asking/framing research questions; designing investigations, conducting investigations; collecting data; and drawing conclusions. Multiple regression

analysis also gives an indication of the relative contribution of each independent variable to the total score. Mean scores for each component and the overall LPCI instrument were calculated. Standard Multiple Regression Analysis was used to perform the two afore-mentioned validity processes. Results are presented below.

4.2.2 Construct and criterion validity results

Five variables namely; asking/ framing research questions, designing investigations, conducting investigations,, collecting data and drawing conclusions in the science classroom were found to substantially correlate with each other (that is, r was between 0.605 and 0.794) with the dependent variable -total score of all five sub-processes. One of the variables, 'Collecting data' was found to have a correlation of 0.794 with Facet Total which is a bit too high. The 'framing research questions' and 'designing investigations' sub-processes were found to have a bivariate correlation of less than 0.3 with the 'drawing conclusion' sub-process which is 0.199 and 0.139 respectively. To Tabachnick and Fidell (2001), a variable should have correlation between 0.3 and 0.7 with one another for it to be significant. Because only one variable 'collecting data' had a high correlation, greater than 0.7, after "thinking carefully" it could not be omitted since there was no other variable to form a composite variable with it. The two variables with a correlation below 0.3 were retained when running Multiple Regression Normality plot analysis because they showed at least some relationship with the dependent variable, total score of all five sub-processes.

Collinearity diagnostics was performed on the five variables since they had significant correlation with the dependent variable as part of the multiple regression procedure. The results are presented in Table 4.4.

Table 4.4: Collinearity diagnostics

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	2.315	.000		.000	1.000		
	Asking research questions	1.000	.000	.319	1.255	.000	.724	1.381
	Designing investigations	1.000	.000	.250	1.001	.000	.749	1.336
	Conducting investigations	1.000	.000	.270	1.096	.000	.771	1.297
	Collecting data	1.000	.000	.356	1.327	.000	.650	1.538
	Drawing Conclusions	1.000	.000	.280	1.162	.000	.807	1.239

Dependent Variable: Total Score of all five sub-processes

Two values are given in Table 4.4 namely tolerance and VIF (Variance inflation factor). As shown on Table 4.4, the tolerance value for each independent variable is between 0.650 and 0.724. Pallant (2005) suggests that if the value is very small (less than 0.10), it indicates that multiple correlation with other variables is high, suggesting the possibility of multicollinearity. In this case, the multicollinearity assumption was not violated. VIF is the inverse of the tolerance value (1 divided by Tolerance). VIF values above 10 would be a concern here, indicating multicollinearity. VIF values are between 1.297 and 1.538 which are well below the cut-off of 10. This further supports the fact that there is the multicollinearity assumption was not violated.

Table 4.5: Model Summary

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	1.000[a]	1.000	1.000	.000

a. Predictors: (Constant), Asking /framing research questions, Designing investigations, Conducting investigations, Collecting data, Drawing Conclusions

b. Dependent Variable: Total Score of all five sub-processes

From Table 4.5, the given value under the heading R Square is 1.000. This tells how much of the variance in the dependent variable (Total Score of all five sub-processes) is explained by the model (including the five variables). Expressed as a percentage, it means the model (which includes the five variables) explains 100 per cent of the variance in Total Score. However, a sample of 90 can be considered not very big so the R square value in the sample tends to be rather an optimistic overestimation of the true value in the population hence the Adjusted R square statistics 'corrects' the value to a better estimate of the true population value. Because the standard Error of the Estimate is 0.000, in this case, this remains 100 per cent. This is highly a respectable result when comparing to some of the results that are reported in literature. Finally, from multiple regression analysis conducted, statistical significance of the result was assessed by checking from the output tabled ANOVA. This tested the null hypothesis that multiple R in the population equals 0. The model reaches statistical significance (Sig .000, meaning p <.0005) meaning result is statistically significant.

Inspecting the Normal Probability Plot of the regression standardized residuals and the residual scatterplot were requested as part of the analysis. Figure 4.3 gives a scatterplot of the standardized residual analysis. From Figure 4.3, the residuals are roughly rectangularly distributed, with most scores concentrated in the centre (along the 0 point). There is no clear or systematic pattern to the residuals (e.g. curvilinear, or higher on one side than the other) showing that there are no deviations from a centralized rectangle suggesting that there is no violation of the assumptions.

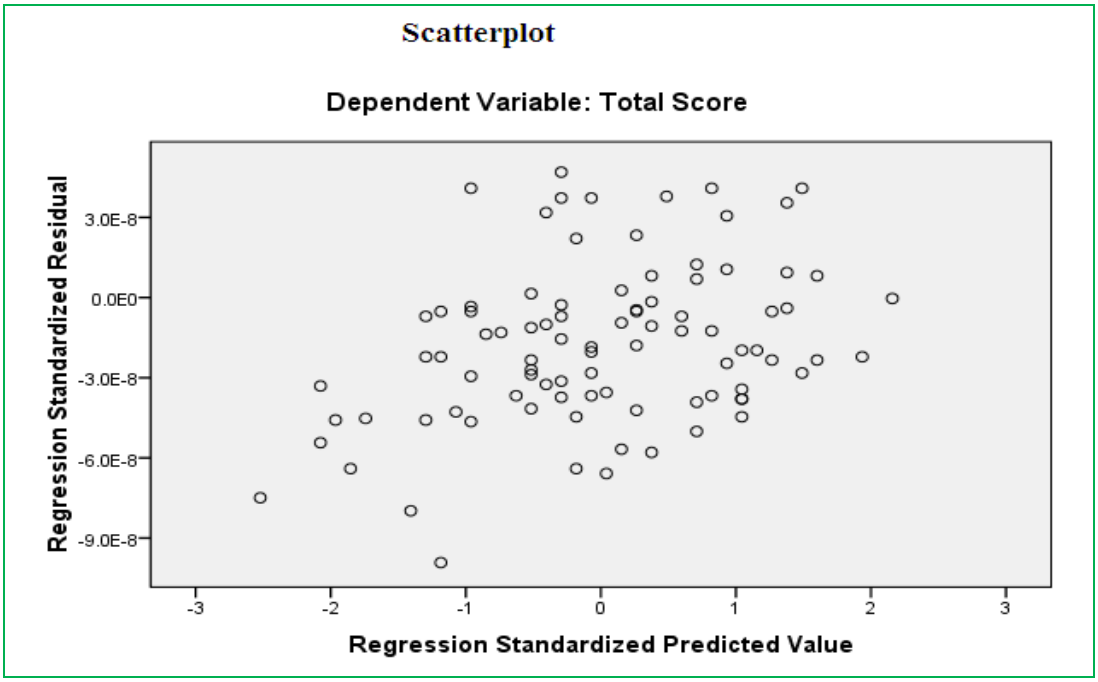

Figure 4.3: Scatterplot of the standardized residual analysis

4.2.3 Face and content validity results

Professional science educators: Four university professional science educators three, Professors and a doctoral student working in the field of scientific inquiry were asked questions which address face and content validity of the instrument. These were among the same ones who had participated in the validation of the LUSSI. Below are some of the responses the experts gave to the following question; what is scientific inquiry in line with the new National Curriculum Statement (NCS)?:

Expert 1 (Professor 1): Learners should be in a position to ask questions, propose ideas, and justify explanations based on evidence and findings before communicating results. Learners must also be in a position to display some creativity.

Expert 2 (Professor 2): My understanding is that learners should be able to perform the five skills spelt by the NCS subject statement for Physical Sciences which are: (1) plan investigations; (2) conduct investigations; (3) interpret data and draw conclusions; (4) solve problems; and (5) communicate and present information and scientific arguments.

Expert 3 (Professor 3): Doing scientific inquiry in this case means that the learners are in total control of their learning. Learners must not be allowed to follow the 'scientific method' when doing investigation. By 'scientific method' I mean following the recipe-type kind of experiments where every step, for example questions, methods and interpretation of results is provided. Learners must be in a position to design investigation on their own.

Expert 4 (Doctoral student): From my understanding of scientific inquiry, it involves framing research questions; designing investigations; conducting investigations; collecting data; and drawing conclusions. This is the definition which is given in literature and I presume the Department of Education (DOE) curriculum planners had this in mind when designing the NCS.

It is important to mention that the experts were asked this question before they were handed the LPCI instrument for comments. After going through the instrument, the experts were asked questions like: How easy or difficulty would each individual learner complete the questionnaire? How relevant are the instrument items and the instrument as a whole in eliciting learner perceptions of their experiences to classroom inquiry? The experts responded as follows:

Expert 1 (Professor 1): …the instrument items are relevant. They seem to be aimed at bringing out learner perceptions of their experiences to classroom inquiry as per NCS requirement. The instrument as a whole to me is clear and well-organized. Learners can complete it with ease and the language to me is simple. Where did you get this instrument?...

Expert 2 (Professor 2): All the five skills stated in the NCS subject statement for Physical Sciences which I listed earlier are covered in detail in this survey instrument. It seems the instrument developer just followed the NCS guidelines. The questions are very clear and they fall into the area of scientific inquiry. All aspects of scientific inquiry are

covered in the survey instrument. I have a question though, why is that there are no open-ended questions below each envisaged skill?

Expert 3 (Professor 3): Ah…ah! *I like this instrument. I like this instrument*. Look here, the 4 statements after each scientific sub-process are simple and clear. For example, this one which says, "I am given step-by-step instructions before conducting experiments" will tell you what kind of practical work is taking place in the classroom. From such a question, one does not expect a vast range of responses from learners in the same classroom. From learner's responses one can tell if learners are practising closed experiments- following the scientific method or open-ended experiments as promulgated by the NCS. The language is also simple. You know our South African secondary school learners, English as a language is very difficult for them. The instrument is good. Ya…ah, to me it is about learners' perceptions about their experiences of scientific inquiry.

Expert 4 (Doctoral student): Basically what the developers of this instrument have done is to look at the basic skills or sub-processes which constitute scientific inquiry. Looking at a target group of learners, the individual asked themselves questions like will this instrument measure something like eh---eh perceptions about learners' experiences of scientific inquiry? To me the questions measure perceptions about learners' experiences of scientific inquiry. The instrument is well-organized, and four questions pertaining to a certain sub-process like designing investigations are asked below the 'designing investigation' sub-process theme. To me this is clear. The questions do fall into the area of scientific inquiry. I am also impressed by the usage of simple language in the instrument. South African learners struggle a lot when it comes to the English language. I do not foresee learners having difficulty with the language issue here. Responses won't be too diverse for a certain group of learners in the same class.

Generally, all the four interviewed science education experts agreed that the Learner Perceptions of Classroom Inquiry (LPCI) instruments' items do capture learners' perceptions of the extent of *open-endedness* of the inquiry in science classrooms. One interviewee said:

Expert 4 (Doctoral student): ... If you know what scientific inquiry is, and what it involves, then you can safely say that this instrument does capture the basic elements or if you are from a traditional perspective the steps or processes involved in scientific inquiry, I think it can tell us what learners think about what we do from their own experiences in the classroom...

Learners: As mentioned in Chapter 3, learner focus group interviews (5 learners in each group) were held after administration and completion of the LPCI questionnaire. It is worth-mentioning that the two groups were being taught by different teachers. Learners were asked such questions as: Explain what actually happens in the laboratory when conducting investigations. Where do you get investigative questions from? Who frames the investigative questions? How do you conduct the designing stage of investigations? How do you conduct investigations? How do you make observations? How do you collect data during investigations? How do you arrive at conclusions?

In focus group 1, some of the learners said:

Learner 1: Our science teacher frames the actual questions we have to research on as well as gives us [learners] the step-by-step method which we have to follow when we conducting investigations in groups.

Learner 2: ... we make observations in our groups and record results on pieces of paper. Soon after the investigation, we sit in their groups and discuss findings before we come up with conclusions as a group.

In focus group 2, some learners said:

Learner 3: It depends with the type of investigation. If it is an easy investigation, we design our own investigations but if it is difficult, then the teacher designs the investigation for us.

Interviewer: What do you mean by an easy and difficult investigation?

Learner 4: I will give you an example of the investigation on Ohm's law investigation as an easy one and all investigation involving chemicals as difficult ones.

Learner 5: Another point is that all investigations involving dangerous chemicals are performed by the teacher. For the "easy" investigations we conduct them in groups on our own. In all investigations, each one of us makes an observation, records it down and later discusses the findings with the group so as to arrive at conclusions.

When asked to comment on the LPCI in relation to their classroom experiences, one of the learners replied:

...the questionnaire is just one page, it is short enough. The language is so simple. It asks about what we do during practical investigations and how we do it. The statements are also short and most important of all are very clear.

This appeared to be the general sentiment expressed by most of the interviewed learners.

4.2.4 Internal consistency

The internal consistency of the items chosen for this study was determined using the Cronbach alpha. The Cronbach alpha values for each subscale were calculated and found to be as follows; Asking/framing research questions ($\alpha = 0.81$), designing investigations ($\alpha = 0.75$), conducting investigations ($\alpha = 0.77$), collecting data ($\alpha = 0.83$), and drawing conclusions ($\alpha = 0.77$). As mentioned earlier, a Cronbach alpha as low as 0.55 can still be recognized and accepted for statistical consideration (Hatcher & Stepanski, 1994). Considering that no Cronbach alpha value was found below 0.55, it signifies that the results indicate that the instrument achieved a satisfactory level of internal consistency. An overall Cronbach alpha value of 0.79 was obtained. The actual PSI-S questionnaire responses used in the production of the instrument produced an overall Cronbach alpha of 0.64 (Campbell, et al., 2010) for the whole instrument.

4.3 Discussion

In this section, results from the pilot study are discussed. This discussion is organized under the LUSSI instrument and the LPCI instruments respectively.

4.3.1The LUSSI instrument

Evidence relating to criterion and construct validity of the LUSSI instrument is provided by the findings of the pilot study. Results from multiple regression analysis show that five out of six variables correlate substantially with the dependent variable and because one variable (change of scientific theories) did not substantially correlate with the dependent variable, SC Total, it was dropped before running the collinearity diagnostics. Collinearity diagnostics was performed on the five remaining dimensions of the instrument since they had significant correlation with the dependent variable as part of the multiple regression procedure. No problems were found with multicollinearity. Assumptions like outliers, normality, linearity, homoscedasticity and independence of residuals were checked and no violations to the assumptions were found.

The pilot study has provided some evidence relating to face, content, criterion and construct validity of the LUSSI instrument as used in the South African context. Both professional science educators and post-graduate students agreed that the instrument items aim to solicit from learners' their views on the processes of science and how science develops, i. e. their conceptions of the nature of scientific inquiry. These results are consistent with the findings of Liang et al. (2006) who interviewed professors of science education from China, USA, Taiwan and Turkey and found the SUSSI have face and content validity. If these findings are combined with results form both criterion and construct validation and internal consistency results where a relatively high Cronbach alpha (0.80) value was obtained in the pilot study one can safely and confidently recommend the use of this instrument in large scale quantitative studies on the African continent. But at the same time suggesting that researchers and professional developers using the instrument in the future still pilot the instrument as the tenet (changes of scientific theories) did not correlate with others before running multiple regression analysis.

4.3.2 The LPCI instrument

This study has provided some evidence relating to face, content, criterion and construct validity of the LPCI instrument as used in the South African context. Contrary to the researcher's expectations, results from interviews with expert science educators and the learners themselves point towards the instrument having face, content and construct validity even within the context of the South African science classroom. Like what other researchers did (e.g., Angoff, 1988; Cronbach & Quirk, 1976; Li, 2003) the researcher investigated the fit between the conceptual definitions and operational definitions of variables in the LPCI qualitatively. Interview results appear to give this instrument a thumps up. If these findings are combined with the relatively high Cronbach alpha (0.80) value obtained in this pilot study- based on the sample, one can safely and confidently recommend the use of this instrument in large scale quantitative studies on the African continent. The findings from learner interviews are consistent with previous work by Campbell et al. (2010) with 130 secondary science students in the, USA. Their results support the face validity of the LPCI. The fact that the LUSSI produced these results with South African learners is a surprising finding. This was unexpected given the poor language proficiency of South African secondary school learners (Linneman, et al., 2003).

From the two focus group interviews held with the learners we can conclude that the LPCI instrument appears to have both face validity and to be written in a language which the learners can understand. "On its face", the instrument seems like a good translation of the construct (McGartland & Kimberly, 2005; Miller, 2009). Overall, from the discussions held with the experts one can "safely say" the instrument shows content and construct validity. Taking the above responses into account, the instrument can be said to measure what it is suppose to measure.

Results from multiple regression analysis show that five variables correlate substantially and because correlation is substantial, no variable was dropped before running the collinearity diagnostics. Collinearity diagnostics was performed on the five categories of

the instrument since they had significant correlation with the dependent variable as part of the multiple regression procedure. No problems were found with multicollinearity. Assumptions like outliers, normality, linearity, homoscedasticity and independence of residuals were checked and no violations to the assumptions were found. Since criterion validity is about prediction rather than explanation and is concerned with non-casual or mathematical dependence, we can safely say, the multiple regression analysis results provide evidence relating to criterion validity of the LPCI instrument. This is consistent with findings from other studies (e.g., Heppner, et al., 1992; Meyer, Miller, Metzger, & Borkovec, 2002; Sullivan & Karlsson, 1999) where Regression analysis was used to validate research instruments.

In explaining how much variance in learners' perceptions of classroom inquiry could be explained by scores on the five facets of scientific inquiry, the model (which includes the five variables) explained 100 per cent of the variance in Total Score. The model also reached statistical significance (Sig .000, meaning $p < .0005$) meaning result is statistically significant. These results show that both criterion and construct validity were tested for in the instrument through use of multiple regression as done in other studies (see, Arozullah, et al., 2007; Osborne, 2000). From the results the pilot study recommends the use of multiple regression analysis as a methodological technique in predicting criterion validity of phenomena related to learners' experiences of scientific inquiry.

Internal consistency results show that all five processes of science in the LPCI instrument correlated very well with high Cronbach alpha values obtained. These results are consistent with findings from the study by Campbell et al. (2010) when they piloted the same instrument. A decision was made to maintain the five original categories of the instruments in the final version of the instrument used in the main study. However, a recommendation made is that researchers and professional developers using the instrument in future be cognisant of internal consistency of instrument items as potential measures of progress toward reform in implementing inquiry as an instructional strategy.

From the interview results above, the interviewees' responses point to the fact that the LPCI was found to be face and content valid. Responses also point in the direction that the LPCI instrument purports to measure what it is intended to measure, that is, learners' perceptions of the extent they practice inquiry in their science classroom. Thus the instrument was found suitable for use in the South African classroom.

4.4 Conclusion

Both the investigated instruments were found to be suitable for use in the main study. The confidence to use the instruments came from the results of both multiple regression analysis and interviews. In terms of face, content, criterion and construct validity, the two instruments can be said to have passed the test. Interviews (individual and focus group interviews) provided rich qualitative data that made it possible to conclude about the validity of each instrument. However, based on the pilot findings, the performed inferential statistics suggest that the tenet 'change of scientific theories' on the LUSSI instrument may be dropped from the instrument to ensure that the remaining tenets correlate. However, it was retained in the instrument for the main study because the participants appeared to be more informed about the tentativeness and durability of theories in their open-ended responses.

The results of this pilot study are significant in that they provided guidance about the sample sizes for the main study. The pilot also helped in shaping the sampling procedure and techniques for the main study. Furthermore, the results from the pilot invite thought about how NOSI views and learner perceptions of the extent of inquiry in science classrooms can be measured in larger populations. They also provide insights into the complexity and challenges involved in measuring and interpreting learner NOSI views and learner perceptions of the levels of classroom inquiry.

CHAPTER FIVE

Learners' conceptions of the nature of scientific inquiry

5 Introduction

In this Chapter the findings on investigation of learners' conceptions of the nature of scientific inquiry (NOSI) are presented and discussed. In this effort quantitative and qualitative data pertaining to the study's first research question is presented, analyzed and discussed. This question reads: what are learners' conceptions of the nature of scientific inquiry?

One of the goals of this study was to understand and elucidate South African Grade 11 learners' conceptions of the nature of scientific inquiry using three sources of data, namely; a LUSSI questionnaire, probes and interviews. Six NOSI tenets were investigated, which are: laws and theories serve different roles in science; observations are theory-laden; scientists use a variety of methods to conduct scientific investigations; scientists require accurate record keeping, peer review and replicability; scientific knowledge is socially and culturally embedded; and scientific knowledge is partly the product of human creativity and imagination.

In presenting of results, quantitative results are given first followed by the qualitative results. The quantitative data is organized and interpreted in the following order; quantitative data from the LUSSI questionnaire, descriptive data from the closed section of the probes instrument, and qualitative data from open ended LUSSI section, probes and interviews. Qualitative data was obtained from analyses of learners' responses to open-ended questions and the semi-structured interviews. In approaching the analysis, there was a deliberate effort to make the qualitative data follow on and provide more meaningful explanations to the quantitative data, as recommended by Creswell et al. (2003) and Moghaddam et al. (2003).

The major theoretical tools guiding the data analysis were: a framework that categorizes NOSI views as inadequate, transitional and adequate (Liang, et al., 2008); and the multidimensional framework (Deng, et al., 2011). These theoretical tools were discussed in Chapter 2. It was mentioned that the multidimensional framework treats learners' views of the NOSI as multiple dimensions that are more or less independent.

5.1 Quantitative Results

5.1.1 Results from the LUSSI questionnaire

Analysis of responses to the LUSSI instrument reveals that as a group the learners can be said to habour NOSI views ranging from *inadequate/naïve to extremely adequate or informed.* By extremely adequate *or informed* views of the NOSI, this study refers to individuals holding acceptable conceptions on the nature of scientific inquiry including its reliance on scientific inquiry. The term *extremely adequate* was used with the understanding that learners were able to gather together evidence when explaining a NOSI aspect to support and criticize their own philosophical positions. The opposite is true for inadequate views implying individuals hold misconceptions on the NOSI. In Chapter 2 it was argued that the use of terms such as *sophisticated* in categorizing NOSI views is replete with multiple interpretations. Matthews (2002) contends that the use of the phrase *sophisticated views* is debatable. This is especially so from those philosophical establishments which are not constructivist (Deng, et al., 2011).

5.1.2 LUSSI closed responses

Responses to Likert part of questionnaire

In Chapter 3 it was mentioned that the SUSSI rubrics provided by Liang et al. (2009) were adopted for scoring both LUSSI closed and open-ended learner responses. Few minor syntactical changes were made to the SUSSI as explained in Chapter 3, and not much changed on the adopted instrument. Both the instrument and the

rubrics had gone through a successful validation process in various educational contexts similar to South Africa such as Taiwan and China and found valid. The SUSSI rubrics were also used to categorize LUSSI pilot responses for both learners and teachers and found to appropriately categorize participants' responses hence chosen as valid for this study. For closed responses scoring was done as follows: *strongly agree* = 1, *agree* = 2, *not decided* = 3, *disagree* = 4 and *strongly disagree* = 5 (Liang, et al., 2006). Items representing *inadequate/naïve* conception of science (negative Likert items) were scored in reverse. These items are: 1B, IC, 2D, 3B, 3C, 4A, 4D, 5C, 5D, 6B, and 6C. A low total (minimum score = 24) score meant agreement with naive views of science and scientific knowledge and a high total score (maximum score = 120) meant views that were informed or extremely adequate. In Table 5.1 learners responses to Likert items are summarized. These results are from all the five schools.

Table 5.1: Placement of learners along a normative map based on learners' total score on closed (Likert) responses to the LUSSI questionnaire (n = 167).

Categorization of learners' views		Scaled Score Range	Score Range	Count (Number of students)	Frequency as a percentage
Inadequate	naive	1.4 - 2.3	25 - 43	0	0
Poorly adequate	naive	2.4 - 3.4	44 - 62	11	7
Moderately adequate	transitional views	3.5 - 4.5	63 - 81	138	82
Highly adequate	informed	4.6 - 5.5	82 - 100	18	11
Extremely adequate	informed	5.6 - 6.6	101 - 120	0	0
------		------	Totals	167	100

When scoring learners' closed responses, the inadequate/ *extremely* adequate categorization was equated to the naïve/informed classification. Highly and extremely adequate views refer to responses which are considered informed by the science community. As is shown in Tables 5.1, the number of learners falling into each category along a normative scale ranging from inadequate to extremely adequate varies. Scores below the theoretical

midpoints (74) are taken to show inadequate views and scores above the theoretical midpoints to indicate adequate views. Within the inadequate views category, learners can fall into the inadequate (also known as naive) (score range 25-43) and poorly adequate (score range 44-62). A similar categorization is shown for adequate views. Within the adequate views category, learners can fall into the moderately adequate group (also known as the transitional views) (score range 63-81), highly adequate (score range 82-100) and extremely adequate (also known as informed views) (score range 101-120). The majority of the learners (82 %) held moderately adequate (transitional) views of the NOSI. Table 5.2 gives the descriptive statistics showing the variability for learners' scores on the LUSSI closed (Likert) responses.

Of the 13 items phrased in the informed view sense, there was more than 69 % agreement (percentage of learners saying agree or strongly agree) for nine of the items. Some notable statements getting high approval (with the cumulative percentage of learners strongly agreeing and agreeing in brackets) from the learners are:

- Scientists use a variety of methods to conduct scientific investigations (86 %)
- Scientists' may make different interpretations based on the same observation (95 %)
- Scientific theories are subject to on-going testing and revision (72 %)
- Scientific theories exist in the natural world and are uncovered through scientific investigations (72 %).

Learners also showed strong naive views on some items. Some examples (with cumulative percentages of learners strongly agreeing and agreeing in brackets) include:

- Scientific laws are theories that have been proven (82 %)
- Unlike theories, scientific laws are not subject to change (69 %)
- When scientists use the scientific method correctly, their results are true and accurate (72 %).

5.1.3 Comparison across schools

The LUSSI closed response scores (Table 5.2) show that there was little variation in the views of the learners on moving from one school to the next. Although the sample sizes per school were small (ranging 23-44 learners), the average scores from school to school generally show little variation. This variation is further clarified and shown on Figure 5.1.

Table 5.2: Descriptive statistics showing the variability for learners' scores on the LUSSI closed responses.

School	Sex	Mean	Std. Deviation	N
A	Male	73.75	5.396	12
	Female	72.96	7.208	23
	Total	73.23	6.571	35
B	Female	70.06	6.988	32
	Total	70.06	6.988	32
C	Male	74.40	4.570	20
	Female	71.08	5.324	24
	Total	72.59	5.213	44
D	Male	76.60	9.218	15
	Female	72.63	7.328	8
	Total	75.22	8.655	23
E	Male	73.08	7.077	12
	Female	76.38	6.924	21
	Total	75.18	7.055	33
Total	Male	74.56	6.637	59
	Female	72.32	6.971	108
	Total	73.11	6.918	167

As shown in Figure 5.1, it can be seen that school B, located in the city a former model C school which formerly had the best facilities, best teachers and best educational opportunities for children recording the lowest mean of total score and school D, located in the townships and previously a historical disadvantaged school recorded the highest. However, the difference in the mean scores between school D and school E, also located in the townships and a previously historical disadvantaged school is very small (75.22, 75.18).

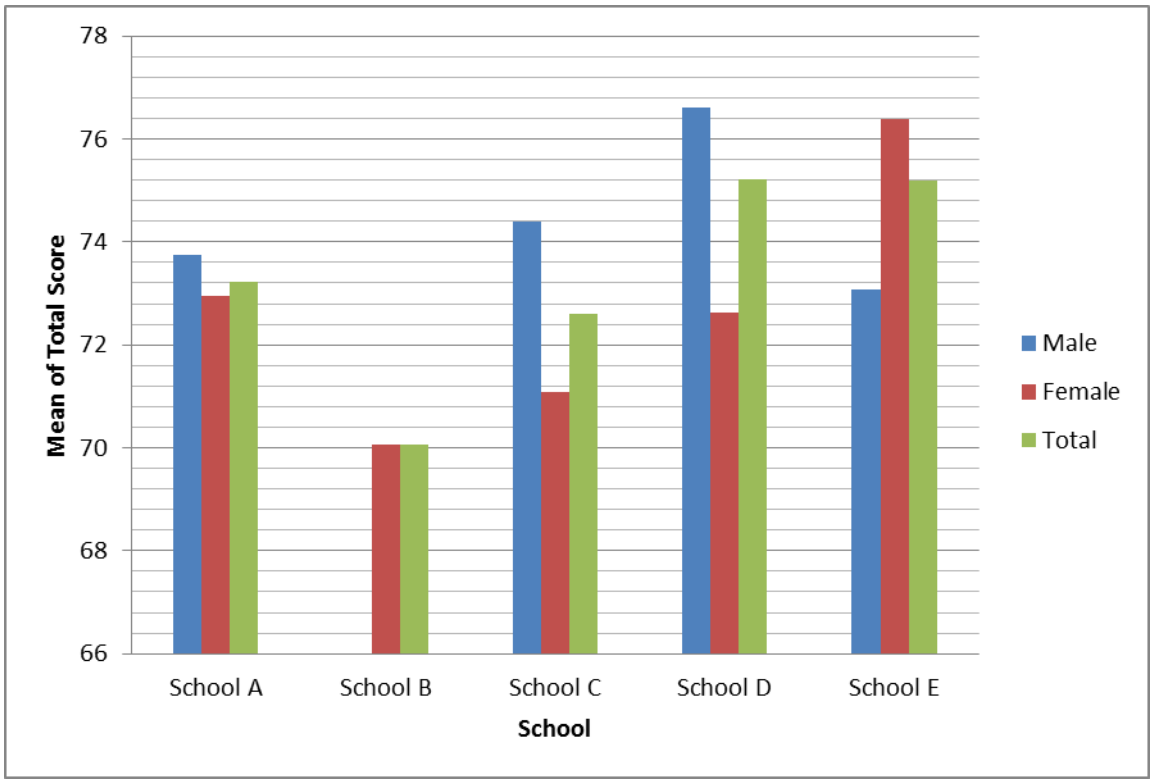

Figure 5.1: Variation of learners' scores on views of the NOSI across the schools

A two-way between-groups analysis of variance was conducted to explore the effect of school on views of learners' conceptions of the NOSI, as measured by the closed response section of Learners Understanding of Science and Scientific Inquiry (LUSSI) instrument. Subjects were divided into five groups according to their schools (School A: 35 learners; School B: 32 learners; School C: 44 learners; School D: 23 learners; School E: 33 learners). There was a statistically significant main effect for the school [F (4, 158) = 3.03, p = .02]; however the effect size was small (partial eta squared = .40). Post-hoc comparisons using the Tukey HSD test indicated that the mean score for school B (M = 70.06, SD = 6.99) was significantly different from school D (M =75.22, 8.66) and school E (M = 75.18, SD = 7.06). The other two schools, school A (M = 73.23, 6.57) and school C (M = 72.59, SD = 5.21) did not differ significantly from either of the other groups. The main effect for sex [F (1, 158) = .94, p = .33] and the interaction effect [F (3, 158 = 1.82, p = .15] did not reach statistical significance. These differences are explained on the discussion section.

5.1.4 Comparison across gender

A two-way between-groups analysis of variance was conducted to explore the relationship between gender and learners' conceptions of the NOSI, as measured by the closed response section of Learners Understanding of Science and Scientific Inquiry (LUSSI) instrument. The LUSSI closed response scores also show that there was little variation in the views of the learners according to gender. This variation is further clarified and shown on Figure 5.2.

No difference was found between males and females in their responses to the LUSSI closed (Likert) response items. There is no bar for males at school B because school B is a girl's only school. The graph (Figure 5.2) shows as if there is an enormous difference between male and female scores for school D. However, reading across to the scale, the difference is only small (72.63 as compared with 76.60). The two-way between-groups analysis of variance performed to determine differences between the males and females' mean scores with alpha set at .05 showed that males and females perceived the NOSI in the same manner ([F (1, 158) = .94, p = .33]) when the total score on the LUSSI instrument was considered.

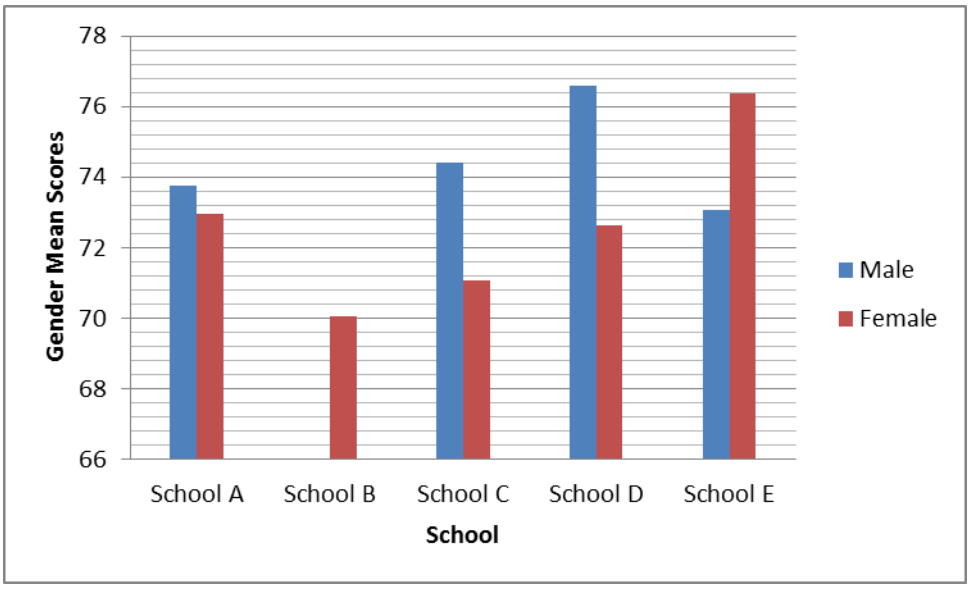

Figure 5.2: Variation of learners' gender scores on views of the NOSI across the schools

Since SPSS for Windows Version 16.0 does not provide eta squared values for t-tests, the values were calculated manually using information provided in the output (see Appendix I) using the formula for eta squared as follows:

$$\text{Eta squared} = \frac{t^2}{t^2 + (N1 + N2 - 2)}$$

where N1 = number of males; and N2 = number of females

Gender responses (both males and females as a group) to the LUSSI closed items were related (Pearson r.) to the school (r = -.176, p = .02 for a 2-tailed test) with alpha set at .05. Gender responses to the LUSSI closed items were also related to the total score (r = -.155, p = .046 for a 2–tailed test) though the correlation was negative. Responses only to the 'observation and inferences' sub-items were however found to be related to the school (r = .193, p = .01 for a 2–tailed test). Responses to all six tenet's sub-scale scores were however found to be related to learners' total score [observations and inferences (r = .418, p = .00); change of scientific theories (r = .448, p = .00); scientific laws versus theories (r = .169, p =.03); social and cultural influence on science (r = .482, p = .00); imagination and creativity in scientific investigations (r = .632, p = .00); methodology of scientific investigations (r = .434, p = .00) with alpha set at .05 for a 2–tailed test]. All six tenets' sub-scales scores showed strong positive correlations with the total score.

5.1.5 LUSSI open-ended responses

As done with the closed responses, the inadequate/adequate categorization was equated to the naïve/informed classification when scoring learners' views on open-ended responses. Using Liang et al.'s (2008) rubric for scoring open-ended responses, learner open-ended responses were scored by categorizing responses as informed (3), transitional (2), naïve (1), or not classifiable (0) with the scores in brackets. The open-ended section of the LUSSI instrument had a total possible score of 18 as opposed to the closed section which had a total possible score of 120. As a result of this difference in scores, learner scores could not

be matched and placed on the same normative map. Table 5.3 shows a summary of learners' responses to open-ended questions.

Table 5.3: Placement of learners along a normative map based on learners' total score on open-ended responses to the LUSSI (n = 167).

Categorization of learners' views		Scaled Score Range	Score Range	Count (Number of learners)	Frequency as a percentage
Inadequate	naive	0 - 1.0	0-3	8	5
Poorly adequate	naive	1.1 - 2.3	4-7	45	27
Moderately adequate	transitional views	2.4 - 3.7	8-11	81	49
Highly adequate	Informed	3.8 - 5.0	12-15	30	18
Extremely adequate	Informed	5.1 - 6.0	16-18	1	1
------		------	Totals	167	100

As shown in Table 5.3, within the inadequate views category, learners could fall into the inadequate (very low score below 8) and poorly adequate (score range 0-3). A similar categorization is used for adequate views. Within the adequate views category, learners could fall into the moderately adequate group also known as the transitional views (score range 8-11), highly adequate (score range 12-15) and extremely adequate also known as informed views (score range 16-18). The majority of the learners (49 %) held moderately adequate (transitional) views of the NOSI. For the open-ended responses, a total score of zero (0) was possible based on the scoring rubric, for any of the following reasons; (1) if a learner stated he/she did not know, (2) the response did not address the prompt, (3) response could not be classified based on rubric description, or (4) there was no response (no attempt) to justify the chosen Likert scale response for each dimension or tenet item. It is worth noting, however, that one learner which translates to only 1% of the participating learners scored within score range 16-18 showing that only one learner harboured extremely adequate or constructivist views of the NOSI. The majority of the participants (18%) scored within the score range 12-15 indicating highly adequate views. About half of the participants (49 %) were in the score range 8-11 indicating moderately adequate

(transitional) views. The remaining participants harboured views which were poorly adequate (27%) or inadequate (5%). Table 5.4 gives the descriptive statistics showing the variability for learners' scores on the LUSSI closed responses.

Table 5.4: Descriptive statistics showing the variability for learners' scores on the LUSSI open-ended responses

School	Sex	Mean	Std. Deviation	N
A	Male	7.83	2.443	12
	Female	8.61	3.551	23
	Total	8.34	3.199	35
B	Female	10.03	2.788	32
	Total	10.03	2.788	32
C	Male	7.35	2.739	20
	Female	8.33	2.239	24
	Total	7.89	2.499	44
D	Male	8.40	3.158	15
	Female	9.88	3.091	8
	Total	8.91	3.147	23
E	Male	8.83	2.290	12
	Female	8.43	2.908	21
	Total	8.58	2.670	33
Total	Male	8.02	2.707	59
	Female	9.03	2.950	108
	Total	8.67	2.899	167

The LUSSI open-ended response scores show that there was little variation in the views of the learners on moving from one school to the next. Although the sample sizes per school were small (ranging 23-44 learners), the average scores from school to school generally show little variation. This variation is further clarified and shown on Figure 5.3. The LUSSI open-ended response scores show that there was also little variation in the views of the learners according to gender. This variation is further clarified and shown on Figure 5.4 in the proceeding section.

5.1.5.1 Comparison across schools

As shown in Figure 5.3, it can be seen that school B recorded the highest mean of total score and school C recording the lowest. However, the difference in the mean scores between school D and school E is very small (8.91, 8.58).

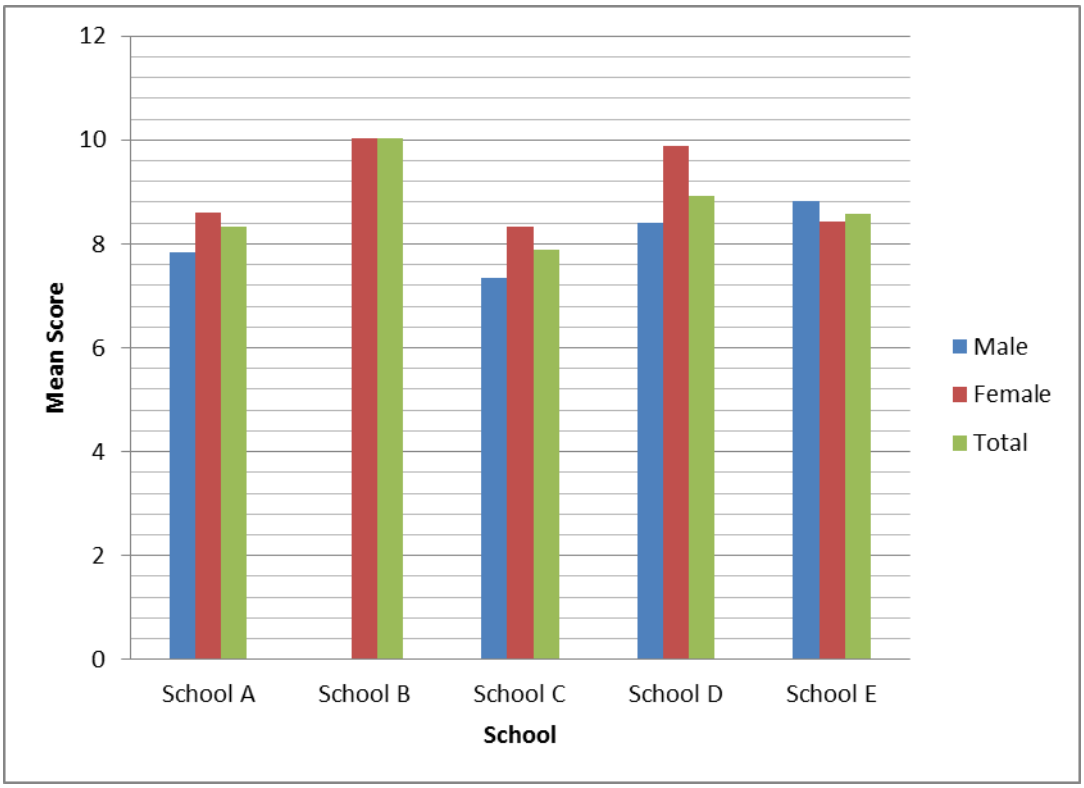

Figure 5.3: Variation of learners' scores on views of the NOSI across the schools

Using Pearson Product Moment Correlation coefficient to determine the correlation between the school and the total score, it was found that the school was not related to the total score ($r = -.32$, $p = .69$) when considering LUSSI open-ended responses. This implies that scoring high marks in the LUSSI open-ended section is not related to the school an individual learner attends.

5.1.5.2 Comparison across gender

No difference was found between males and females in their responses to the LUSSI open-ended response items. As mentioned earlier, there is a break in the male's line graph at school B because school B is a girl's only school. The graph (Figure 5.4) shows as if there is an enormous difference between male and female scores for school D. However, reading across to the scale, the difference is only small (8.40 as compared with 9.88). The two-way between-groups analysis of variance performed to determine differences between the males and females' mean scores with alpha set at .05 showed that males and females perceived the NOSI in the same manner ([F (1, 158) = 1.83, p = .18]) when the total score on the LUSSI instrument was considered.

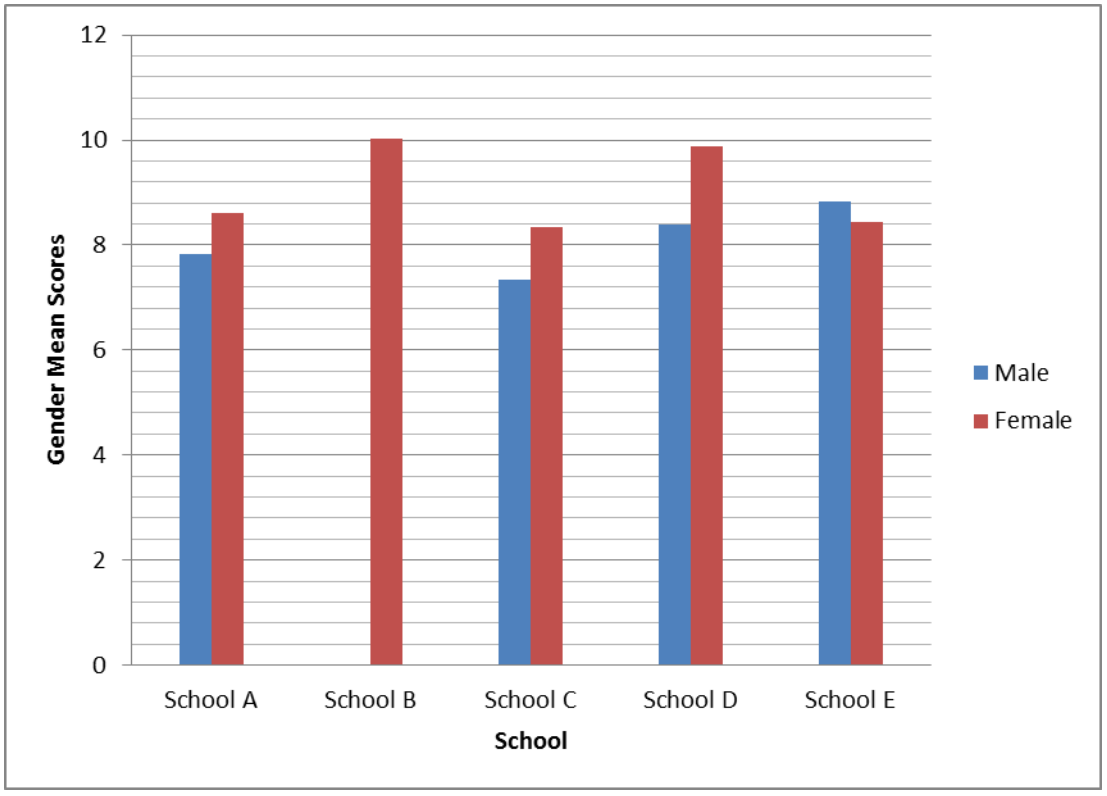

Figure 5.4: Variation of learners' gender scores on views of the NOSI across the schools

To determine if there was a significant difference in the mean LUSSI open-ended response scores for males and females, an independent-samples t-test was conducted to cross-check

and confirm results from the two-way between-groups analysis of variance reported above. First the total scores were obtained for each tenet as explained in Chapter 3, LUSSI analysis section. Secondly, sub-scale scores for each tenet were added to give a total score for each learner. It was found that there was no significant difference in scores for males and females in five of the six tenets.

These are [observations and inferences, for males (M = 1.58, SD =.99) and females {M = 1.80, SD = 1.04; t (165) = -1.33, p; change of scientific theories, males (M = 1.51, SD =.94) and females {M = 1.74, SD = .98; t (165) = -1.49, p = .14}; scientific laws versus theories, males (M = .93, SD =.72) and females {M = 1.09, SD = .70; t (165) = -.40, p = .16}; imagination and creativity in scientific investigations, males (M = 1.59, SD =.99) and females {M = 1.45, SD = .86; t (165) = .95, p = .34}; methodology of scientific investigations, males (M = 1.42, SD =.97) and females {M = 1.63, SD = 1.03; t (165) = -1.26, p = .21}]. Only the social and cultural influence on science tenet had a significant difference in scores for males (M = .98, SD = .84) and females {M = 1.31, SD = .93; t (130.43) = -2.34, p = .02}. The magnitude of the differences in the means was very small (eta squared = .01 for observations and inferences; .01 for change of scientific theories; .001 for scientific laws versus theories; .01 for methodology of scientific investigations; .01 for imagination and creativity in scientific investigations; and .03 for social and cultural influence on science) for all six tenets.

Gender responses (both males and females as a group) to the LUSSI open-ended items were however found related (Pearson r.) to the total score (r = -.167, p = .03) and the school (r = -.176, p = .02) for a 2-tailed test with alpha set at .05.

5.1.6 Probes

5.1.6.1 Closed probe responses

In this section, results are considered for learners' conceptions of the nature of scientific inquiry based on probes' closed responses.

Table 5.5: Summary of Probes Closed-ended responses (n = 167).

Probe	Choice	Description	No. of learners who chose statement (no. of learner as %)
1	A	Laws and theories serve different roles in science	115 (69)
	B	No, laws and theories serve same roles in science	41 (24)
	C	I have another view which I will explain	11 (7)
2	A	Observations are theory-laden	97 (58)
	B	No observations are not theory-laden	35 (21)
	C	I have another view which I will explain	35 (21)
3	A	Scientists use one method to conduct investigations	28 (17)
	B	No, scientists use a variety of methods to conduct investigations	127 (76)
	C	I have another view which I will explain	12 (7)
4	A	Scientists require accurate record keeping, peer review and replicability	148 (89)
	B	No scientists do not require accurate record keeping, peer review and replicability	8 (5)
	C	I have another view which I will explain	11 (6)
5	A	Scientific knowledge is socially and culturally embedded	81 (48)
	B	No, scientific knowledge is not socially and culturally embedded	46 (28)
	C	I have another view which I will explain	40 (24)
6	A	Scientists use human creativity and imagination to create scientific knowledge	99 (59)
	B	No, scientists do not use human creativity and imagination to produce scientific knowledge	28 (17)
	C	I have another view which I will explain	40 (24)

The data in Table 5.5 generally shows that most learners harboured highly (informed views) and extremely adequate views (informed views) of the nature of scientific inquiry. Slightly above two thirds of the sample (69 %) believed laws and theories serve different

roles in science which is true while 24 % of the learners harboured inadequate views (naive views) on this NOSI aspect. The remaining 6% of the sample had other views which could be classified as inadequate, moderately adequate (transitional) or adequate. The second probe focused on observations learners make in science and 97 (58 %) of the learners agreed that the observations they make in science are theory-laden. About one-fifth (21 %) of the sampled learners held inadequate views and the same percentage (21 %) had other ideas which could still be classified as inadequate, moderately adequate or adequate. Regarding methodology used to conduct investigations by scientists, it can be seen from Table 5.5 that 76 % of the learners chose the option that said scientists use a variety of methods to conduct investigations which is classified as highly adequate view of the NOSI tenet. A small proportion (17 %) held inadequate views and a very small number 7 % had other views which could be categorized as inadequate, moderately adequate or adequate.

The fourth probe which talks about the ways scientists validate knew knowledge is the one in which most learners showed adequate views of the NOSI. Out of 167 learners, 148 (89 %) chose the option that scientists require accurate record keeping, peer review and replicability and only 8 learners (5%) disagreed. A small percentage had another view which they explained and was categorized as inadequate, moderately adequate or adequate. On the nature of scientific knowledge, 81 learners (48 %) believed that scientific knowledge is both socially and culturally embedded. However, this probe had the highest number of sampled learners (28 %) with inadequate views and also the highest number of learners (24%) who had a different view which they explained and categorized as inadequate, moderately adequate or adequate. The last probe is based on how scientific knowledge is created. Of the sampled learners, 59 % agreed that scientists use human creativity and imagination to create scientific knowledge. Just under a fifth of the learners (17 %) disagreed showing they harboured inadequate views and 24 % had other ideas which they explained.

5.2 Qualitative data

In this section, qualitative data is presented. Data from open-ended responses from the LUSSI the probes' and interviews are presented concurrently. As discussed in Chapter 3, the rubric provided by Liang et al. (2009) was used to analyze LUSSI open-ended responses. Additionally, the *hybrid model* produced after fusing the Ibrahim, Buffler and Lubben's (2009) coding model with Liang et al.'s (2009) rubric for the SUSSI instrument was used for coding probes open-ended responses as again mentioned in Chapter 3. Interview data was analyzed using a combination or "hybridization" of the processes of analytic induction (Murcia & Schibecci, 1999), sequential analysis (Harwell, 2000), and interpretational analysis (Gall, et al., 1996) as also descibed in Chapter 3. The thinking on one tenet by an individual is not the same with the thinking on the other and this agrees with the multidimension framework. Because individuals think of NOSI in various ways, an individuals conceptions of the NOSI was considered after eliciting his or her views on all the six tenets.

5.2.1 Problems encountered with the coding process

The procedure for coding LUSSI open-ended responses was adopted from the rubric for scoring SUSSI open-ended responses developed from Liang et al. (2009) (see Appendix A1). Using this coding system, frequencies of open-ended scores for all six aspects reflect challenges in using the LUSSI and similar instruments to study learner nature of scientific inquiry views. For example, the coding as non-classifiable (0) within each component for the sub-groups is large; observation and inference (23 responses-14%), change of scientific theories (24 responses-14%), scientific laws versus theories (29 responses-17%), social and cultural influences on science (36 responses-22%) imagination and creativity in science (25 responses-16%) and methodology of scientific investigations (20 responses-12%). Non-classifiable is represented when; (1) learners did not complete a particular question, (2) learners indicated they did not know an answer, (3) the writing did not address an intended topic, (3) or response could not be classified based on rubric description. For example, learner written responses to the sixth aspect of the LUSSI "methodology of scientific

investigations" at times were unclear in terms of whether learners were referring to experimental protocols or wider issues of methodology. Both learner writing skills and attention to the task influenced the ability of the researcher to interpret and use their responses.

The three-level naive-transitional-informed scale at times complicated the scoring of open-ended responses because it did not fully reflect the subtlety of differences in learner NOSI views. For example, some responses to the prompt for 'Scientific laws versus scientific theories' and 'Social and Cultural Influences on science' classified as naive seemed to indicate views moving toward what would be classified as transitional, whereas others showed no evidence of this development. Still on the 'Scientific laws versus scientific theories' component, very few learner responses (7%) were classified as informed partially due to the lack of explicit mention of scientific laws being subject to change. It is unclear whether this was effectively differentiating transitional and informed views, as learners may not think to comment on both scientific laws and theories being subject to change if not directly prompted. Semi-structured interviews held with selected learners would aid in interpretation of open-ended responses.

The use of transitional as a category raised concern. The term transitional may imply learners' responses could move from naive to informed in an interval step. Rather, the views represented a mix of ideas (as described by Sandoval, 2005) as opposed to a progression of ideas. Finally, the *no response* category for all six categories on the probes instrument was difficult to interpret unless learners were prompted to explain why they left the question unanswered. Several meanings could be attached to the no response, for example, learners did not know an answer, or this represented a transitional view.

5.2.2 Open ended responses from the LUSSI and probes instruments and from interviews

The purpose of the open-ended response section was for learners to explain the basis of their answers and eventually their choices in the closed section of the LUSSI and probes

questionnaire instruments. Data from LUSSI open-ended responses is summarized in Figures 5.5, 5.6, 5.7, 5.8 and 5.9. The figures show frequencies of responses showing similar types of reasoning that were identified. Data from the probes questionnaire is summarized in Tables 5.6, 5.7, 5.8, 5.9, 5.10 and 5.11. The tables show clusters and sub-categories of responses formed for each probe item. For triangulation purposes, interview data is reported in verbatim to corroborate learners' responses from both the LUSSI and probe items. To ensure rigour in the analysis, the researcher asked another researcher (assistant) to re-code a selection of his data based on the categories defined in Tables 5.6, and Figures 5.5. Although at the start, the researcher and his assistant's congruence was about 87%, discussion of the categories from the LUSSI and probes' instruments and the hybridization model used for coding enabled complete agreement between the two by the end of the process. An inter-coder reliability Kappa (κ) coefficient of 0,952 was obtained. Presentation of open-ended responses for all instruments; the LUSSI and probes' questionnaires and interviews is done tenet by tenet. Results are presented in the order: (1) laws and theories serve different roles in science; (2) observations are theory-laden; (3) scientists use a variety of methods to conduct scientific investigations; (4) scientists require accurate record keeping, peer review and replicability; (5) scientific knowledge is socially and culturally embedded; and (6) scientific knowledge is partly the product of human creativity and imagination.

5.2.2.1Theories and laws serve same roles in science

Both the LUSSI and Probes questionnaire instruments had a NOSI tenet on theories and laws. For the LUSSI questionnaire it was worded as scientific laws versus scientific theories and for the Probes questionnaire it was worded as roles of laws and theories in science. The LUSSI responses were categorized into four perspectives namely not classifiable, naïve (inadequate), transitional (moderately adequate) and informed (adequate) views. The accompanying codes and frequencies for all the 167 learners in all five schools are shown in Figure 5.5 below.

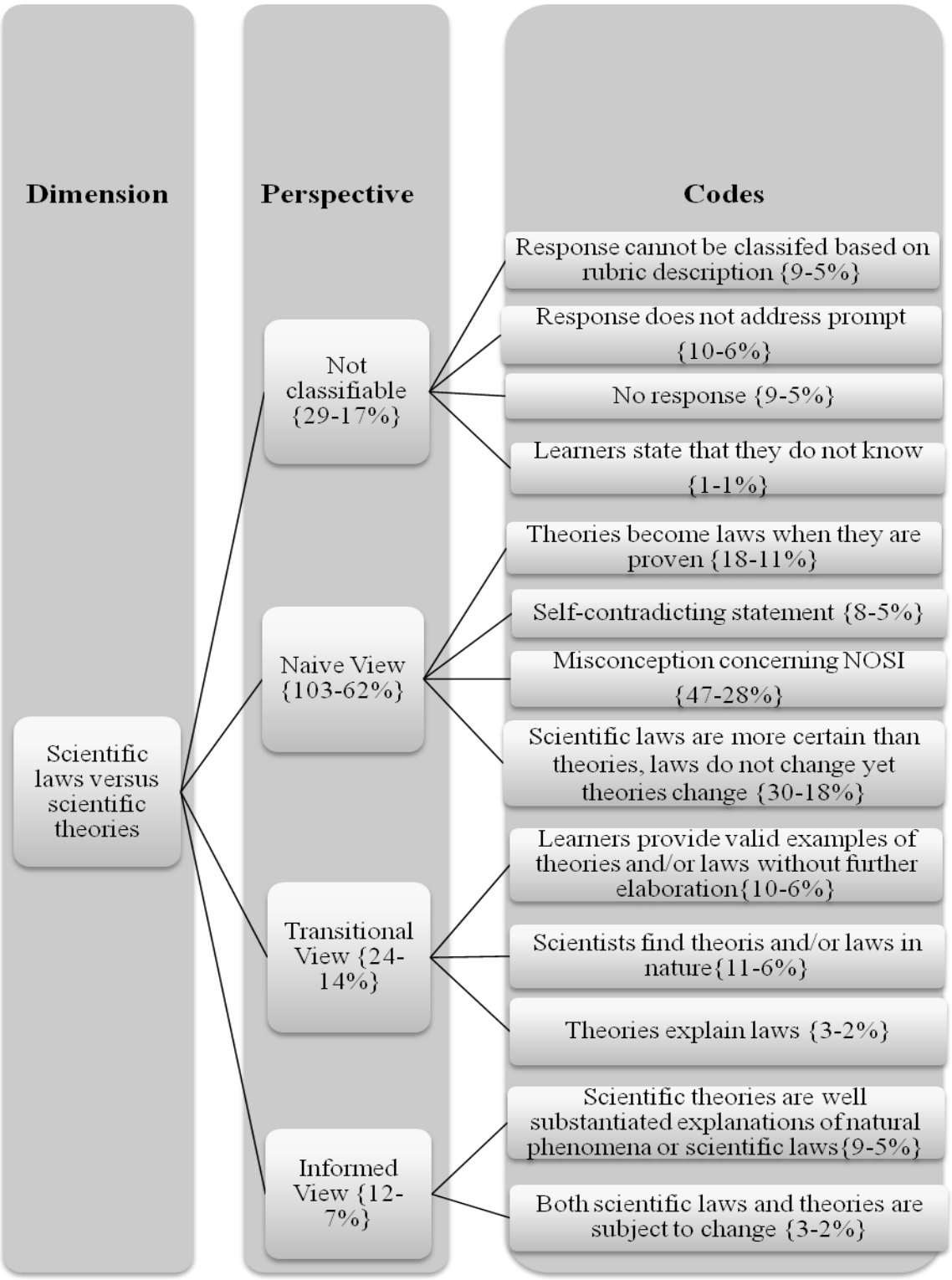

Figure 5.5: Scientific laws versus scientific theories (SLVT) responses from the LUSSI instrument

The Probes questionnaire item responses on roles of laws and theories in science produced six categories. The *no response* category means that the learners did not complete the question, there was no response or learners stated that they did not know. The *not able to code given reason* category means that the response did not address the prompt or the response cannot be classified based on the rubric descriptions. Table 5.6 shows the frequencies of these main ideas. The frequencies add up to 100%. The description for each main idea is a summary by the researcher based on the responses. These have been listed in order of most naive (inadequate) through moderately adequate (transitional) to highly adequate (informed) views.

Table 5.6: Summary of responses to the first probe on roles of laws and theories in science from the Probes questionnaire (n = 167).

Category	Description	No. of learners (%)
RLTS0	No response	5 (3)
RLTS1	Not able to code reason given	51 (31)
RLTS2	Theories and laws serve same roles in science, with no further elaboration	16 (9)
RLTS3	Scientific laws are more certain than theories, for example, theories change because they are ideas not yet proven. However, laws do not change because they are facts already proven. Theories become laws when they are proven.	43 (26)
RLTS4	Theories and laws serve different roles in science, with no further elaboration	43 (26)
RLTS5	Valid example(s) of scientific laws and theories are stated without further elaboration	1 (1)
RLTS6	Scientists FIND theories or laws in nature.	2 (1)
RLTS7	Scientific laws are generalizations, principles or patterns in nature and theories are the explanations of those generalizations. Both scientific laws and theories are subject to change.	6 (3)

Theories and laws serve same roles in science, with no further elaboration

Category RLTS2 comprises those responses that merely state that theories and laws serve same roles in science with no further elaboration indicating misconceptions concerning the nature of scientific inquiry. The quotations given below taken from learners' probes open-ended responses illustrate learners' misconception regarding this probe. Characteristic responses are:

PRLTSL 137: No, I think they serve the same roles in science;

PRLTSL 94: Laws and theories serve the same roles in science;

PRLTSL 44: They serve the same roles because they keep on track scientifically. They also help you to conduct investigations with ease;

PRLTSL 159: They have the same roles because they make science easier to understand and they are linked; and

PRLTSL 115: I think they are the same and they serve the same roles.

These are misconceptions because scientific theories are explanations of scientific laws. They two are not the same and they serve different roles though related. However, it must be pointed out that not all laws have accompanying theories. From the LUSSI instrument, out of 167 respondents, 47 learners (28%) held misconceptions concerning this NOSI aspect (see Figure 5.3). Two learners wrote:

SLVTL 58: Laws and theories are the same thing and they both serve the same role

SLVTL 114: Both laws and theories are made up by scientists hence they are the same.

The percentage of learners harbouring this inadequate (naive) view is slightly higher for the LUSSI instrument because all other unclearly defined responses which showed misconceptions concerning laws and theories in science were grouped under this category. Possible explanation is that learners might have had an explanation for a choice but not the words to express it. This was elicited during interviewing when a small minority articulated their sense of frustration for not having words to explain their choice. A much deeper

misconception of this NOSI aspect is apparent in learner L4SCInt13's description of the difference between laws and theories. She said:

L4SCInt13: Laws and theories are the same because we have to follow certain rules when we are proving them.

Scientific laws are more certain than theories

Learners placed in category RLTS3 of the probes open-ended responses believed that theories and laws are very different kinds of knowledge. Although there is a relationship between laws and theories, one simply does not become the other no matter how much empirical evidence is amassed (Lederman & Abd-El Khalick, 2002). About a quarter of the respondents (26%) believed scientific laws are more certain than theories and theories become laws when proven. Typically they argued that:

PRLTSL 138: Theories are things which have not exactly been proved yet, so they would probably be different to laws because the term law is quite stable in science; or that

PRLTSL 118: Laws cannot be changed but theories can be changed; or that

PRLTSL 4: Theories are made up and when they are proven, they are taken as law; or that

PRLTSL 42: Theories if actually proven they actually make the scientific laws.

Learner responses on this same dimension of the LUSSI instrument pointed to the fact that more or less the same percentage of respondents in the probes questionnaire harboured inadequate (naive) views. Out of 167 learners, 30 (18%) responded by saying scientific laws are more certain than theories because they are proven "true" through repeated testing and 11% of the respondents said theories become laws when proven (see Figure 5.3). The fallacy of this inductive dictum is well known because "no rule can ever guarantee that a

generalization inferred from true observations however repeated is true" (Popper, 1988, p. 25). One characteristic response given is:

> SLVTL64: Scientific laws are theories that have been proven through experiments. Experiments are done, theories are made, and theories became laws - through explaining laws.

Interview responses on the same dimension reveal that there was congruence in learners' responses. One learner had this to say:

> L4SDInt9: A scientific law is different from a theory in that a law is proved and a theory is like a hypothesis because it is not proven. With scientific theory it has not been well understood. There are still some gaps within it yet with a law that is constant, it is known and it is correct.

Theories and laws serve different roles in science, with no further elaboration

The cluster RLTS4 comprised of 43 learners (26 %) who mentioned that theories serve different roles in science with no further elaboration. Failure to provide reasons for justification may indicate a moderately adequate (transitional) view of this tenet of the nature of scientific inquiry. For example, three of the learners wrote:

> PRLTSL 68: I agree with A, because laws are also different so it is impossible for them to serve same roles in science;

> PRLTSL 47: I chose A, because laws and theories serve different roles in science; and

> PRLTSL 123: A, because laws and theories serve different roles in science.

Inspection of the LUSSI instrument responses show that 14% of the respondents harboured moderately adequate views. On the LUSSI, these learners either stated that theories explain laws (2%), scientists find theories and or laws in nature (6%) or learners provided valid

examples of theories and /or laws without further elaboration (6%) (see, Figure 5.3). Responses in RLTS5 just gave valid examples of scientific laws and theories. Surprisingly only one learner did so in the probes yet 10 (6%) gave examples like the law of conservation of mass and energy, Newton's laws of motion, the laws of thermodynamics Charles' law, Boyle's law, Atomic theory and the kinetic theory of gases as part of their LUSSI responses. No further elaboration on these was given. The one learner wrote:

> PRLTSL 71: Scientific law- e.g. Boyle's Law, Newton's Laws, Ohm's law, Coulomb's Law; Scientific Theory e.g. Kinetic theory of matter, Big Bang theory.

This was categorized as a moderately adequate view in both instruments.

Scientists FIND theories or laws in nature

Category RLTS6 consists of responses that made relevance to the source of theories and laws. Only two learners belonged to this group in the probes yet 11 (6%) learners' responses belonged to this code on the LUSSI instrument. One learner in this group wrote:

> PRLTSL 124: Both scientific laws and theories are found in nature. Theories are firmly grounded in and based upon evidence whereas scientific laws are description of a natural phenomenon that invariably holds true under specific conditions; and another

> PRLTSL 16: A scientific law describes what nature does under certain conditions whereas a theory explains how nature works.

One typical LUSSI response is:

> SLVTL6: Scientific theories exist in the natural world and are uncovered through scientific investigations.

Scientific laws are generalizations, principles or patterns in nature and theories are the explanations of those generalizations

The most sophisticated reasoning was evidenced by 3 % of the learners who are part of category RLTS7. The responses in this category indicated the tentativeness of both scientific laws and theories. Specifically, learners reiterated the fact that scientific laws must be simple, true, universal and absolute. Scientific laws represent the cornerstone of scientific discovery, because if a law ever did not apply, then all science based upon that law will be invalid. Learners in this category gave the example of Stephen Hawkins law and the Atomic theory having changed before. One learner wrote:

> PRLTSL 48: A theory explains an entire group of related phenomena and theories do change, for example, the scientific theories about the atomic model changed over time with further developments, e.g. Rutherford had a different idea with that of Charles Dalton. Galileo during his time falsified the law that said the sun went round the earth and Stephen Hawkins' laws have been disapproved.

Included in category RLTS7 are responses that focused on the definitions of both scientific laws and theories. One explained:

> PRLTSL 97: A scientific law is a generalizable statement that has become consolidated by repeated successful testing whereas a scientific theory is a body of knowledge that seek to increase our explanation of a major phenomenon of nature.

However, it was good to see learners stating that most theories explain laws though not all laws have accompanying explanatory theories. For example, one learner in his LUSSI response wrote:

> L3SDInt8: Scientific theories are there to explain scientific laws but not all laws have accompanying theories; and another

L4SBInt5: Scientific laws and theories are linked and they serve to support each other, for example, most scientific laws have theories which explain them.

There was an item in the LUSSI instrument which further corroborated the tentativeness of scientific theories. A considerable number (13%) harboured highly adequate views and believed theories change when existing evidence is re-interpreted. About a third of the respondents (34%) believed scientific theories change with new evidence and 11% of the respondents were of the conviction that scientific theories change with improvement in experimental techniques. Both are moderately adequate (transitional) views. This is what two learners had to say during interviewing when asked about the tentativeness of scientific theories:

L1SBInt1: Theories do change, for example, if there are technological advances overtime, theories will definitely change.

L2SDInt7: Theories change because with changing times more scientific tests are being done with sophisticated equipment and more information is brought up. This information can be re-interpreted to falsify the existing theories.

5.2.2.2The difference between observations and inferences

The second probe was on observations in science. Both the LUSSI and Probes questionnaire instruments had a NOSI tenet on the differences between observations and inferences. For the LUSSI questionnaire it was worded as observations and inferences in science and for the probes questionnaire it was worded observations in science. The LUSSI responses were categorized into four perspectives namely not classifiable, naïve (inadequate), transitional (moderately adequate) and informed (adequate) views as done with the first probe. The accompanying codes and frequencies for all the 167 learners in all five schools are shown in Figure 5.6. All frequencies for the categories and the codes add up to 100%.

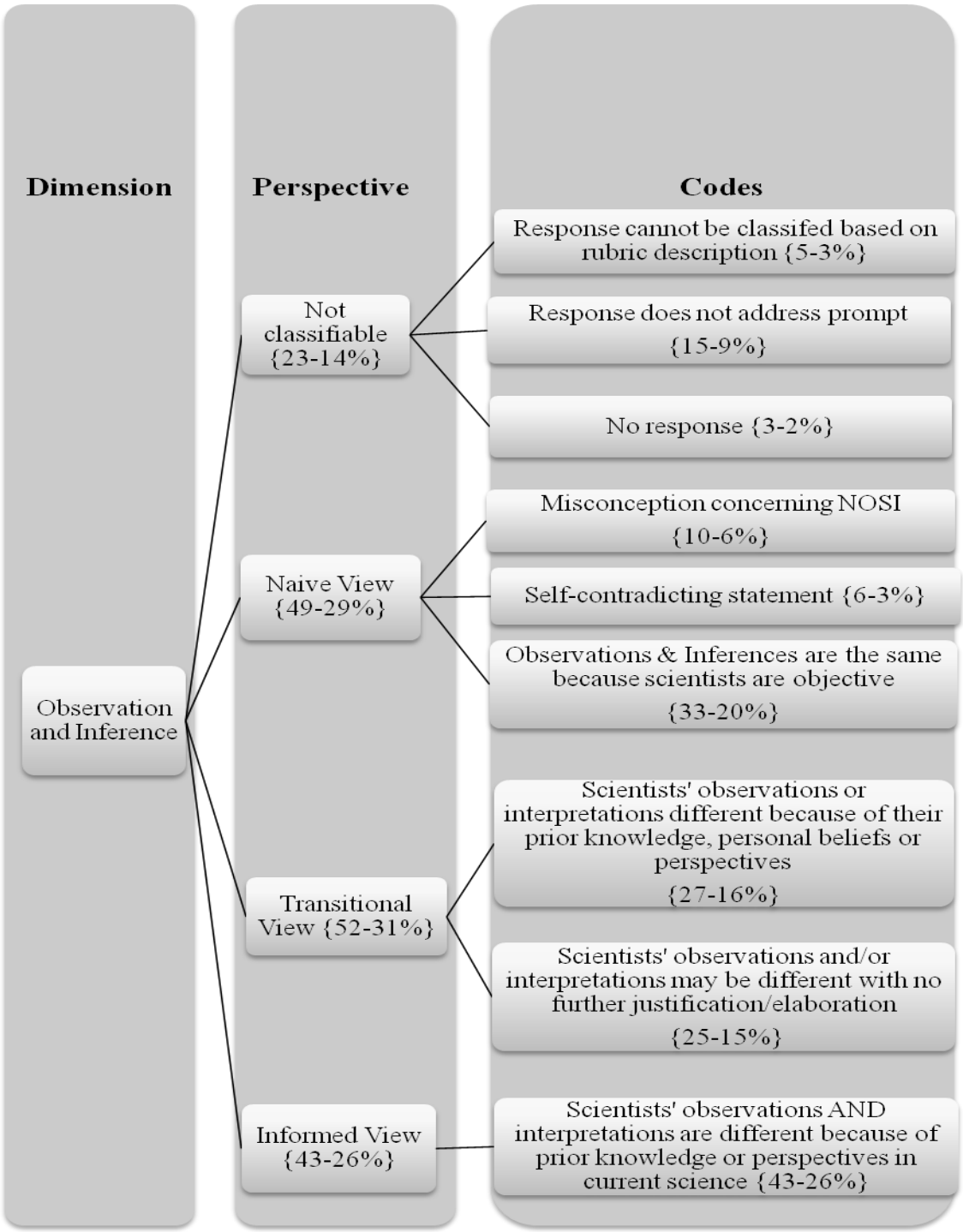

Figure 5.6: Observation and Inference (OI) responses from the LUSSI instrument

The probes questionnaire item responses on the difference between observations and inferences produced four categories. As with the first probe, the *no response* category means that the learners did not complete the question, there was no response or learners stated that they did not know. The *not able to code given reason* category means that the response did not address the prompt or the response cannot be classified based on the rubric descriptions. Table 5.7 shows the frequencies of these main ideas. The frequencies also add up to 100%. The description for each main idea is a summary by the researcher based on the responses. These have been listed in order of most naive (inadequate) through moderately adequate (transitional) to highly adequate (informed) views. The probe solicited information on the differences between observations and inferences. Table 5.7 summarizes the codes and their frequencies obtained from the analysis of probes questionnaire's open-ended responses.

Table 5.7: Summary of responses to the 2nd probe on observations in science from the Probes questionnaire (n = 167).

Category	Description	No. of learners (%)
ObS0	No response	7 (4)
ObS1	Not able to code reason given	23 (13)
ObS2	Observations of the same event in science are the same because like scientists, learners are objective and not based on theory	50 (30)
ObS3	Observations of the same event in science may be different, with no further elaboration.	48 (29)
ObS4	Observations of the same event in science may be different because of learners' prior knowledge, personal perspective, or beliefs.	18 (11)
ObS5	Observations of the same event in science may be different because of learners' prior knowledge and perspectives in current science.	21 (13)

A group comprising 13% of the learners had responses which were not codeable. A very small number (about a tenth) of responses in this cluster (ObS1) confused theories with hypothesis. One learner in this group wrote:

PObSL 65: I chose option C (I have another view which I will explain) because to me observations are based on hypothesis.

It is true; a hypothesis being an educated guess is based upon observation but a theory goes on to summarize a hypothesis or group of hypotheses that have been supported with repeated testing. It is this reasoning that led such responses to be categorized as not codeable. All in all, 14% of learners' responses were categorized as not codeable in the 'observation and inference' dimension of the LUSSI instrument. As explained before, the purpose of the tenet was to corroborate the 'observation in science' probe. A small proportion, about 3% of the responses confused theories with hypothesis when responding to the LUSSI instrument tenet (see Figure 5.5).

Observations of the same event in science are the same

Category ObS2 consists of learners that are more of logical empiricists who argue that all knowledge that is true comes from the senses and is based on observations. This group of learners believed that only empirically verifiable claims make genuine assertions about the world and are, in this broad sense, scientific. From Table 5.7 and Figure 5.5, 30% and 20% of the respondents belong to this grouping respectively. One learner in this group wrote:

PObSL 139: Observations are concerned only with what have been seen, heard or smelled. They have nothing to do with the theories.

During interviewing one learner clarified this misconception by saying:

L4SAInt18: Scientists' observations would be the same because science has set laws and facts which one cannot bend. Because scientists are objective, both learners and scientists should observe in the same manner and conclusions would be the same.

Included in category ObS3 are responses from the probes questionnaire where learners stated that observations of the same event which they make in science are different without

providing reasons for justification. A reasonable number (29%) harboured this view. A typical response was:

PObSL 155: Observations are always theory-laden.

Observations of the same event in science may be different because of learners' prior knowledge, personal perspective, or beliefs.

The responses in category ObS4 indicated that learners believed observations they make in science are theory-laden. Prior knowledge, personal perspective or beliefs all contribute to the process of making observations. Learners in this category were categorized as holding moderately adequate views in both the probes and LUSSI instrument analyses. The percentage responses by learners in this category did not vary much, 11% for the probes and 16% for the LUSSI instrument (see Table 5.6 and Figure 5.5). One learner explained that:

PObSL 93: Yes, observations are theory-laden because prior knowledge, what one knows and beliefs will assist one explain what is happening during an experiment.

Observations of the same event in science may be different because of learners' perspectives in current science.

Category ObS5 comprises those responses that demonstrated informed views of this NOSI aspect. This group of learners managed to realize that the act of observation is selective and one's selection depends on who he/she is and one's history including what one already knows and what one wants or expects to find out. Therefore it is not possible to eliminate bias completely as a result of prior ideas. For example, one learner in this category wrote that:

PObSL 50: When observing, for example, during a scientific experiment, one applies scientific knowledge he or she already knows and this is informed by theories to make a better observation and because we come from different backgrounds, our observations then differ.

Interestingly, 26% of learners elicited this highly adequate view when responding to the LUSSI instrument as opposed to 13% (which is half of the responses on the LUSSI instrument) when responding to the Probes instrument. Of the 23 participants who were interviewed, only a small minority (2 participants) demonstrated highly adequate views of this tenet. This discrepancy is explained in the discussion section.

5.2.2.3 Methodology of Scientific Investigations

The third probe was on methodology of scientific investigations. Both the LUSSI and Probes questionnaire instruments had a NOSI tenet on methodology of scientific investigations. The LUSSI questionnaire item on this probe was worded as methodology of scientific investigations whilst for the probes questionnaire it was worded *methods scientists use to conduct investigations*. The LUSSI responses were categorized into four groupings namely not classifiable, naïve (inadequate), transitional (moderately adequate) and informed (adequate) views as done with the other aspects of the NOSI on the same instrument. The accompanying codes and frequencies for all the 167 learners in all five schools are shown in Figure 5.7. All frequencies for the categories and the codes add up to 100%.

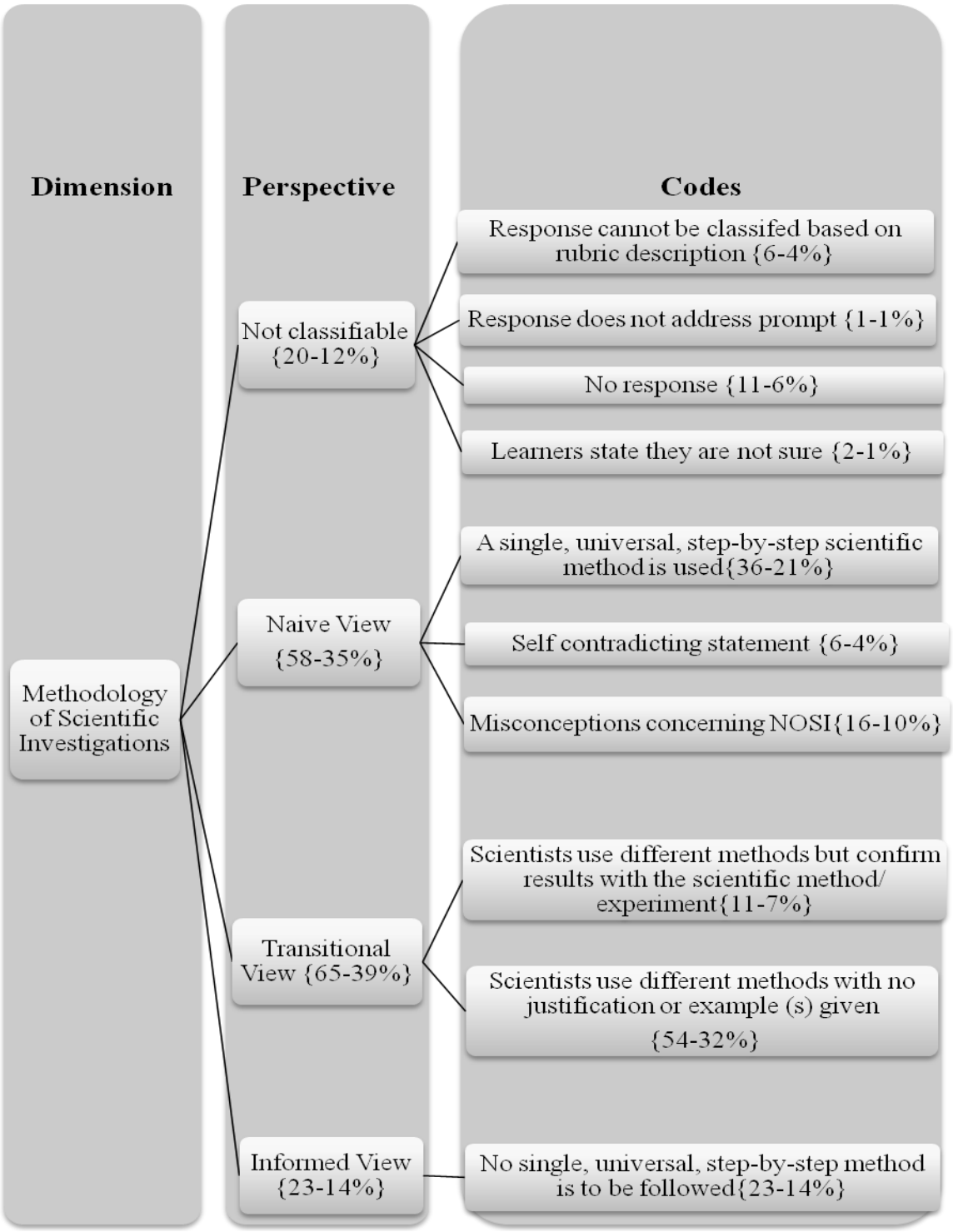

Figure 5.7: Methodology of Scientific Investigations (MOSI) responses from the LUSSI instrument

The probes questionnaire item responses on the difference between observations and inferences produced four categories. As with the first two probes' items, the *no response* category means that the learners did not complete the question, there was no response or learners stated that they did not know. The *not able to code given reason* category means that the response did not address the prompt or the response cannot be classified based on the rubric descriptions. Table 5.8 shows the frequencies of these main ideas. The frequencies also add up to 100%. The description for each main idea is a summary by the researcher based on the responses. These have been listed in order of most naive (inadequate) through moderately adequate (transitional) to highly adequate (informed) views.

Table 5.8: Summary of responses to the 3rd probe on methods scientists use to conduct investigations in science from the Probes questionnaire (n = 167).

Category	Description	No. of learners (%)
MSCI0	No response	4 (2)
MSCI1	Not able to code reason given	17 (10)
MSCI2	There is a single, universal, or step-by-step scientific method that should be used.	22 (13)
MSCI3	Scientists use different methods with no further elaboration or examples given	62 (38)
MSCI4	Scientists may use different methods, but their results must be confirmed by the scientific method or experiments	3 (2)
MSCI5	There is no single, universal step-by-step scientific method that all scientists follow. Scientific knowledge is gained in a variety of ways including observation, analysis, mathematical deduction, speculation, library investigation, and experimentation.	58 (35)

There is a single, universal, or step-by-step scientific method

Responses in category MSCI2 indicated that science is a linear process often portrayed in the science classroom by the scientific method. These responses fitted into Rudolph (2005) description of the scientific method when he lamented that the more nuanced step-based

accounts of scientific processes, when formalized for school curricula, risk getting altered and distorted into rigid steps. In their responses, 13% of participants indicated that there is a single, universal, or step-by-step method that should be used. Of the 167 participants who responded to the LUSSI instrument, 36 participants (31%) shared the same view. Typically, learners in this Probes questionnaire response category argued that:

> PMSCIL 21: In order for scientists to prove each other incorrect in scientific arguments, the same method of scientific investigation should be used and the scientific method is the one for accuracy; or that

> PMSCIL 165: By using several methods, scientists will get a wrong answer for the scientific investigation hence the scientific method is the only best method to use for each of the different investigations.

This line of reasoning was confirmed during interviewing. The researcher tried to make no reference to 'the scientific method' but to 'methods of conducting scientific investigations' but nonetheless, learners said:

> L3SDInt8: To get results that will be recognized internationally by other scientists, you have to follow the scientific method so I think that is the only way you can do that; Yaah... there is only one method which is the scientific method, there is non-other; an another said:

> L1SBInt1: Science is different from other disciplines because it has its own way of doing it. This method is systematic, structured and logical. For example, you come up with a question, develop a hypothesis, test the hypothesis, reach a conclusion and evaluate your hypothesis. You see what I mean...

Scientists may use different methods, but their results must be confirmed by the scientific method

Category MSCI3 comprises of those responses (38 %) that stated scientists use different methods without providing any justification or examples. The responses can be categorized as moderately adequate views of the understandings of nature of scientific inquiry. From the LUSSI instrument, 32% demonstrated this moderately adequate view. One learner in this group wrote that:

> PMSCIL 59: Scientists cannot use the same method to conduct different investigations so they use many methods.

Included in category MSCI4 are responses that acknowledged the importance of the basic components that are often found on the scientific method list. Responses pointed to the need of the components to be considered just not in the rigid and inflexible manner that they are often presented. Other methods can be used to conduct investigations but components of the scientific method should be used to confirm the results. A characteristic response was:

> PMSCIL 89: A number of methods can be used when conducting scientific investigations but at the end the scientific method should be used to check if the answer is correct.

This interesting category whose views are categorized as moderately adequate was also developed from the LUSSI instrument responses where 7 % of the participants indicated scientists use different methods but confirm results with the scientific method or experiment. A characteristic response is:

> MOSIL74: There are multiple ways of doing science; it is not the only method. After using whatever ever method, one must confirm his results by subjecting his or her results to the scientific method so that other scientists can follow.

While being interviewed, some of these learners were explicitly asked whether they thought scientists followed an orderly step-wise procedure. A reasonable number (39%) answered in the positive. However, further probing indicated that these participants still believed in a general overarching method. They held that scientific investigations are conducted for a variety of reasons and scientists use a variety of reasons. However, for confirmation of results scientists had to use an orderly step-wise procedure:

> L4SCInt13: The scientific method is not the only way of doing science; there are plenty of ways, scientists use to conduct investigations. However, to be sure of their results, scientists follow a logical common method. For them to address a problem they have questions and from there they develop hypothesis, from there they design an experiment and perform it, then collect results and proceed from there.

There is no single, universal step-by-step scientific method that all scientists follow

Category MSCI5 responses (35%) demonstrate a more advanced understanding of this NOSI tenet. Learners explicitly stated that there is no single, universal step-by-step scientific method that all scientists follow. This is in agreement with even some proponents of scientific method (e.g., Reiff, Harwood, & Phillipson, 2002) who have emphasized that the steps are not rigid and do not follow a fixed order. The process of science is non- linear, complex, and contingent. Scientific knowledge is therefore gained in a variety of ways. Typically, these learners argued that:

> PMSCIL 76: Scientists are not limited and have no boundaries, so with them using one method means they will not find solutions to their problems; or that

> PMSCIL 43: There are often many ways to a solution therefore scientists come up with different methods of conducting an investigation.

Corroborating responses from the LUSSI instrument # 6 tenet indicated that 14% of the participants held highly adequate views (see, Figure 5.6) as opposed to the 35% on Table 5.7. Some even believed there are discrepancies between the way they do science and the

way scientific work is actually conducted. Only 2 participants out of the 23 interviewed believed otherwise. The rest of the interviewees (21 participants) explicated clear, highly adequate views:

> L5SCInt14: We normally follow the scientific method because it helps us put our thoughts together but that is not the only way of doing science. Other methods can be used, for example, scientists use perseverance and creativity and at times they stumble on discoveries by mere luck. I hope you have heard the famous story about how Isaac Newton discovered the Law of Gravity while sitting under an apple tree. For me, there is no single method.

About 17 participant's responses (10%) were not codeable for this probe a somewhat larger than expected number. More than half of these were so for the reason that the probe was interpreted as a question in which respondents referred to individual experiments and felt that both the scientific method and various other methods could be used.

5.2.2.4 Scientists validate new knowledge

The *fourth probe* was on ways scientists validate new knowledge. The LUSSI did not have a probe item on this NOSI aspect. Only the probes questionnaire instrument and the interview schedule had items eliciting views on this NOSI tenet. On the probes questionnaire the item was worded as *ways in which scientists validate new knowledge*. The Probes questionnaire item responses produced four categories under ways in which scientists validate new knowledge. As with the preceding items on the Probes questionnaire, the *no response* category means that the learners did not complete the question, there was no response or learners stated that they did not know. The *not able to code given reason* category means that the response did not address the prompt or the response cannot be classified based on the rubric descriptions. Table 5.9 shows the frequencies of these main ideas. The frequencies also add up to 100%. The description for each main idea is a summary by the researcher based on the responses. These have been

listed in order of most naive (inadequate) through moderately adequate (transitional) to highly adequate (informed) views.

Table 5.9: Summary of responses to the 4th probe on ways scientists validate new knowledge from the Probes questionnaire (n = 167).

Category	Description	No. of learners (%)
WSVNK0	No response	7 (4)
WSVNK1	Not able to code reason given	28 (17)
WSVNK2	Scientists do not require accurate record keeping, peer review and replicability	67 (40)
WSVNK3	Scientists require accurate record keeping, peer review and replicability with no further elaboration or examples given	40 (24)
WSVNK4	Scientists review and ask questions about the results of others so as to validate discoveries with reasoning	17 (10)
WSVNK5	Communication and peer review impact what and how science progresses.	8 (5)

Scientists do not require accurate record keeping, peer review and replicability

The grouping WSVNK2 comprised of 67 learners (40 %) of the sample who viewed *science* as a solitary pursuit. This is a myth which this group of learners harboured on this NOSI tenet. This group of learners saw no need for scientists requiring accurate record keeping, peer review and replicability. One characteristic response expressed the view that:

> PWSVNKL70: Scientists do not require accurate record-keeping because they must first investigate before they come to know something.

It is noteworthy that the all the interviewed participants (23 learners) indicated the negative and believed scientists require accurate record keeping, peer review and replicability.

Scientists require accurate record keeping, peer review and replicability with no further elaboration

Category WSVNK3 consists of responses that made reference to scientists requiring an accurate record keeping, peer review and replicability without providing any justification or examples. This is categorized as a moderately adequate view basing on a *hybrid model* produced after fusing the Ibrahim, Buffler and Lubben's (2009) coding model with Liang et al.'s (2009) rubric for scoring SUSSI open-ended responses used for coding the probes instrument responses. One learner in this group wrote:

PWSVNKL84: Accurate record keeping, peer review and replicability are always required.

Interestingly, during interviewing, some of the learners in this grouping (60%) managed to explain why accurate record keeping, peer review and replicability are always required. This they had not done in their probe responses. The learners noted that:

L1SBInt1: [...] in school, for example, through accurate record keeping, peer review and replicability other science learners can see where they will have gone wrong in the process of investigations and learn from that scientific experience; and another

L3SCInt12: It is through these processes that scientists validate knowledge because this helps to improve the laws and/or theories as new information comes through investigations or re-interpretation of existing evidence; and another

L4SEInt22: Accurate record keeping, peer review and replicability are important because when investigating something, one should look back to recorded information to compare with what has been obtained so as to falsify existing laws and theories.

Scientists review and ask questions about the results of others

Of 167 participants, 17 (10%) noted that scientists review and ask questions about the results of others so as to validate discoveries with reasoning. This group was coded as category WSVNK4. Included in category WSVNK4 are responses that focused on the

premise that new knowledge must be reported clearly and openly. Developments in scientific knowledge are critically reviewed and may be authenticated and validated by members of the wider community. A typical response was:

> PWSVNKL104: Information and sources should be reviewed by others in order to fully appreciate one's idea, theory or new knowledge. Scientists learn from each other on daily basis and this enables them to validate discoveries with reasoning.

Communication and peer review impact what and how science progresses

Finally on this probe, the responses in category WSVNK5 indicated that science advances through logical skepticism, critical thinking, logic and arguments. Only 5% of the participants held highly adequate views in this regard. Comments under this theme showed the perceived importance of trying to counteract a widespread view of science among learners as the dull accumulation of facts. Prior to publication, new findings and theories will be subjected to critical review, further testing, and possible authentication and validation by others. The scientific community is predominantly self-regulating. Scientists as a result work in teams. For example, learners in this group wrote that:

> PWSVNKL51: Scientists need proof to validate their theories and they need other scientists to come, look and help validate the investigation. They also need to see if different methods affect replicability and if they are able to do it; and

> PWSVNKL30: Scientists review old records then re-construct them adding new additional information or knowledge.

5.2.2.5 Nature of scientific knowledge

The *fifth probe* focused on the nature of scientific knowledge. Both the LUSSI and probes questionnaire instruments had a NOSI tenet on the nature of scientific knowledge. The LUSSI questionnaire item on this probe was worded as social and cultural influence on science whilst for the probes questionnaire it was worded *nature of scientific knowledge*. The LUSSI responses were categorized into four groupings namely not classifiable, naïve

(inadequate), transitional (moderately adequate) and informed (adequate) views as done with the other tenets of the NOSI on the same instrument. The accompanying codes and frequencies for all the 167 learners in all five schools are shown in Figure 5.8. All frequencies for the categories and the codes add up to 100%.

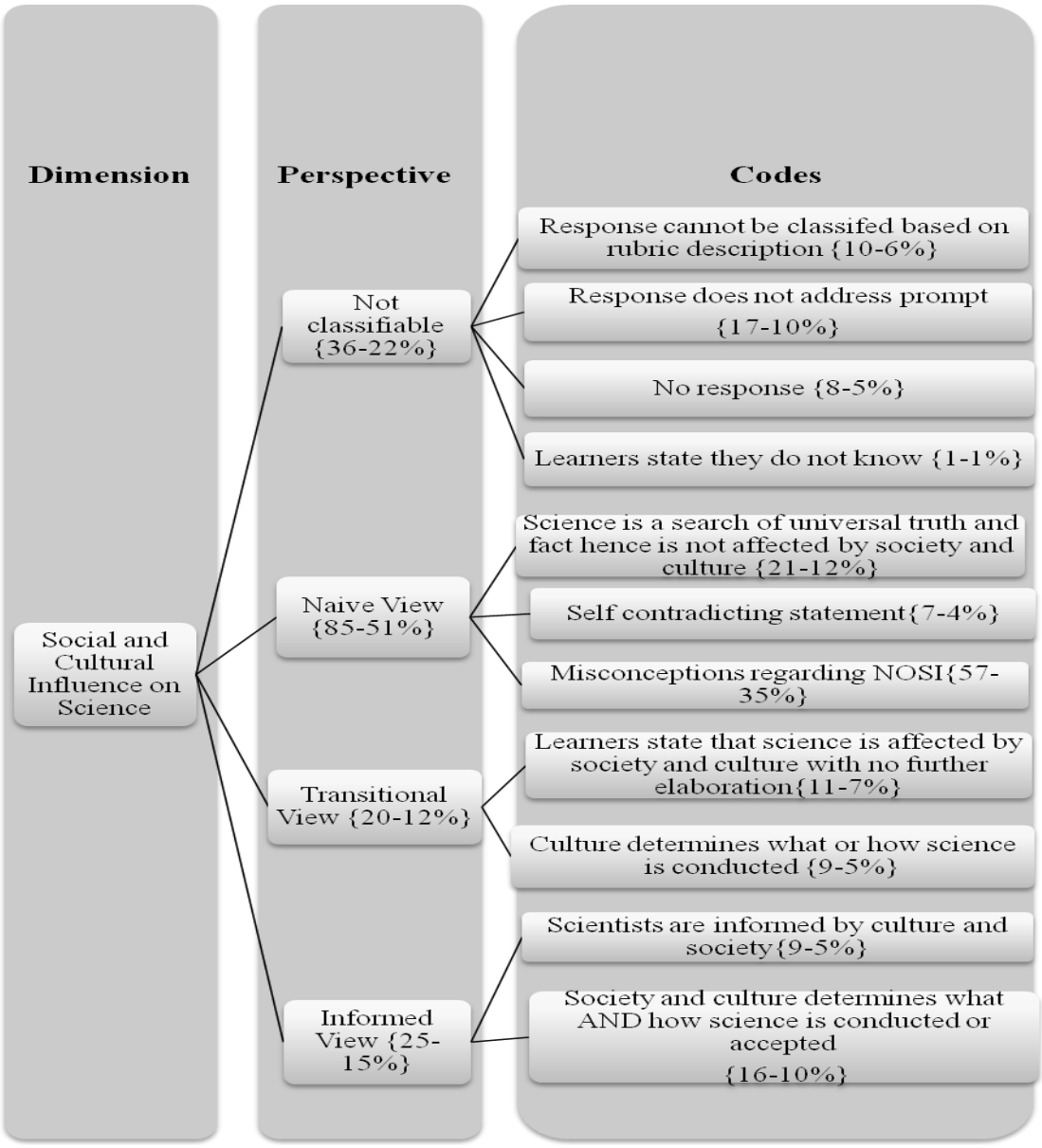

Figure 5.8: Social and Cultural Influences on Science (SCIOS) responses from the LUSSI instrument

The Probes questionnaire item responses on the nature of scientific knowledge generated four categories. As with all probes items on the instrument, the *no response* category means that the learners did not complete the question, there was no response or learners stated that they did not know. The *not able to code given reason* category means that the response did not address the prompt or the response cannot be classified based on the rubric descriptions. Table 5.10 shows the frequencies of these main ideas. The frequencies also add up to 100%. The description for each main idea is a summary by the researcher based on the responses. These have been listed in order of most naive (inadequate) through moderately adequate (transitional) to highly adequate (informed) views.

Table 5.10: Summary of responses to the 5th probe on nature of scientific knowledge from the Probes questionnaire (n = 167).

Category	Description	No. of learners (%)
NSK0	No response	7 (4)
NSK1	Not able to code reason given	28 (17)
NSK2	Science is a search for universal truth and fact which is not affected by culture and society.	64 (38)
NSK3	Science is influenced by culture and society without further elaboration or examples given	43 (26)
NSK4	Scientists are informed by their culture and society. Culture determines what OR how science is conducted, or accepted.	16 (10)
NSK5	Scientists are informed by their culture and society. Society and culture determines when, what AND how science is conducted as well as kinds of scientific discoveries made at any given point in time	8 (5)

Science is a search for universal truth and fact which is not affected by culture and society

The responses in category NSK2 indicate a group of learners who tread in the murky waters of absolutism. Absolutism is the state of being absolute. This group of learners believed facts are the world's data. The alternative framework (misconception) which this group

harboured was that facts mean ‘absolute certainty’. Of the 85 participants who indicated inadequate views on the LUSSI instrument, 12 % shared this same view. Typically they argued that:

> PSCIOSL 30: Science is based on facts from investigations therefore scientific knowledge is due to existing tangible or plausible proof;
>
> PSCIOSL 10: Science is about facts hence it is not socially and culturally embedded. If social and cultural influences are considered then scientists will be subjective and there will be no universal truth; and
>
> SCIOSL30: Culture is customs and beliefs of certain people. Science is about facts-proven laws and theories which come as a result of research and investigations. It is never affected by culture and society as it checks the daily lives of people. Society and culture do not mix with science; they are like water and oil.

This is not true because in science “fact” can only mean ‘confirmed to such a degree that it would be perverse to withhold provisional consent’ (Abd-El-Khalick, 2006). This group of learners therefore harboured inadequate (naive) views of this nature of scientific knowledge probe. Of the 51% participants who harboured inadequate views on the LUSSI instrument, 4% gave self- contradicting statements and 35% gave statements which showed misconceptions regarding the NOSI (see, Figure 5.8).

Science is influenced by culture and society without further elaboration

It can be seen from Table 5.10 that 26 % of the learners fall under category NSK3 which states that science is influenced by cultural and society without further elaboration. The group could not mention how society and culture are embedded in science. Failure to provide reasons for justification may indicate a moderately adequate (transitional) view of this tenet of the nature of scientific inquiry. For example, two learners in this grouping wrote:

PSCIOSL 74: Scientific knowledge is embedded in social and cultural issues; and

PSCIOSL 135: Science is socially and culturally embedded.

Scientists are informed by their culture and society.

Of the 20 participants (12%) who indicated moderately informed views on the LUSSI instrument, 11(7%) did not provide examples or provide elaboration or justification to substantiate their position (see, Figure 5.8). Learners placed in category NSK4 saw science as an endeavour and phenomenon which is not conceived and operated in a cultural and environmental vacuum. This group of learners saw science as a social phenomenon greatly influenced by the prevailing cultural traits and worldview of people such as their social values, priorities, ideas, skills ethics, perception of social reality and belief systems. Typically, these learners argued:

> PSCIOSL 38: People are different and have different cultures. Certain cultures and their respective societies therefore determine the type of science and how the science should be accepted. Certain cultures reject certain science to be conducted like cloning of human beings;

> SCIOSL57: Regardless of the fact that science is objective, cultural morals and values affect the way science is conducted in that cultural values definitely affect scientists' thoughts. Scientists are restricted from doing certain types of scientific research and experiments because their societies and cultures do not allow them to do so, for example, human cloning. Tradition is highly respected.

From interviewing this is what one learner had to say:

> L4SDInt9: Science is affected by social and cultural beliefs because science reacts to societal and cultural problems. Scientific research is influenced by scientists' values, belief system and expectations which determine what and how things are being done hence different cultures many atimes disagree with the way research is done in other cultures.

Society and culture determines when, what AND how science is conducted

The most sophisticated reasoning was evidenced by learners in the grouping NSK5 who saw science as the worldview of a people, that is, the way they think of themselves, their problems, others and their material environment, that fundamentally determine their level of scientific, technological and industrial progress (Inokoba, Adebowale, & Perepreghabofa, 2010). Therefore, to this grouping, there are certain cultural traits, attitudes and belief system that could encourage the growth of science and equally too, there are those that could act as disincentives to scientific advancement. Thus, the dominant cultural setting or the worldview of any society determines to a large extent, the growth of both science and technology (Aikenhead, 1980), and as well as how scientific thought and processes are given priorities in the scheme of things. Of the 167 participants, only 8 (5%) elicited this reasoning on their probe responses as opposed to 16 (10%) on LUSSI instrument responses. For example, when completing the probe, one learner wrote that:

> PSCIOSL 119: Scientific knowledge is embedded in society and culture and its source is problems emanating from society. The question 'why' is the source of investigations and the pursuit of solutions leads to other questions being asked. As a result, society and culture determine when, what and how science is conducted as well as kinds of scientific discoveries made at any given point in time.

During interviews, 10 out of 23 interviewees indicated this extremely adequate view of this NOSI tenet.

5.2.2.6 Creation of scientific knowledge

The *final probe*'s hub was on the creation of scientific knowledge. Both the LUSSI and Probes questionnaire instruments had a NOSI tenet on the creation of scientific knowledge. The LUSSI questionnaire item on this probe was worded as imagination and creativity on scientific investigations whilst for the Probes questionnaire it was worded *creation of scientific knowledge.* The LUSSI responses were categorized into four groupings namely not classifiable, naïve (inadequate), transitional (moderately adequate) and informed

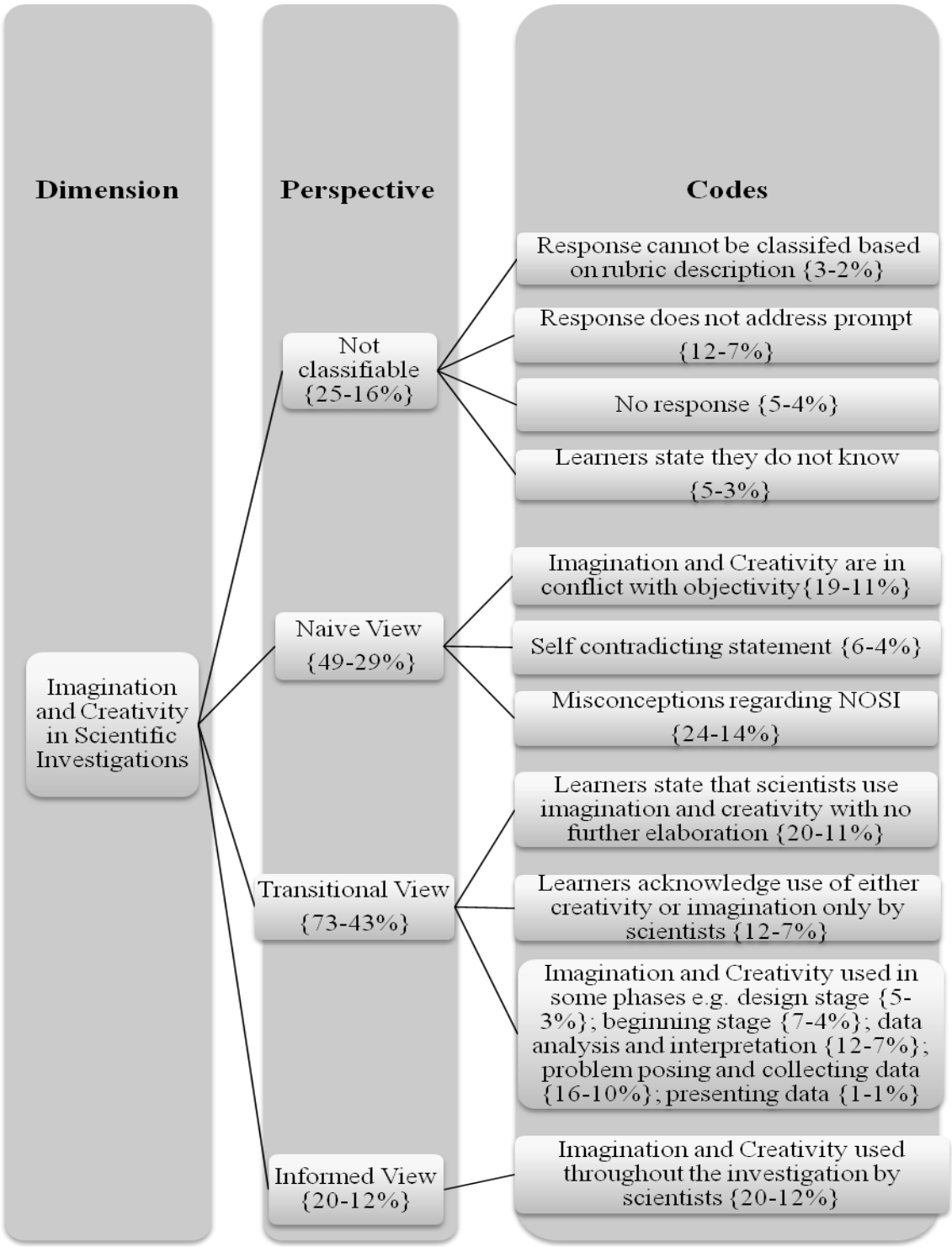

Figure 5.9: Imagination and Creativity in Scientific Investigations (ICISI) responses from the LUSSI questionnaire

(adequate) views as done with the other tenets of the NOSI on the same instrument. The accompanying codes and frequencies for all the 167 learners in all five schools are shown in Figure 5.9. All frequencies for the categories and the codes add up to 100%.

The Probes questionnaire item responses on the creation of scientific knowledge also generated four categories. As with all probes items on the instrument, the *no response* category means that the learners did not complete the question, there was no response or learners stated that they did not know. The *not able to code given reason* category means that the response did not address the prompt or the response cannot be classified based on the rubric descriptions. Table 5.11 shows the frequencies of these main ideas. The frequencies also add up to 100%. The description for each main idea is a summary by the researcher based on the responses. These have been listed in order of most naive (inadequate) through moderately adequate (transitional) to highly adequate (informed) views.

Table 5.11: Summary of responses to the 6th probe on creation of scientific knowledge from the Probes questionnaire (n = 167).

Category	Description	No. of learners (%)
CSK0	No response	6 (4)
CSK1	Not able to code reason given	27 (16)
CSK2	Scientists do not use imagination and creativity because imagination and/or creativity are in conflict with objectivity	43 (26)
CSK3	Scientists use their imagination and/or creativity without further elaboration or examples given	39 (23)
CSK4	Scientists use their imagination and/or creativity in SOME phases of their work, notably in designing experiments or problem solving	8 (5)
CSK5	Scientists use their imagination and/or creativity throughout their scientific investigations	44 (26)

Scientists do not use imagination and creativity because imagination and/or creativity are in conflict with objectivity

Responses in CSK2 category indicated that this group of learners held the most inadequate (naive) views for this NOSI tenet. Out of 167 learners, the responses of 43 (26%) of the learners reflected this inadequate view. Of the 49 participants (29%) who demonstrated inadequate views of this tenet on the LUSSI responses, 19 (11%) belong to this group (see, Figure 5.9) who can said to be *realists*. The realist position posits the existence of objective truth that is independent of one's thinking. The learners put forward the idea that scientists do not use imagination and creativity because these conflict with their objectivity and logical reasoning. To this group, scientific knowledge is provable in an absolute sense, objective, and devoid of creativity and human imagination. From the probes and LUSSI instrument, two learners in this group respectively wrote:

PICISIL 3: Scientists do not use imagination and creativity because it affects their objectivity; they use logical reasoning.

ICISIL17: Scientists do not use their imagination and creativity because these can interfere with objectivity.

During interviewing, about a fifth of the interviewees (5 out of 23) elicited this realist view. One of them said:

L5SCInt14: Well personally I believe with sciences it is never about imagination and creativity, it is usually about facts, facts, and facts. We follow the laws of science because science is all about objectivity.

To the grouping CSK2, scientists are therefore objective. The group believes as scientists engage in their work, they set aside their personal prejudices, perspectives, and beliefs. As mentioned before, this is a naive view since scientists are just human and whatever they do is dependent of what they (scientists) know, believe or how they view the world.

Scientists use their imagination and/or creativity without further elaboration

The grouping CSK3 comprised of learner who harboured moderately adequate views on the creation of scientific knowledge probe. These learners merely stated that scientists use their imagination and/or creativity without further elaboration or giving examples. About 23% were categorized under this grouping based on their probes' responses and the number halved (11%) when considering learners' responses to the LUSSI instrument. Interestingly during interviewing, learners were able to substantiate their positions after probing. A characteristic response was:

> PICISIL 75: I agree with A, scientists use their imagination and creativity when they create scientific knowledge.

Scientists use their imagination and/or creativity in SOME phases of their work

Category CSK4 comprises of those responses that suggested scientists use creativity and imagination in some phases, that is, in part and not as a whole during investigations. Only 8 participants' responses (5%) belonged to this category from the probes' analysis. However, a larger number, 41 (25 %) learners' responses from the LUSSI instrument belonged to this grouping. Of the 25 % who indicated that imagination and creativity are needed in scientific investigations, they differed in their choice of the specific stages in which they thought these attributes were used (see, Figure 5.8). This group of learners are said to be conventionalists. The conventionalist position holds that there is no unique truth. Theory and truth are not fixed by nature but are creations of the mind. The responses of only 3 % indicated imagination and creativity are used during the design stage. When interviewed one learner (L1SEInt19) said, "we use imagination and creativity during the designing stage of the investigation and not throughout the experiment."

Another 4% limited use of imagination and creativity to the planning (beginning) stage. This group believed that using these elements in data collection, data interpretation or in deriving conclusions would result in completely wrong findings. One learner wrote:

ICISIL49: Scientists use their imagination in the beginning stages like planning when they are investigating a problem but when it gets to dealing with the result logic must be used. For example, a scientist cannot do an experiment and use his imagination and creativity at the results stage and thereafter because the scientist would be proving nothing but his inability to focus. Logic is needed afterwards.

About 10% of the participants believed imagination and creativity are used during problem posing and data collection. This group of learners was of the conviction that one has to be creative in problem posing and ways in which the data will be collected and recorded. On all other stages, scientists have to use logic. One learner wrote:

PICISIL 133: Scientists need to be creative and imaginative in order to come up with hypotheses that can be proven. Then they have to figure out how to collect their data and record it. When that is done, scientific knowledge is then created.

Another 7% limited the use of imagination and creativity to data analysis and interpretation and only one learner indicated that imagination and creativity are used when presenting data. One learner (PICISIL 1127) indicated that "scientists use their imagination and creativity only when they analyze and interpret data."

Having established a myriad of responses pertaining to the use of imagination and creativity, a closer examination of the LUSSI and probe responses was done. Further probing during interviewing substantiated the inference that the participants assigned different meanings to the terms imagination and creativity. About 50 % of the participants used the terms to refer to "skillfulness", "cunningness", "initiativeness" or "cleverness" at times "resourcefulness" and not invention of explanations, theoretical models or entities.

Scientists use their imagination and/or creativity throughout their scientific investigations

Finally, the highest level of reasoning on this generation of scientific knowledge probe is given under category CSK5. Imagination and creativity are not something that can be switched on and off. Thus, it is important to collect pure data, but while doing such their mind is always asking questions about what is found/ evident. Of the 167 participants, 44 participants (26%) harboured this extremely adequate view yet 20 participants (12%) indicated this view in response to the LUSSI instrument. This group of learners can said to be both aprioristic and conventionalist. Aprioristic position holds the view that understanding nature can arise as a consequence of reason alone. Typically, learners argued that:

> PICISIL 47: The extent to which we use imagination and creativity is what makes us different therefore scientists use human creativity plus imagination in addition to inquisitiveness and raise question how and why which they answer during throughout investigations using imagination and creativity.

From the results presented above, it can thus be seen that a majority of participants lacked a coherent framework for their NOSI ideas. Learners' views were 'internally' inconsistent, fragmented and fluid. This justifies the use of the *multidimension framework* (MD) as the theoretical framework guiding this study since it treats views of nature of scientific knowledge as a system of more-or-less independent dimensions. The MD also contends that learner's views of the NOSI may not necessarily develop in a coherent manner, and that correlations among the dimensions are not precluded (Deng, et al., 2011). Just like the six tenets of NOSI are fluid and dynamic, the extent to which the schools of thought which characterized the learners conceptions namely; logical positivism, realism, constructivism, conventionalism and apriorism are prioritized depends on the cultural and historical context (Lederman, 1992; McComas, 1998). Very few or no connections seemed to bridge their conceptions.

5.2.3 Some issues about validity: learner interpretation of questions

In this section, the major validity issue tackled is how the learners interpreted the probe questions. Learners' interview responses were also analyzed with the aim of corroborating the learners' responses to some of the LUSSI and Probes items and checking the validity of learners' responses to the probes. For each learner, the responses to each of the explored NOSI issues were examined to determine whether there was congruency between what the learner said and his/her agreement or disagreement or not sure response to related items in the LUSSI and Probes. As an example, in the interview responses learner L1SAInt15 said, "Scientific theories change when existing evidence is reinterpreted". The corresponding/related item in the LUSSI was aspect 2, "With examples, explain why you think scientific theories do not change OR how (in what ways) scientific theories may be changed". The related Probes aspect was probe 1 which asked about the roles of laws and theories in science, as well as the similarities and differences of laws and theories. Learner L1SAInt15 indicated agreement with both aspect 2 of the LUSSI and aspect 1 of the Probes.

While for many learners there was congruency between the views they expressed in the interview and their responses to related items in the LUSSI and Probes, some learners gave contradictory responses. A typical example was learner L2SCInt11 who said "a scientific law is similar to a theory; the two are not different and can be used interchangeably." In her response to one of the LUSSI items, learner L2SCInt11 (whose code number is 69) contradicted herself when responding to aspect 3, "With examples, explain the nature of and difference between scientific theories and scientific laws". The learner acknowledged theories are subject to change but naively disagreed laws can change. The learner wrote:

> SLVTL 69: A theory can be revised if it fails to explain new phenomenon and this leads to change of the theory. Unlike theories, scientific laws are not subject to change because they are proven.

When responding to aspect 1 of the Probes instrument which corroborates the 'scientific laws and theories' tenet, the same learner wrote:

> PRLTSL 69: A scientific law is more factual, has been proven and is definite while a theory has a chance of being proven otherwise; therefore a theory is more like an assumption or hypothesis.

While there seems to be some agreement in the LUSSI and Probes responses, they are both in disagreement with interview responses. This could be as a result of the meanings learners attached to the term "prove" and the fragmented and inconsistent nature of their NOSI views. Almost all learners who harboured naive views on this NOSI aspect frequently used the terms "prove" and "proven" especially when distinguishing between theories and laws. As such, it should "prove" worthwhile to explore in depth the meaning(s) attached to these terms. Learners ascribed different meanings to the term "prove". For instance, some equated the term with providing "support" for a hypothesis:

> L3SBInt3: A scientific theory comes close to a fact especially to scientists who have proved it, some people might believe it but some may not. However, a theory can be taken to refer to a hypothesis which is used to predict something that has not been proven.

However, many used the term to refer to an absolute truism. "A law is something that has been proven and which is absolute" (Learner L3SAInt 17). According to Neufeldt and Guralnik (1996), these latter participants seemed to have used the term "proven" in one of its most common connotations: "to establish as true; demonstrate to be a fact" (p.1082). Of the 23 interviewees, 16 (70%) had used the terms "prove" or "proven" in either the LUSSI and/or Probes responses. When asked to explicate what they meant by these terms and how they thought scientists go about "proving" theories and laws, about 6 of the learners did not perceive "proving" as providing supportive evidence. About 10 of the participants equated the term "prove" with collecting evidence and physical data to back-up certain scientific claims. When asked what they meant by the term "prove", using the term law in the process,

they replied: “To prove means ‘to test’, for example, a law is tested by many scientists hence proven true” (Learner L3SDInt8). Participants noted that the term “prove” implies that a law is “factual”, “absolute” or “permanent”. As such, it is evident that the term “prove” means different things to different participants. This multiplicity of meaning and the various ways participants thought scientists go about “proving” claims coupled with their indiscriminate use of the term seem to have resulted in some confusion or difficulty with validity issues regarding learner interpretation of questions.

Another interesting methodological challenge was presented by interpretation of responses from the third probe “methods scientists use to conduct investigations in science”. The challenge was to try and ascertain whether the learner was reflecting on his/her practical investigation experiences or was thinking about science laboratories in general or drawing his/her answers from some other source when giving responses to some of the LUSSI, Probes and interview questions. In other words, what was the context in which the learner was giving his or her response? The assumption posed by the multidimension framework (framework guiding the study) may be its limitation as well. It posits that learners’ conceptions of the nature of scientific knowledge may be relatively stable and coherently expressed across different contexts (Deng, et al., 2011). Learners’ responses to both closed and open-ended questionnaire items, probes’ items and interview probes are therefore accordingly seen as reliable representation of their views of NOSI in all context of learning. This assumption is increasingly challenged by many empirical studies (Sandoval & Morrison, 2003; Thoermer & Sodian, 2002). For example, some researchers (Abd-El-Khalick & Lederman, 2000b) reported that learners expressed “naive” views of nature of scientific knowledge toward certain questions while “informed” toward others. This framework oversimplifies the role of context in the views of nature of scientific knowledge. The issues in question were: “Did learners base their answers only on their Physical Science knowledge and practical investigation experiences?” that is the context in which the learner was giving his/her response and, “How did the learner interpret the question?” To a very large extent the context in which we give responses to questions is guided by our interpretation of questions.

It was interesting to observe that most of the learners appeared to directly draw upon their experiences in Chemistry practical investigation experiences. When asked "What is your view about the scientific method as a way of doing investigations? The learners responded by saying:

L1SCInt10: We are just following the scientific method when doing investigations and that is the only method I know, there are no methods which I am aware of.

L1SDInt 6: That is one method that scientists and us use to come up with accurate and correct observations; I am not sure if there is any other method.

L2SDInt7: I believe that is the only method because my teacher told me that there is only one method. Even if I wanted to find out if there are other methods, I am no longer interested because I was told this is the only method.

It could be argued that in all the above cases learners reflected on the "methodology of scientific investigations" of their Chemistry practical investigation compared to science laboratories in general or experiences drawn from some other source. Could it be that the learners really reflected on their Chemistry experiences in answering LUSSI, probes and interview probes as the instructions asked them to do? One way of checking on this was to examine some of the learners' responses to the interview probes and compare their answers with how they had responded to both the LUSSI and the probes requiring them to compare the "methodology of scientific investigations" of their practical investigations in science (laboratory work). The corroborating LUSSI question was: "With examples, explain whether scientists follow a single, universal scientific method OR use different types of method to conduct scientific investigations". In responding to this item some learners appeared to reflect on their Physical Science laboratory experiences. Learner L1SCInt10 whose code is MOSIL 68 and PMOSIL 68 to the LUSSI and Probes respectively responded:

MOSIL 68: In science one method is used to do investigations so that scientists can get the correct answer; and

PMOSIL 68: Scientists follow a certain a single, universal scientific method to conduct investigations, and most investigations are conducted according to this method just like we do in the laboratory.

It is probable that learner L1SCInt10 reflected on and drew upon his Chemistry practical investigation experiences in responding to the LUSSI and Probes' items in question. The responses given here are in tandem with the learner's responses to the interview probes which are in agreement with all instruments' responses. In contrast, learners L1SDInt 6 and L2SDInt7 said their experiences in other science subjects' practical investigations gave them a different picture of methods used to conduct science investigations but at the same time partially agreed to LUSSI and Probes items. Their responses to the question "With examples, explain whether scientists follow a single, universal scientific method OR use different types of method to conduct scientific investigations" appear to show that they were not necessarily thinking about their Chemistry practical investigation experiences only in giving their answers. They could have been thinking about science laboratories in general. Probably their experiences in the Physics and Life Sciences also came in. Learners L1SDInt 6 and L2SDInt7 whose code numbers are 117 and 118 respectively gave the following as part of their LUSSI responses:

MOSIL 117: Most scientists follow a specific method, but the way in which they use it might differ slightly. However, there is a specific way to set up investigations which all scientists should follow [...]

MOSIL 118: Scientists use a variety of methods to conduct scientific investigations because different problems call for various and different ways to address them [...]

In response to the Probes' item addressing the same aspect which states; 'indicate the degree to which you *agree* or *disagree* with the following statement by explaining your

choice'; "Scientists use one method to conduct investigations", "No, scientists use a variety of methods to conduct investigations", or "I have another view which I will explain", the two learners wrote:

> PMOSIL 117: [...] Majority of experiments are conducted using the same method, but not necessarily step by step.

> PMOSIL 118: Scientists use different methods depending on the experiments. These different methods help results to be accurate [...]

These responses do not show that the two learners were drawing on their Chemistry practical investigation experiences only. By examining the learners' responses in this way, it became apparent that learners could have been drawing upon their Chemistry practical investigation experiences but most of their responses to the LUSSI and Probes' items as well as interview probes were also under the influence of some other knowledge and experiences, for example, from theory lessons and from science laboratories in general. This appeared to be the case irrespective of whether the question was in the direct context of their Chemistry practical investigation experience or not. The learners' responses to the question "What can you say about the use of imagination and creativity from what you do during Chemistry practical investigations?" also revealed this phenomenon. It would appear learners found it difficult to focus their responses to their Chemistry practical investigations as advised, they still drew upon other "experiences" in answering questions. These observations and the apparent ambiguous interpretations by learners of some of the LUSSI, Probes' and interview probes made the extraction of learners' NOSI conceptions a very challenging task. The analyses and interpretations producing the summarized NOSI conceptions given in Tables 5.5, 5.6, 5.7, 5.8, 5.9 and 5.10 as well as in Figures 5.3, 5.4, 5.5, 5.6, 5.7 and 5.8 above were done with an awareness of the issues raised in this section.

5.2.4 Interview results: Corroboration of LUSSI and Probes findings

The other methodological challenge other than the issue of learner interpretation of questions discussed above was triangulation of LUSSI, Probes and interview findings.

Triangulation is defined as seeking convergence and corroboration of results from different methods and designs studying the same phenomenon (Johnson, Onwuegbuzie, & Turner, 2007). To Bazeley (2004) triangulation can be used as a technique of validation. Following Bazeley's operationalization of the term "triangulation", findings from the LUSSI, Probes and interviews were triangulated using a matrix for cross-case analysis (Miles & Huberman, 1994) with subheadings (and example) as shown in Table 5.12 drawn to facilitate the search for congruency between a learner's normative placement. Analysis revealed that learners hold inadequate views on some NOSI aspects and extremely adequate views to others. This effective, thorough and care analysis allowed for some elaboration on a learner's normative placement done with the LUSSI and Probes' instruments and his/her interview responses.

Table 5.12: An illustration of the matrix used to aid the search for congruency between LUSSI, Probes' and interview responses (23 learners)

School and Learner ID	Learner score (LUSSI Open-ended score)	Categorization of learners' views LUSSI	LUSSI 'Laws versus Theories'	Probes 'Laws versus Theories'	Interview 'Laws versus Theories'
A 10	62 (7)	Poorly adequate	Theories become laws when proven	Laws are more certain than theories	Both laws and theories do not change
B 46	60 (5)	Poorly adequate	Laws guide theories	Laws and theories are the same	A law is set in stone, it will never change
C 88	81 (10)	Moderately adequate	They serve different roles, no elaboration	Valid examples of theories and laws given	Theories do not become laws
D 131	98 (12)	Highly adequate	Laws describe gene-ralized relationships	Both theories and laws are found in nature	Both theories and laws can change
E 156	87 (13)	Highly adequate	Theories serve as a support of laws	Theories are there to explain laws	Theories are explanations of laws
	Summary responses from two NOSI aspects; Imagination and Creativity in Scientific Investigations (ICISI) and Methodology of Scientific Investigations (MOSI)				
LUSSI 'ICISI'	Probes 'ICISI'	Interview 'ICISI'	LUSSI 'MOSI'	Probes 'MOSI'	Interview MOSI'
10-Not used	Not used, they affect objectivity	Not used, they have to prove	Single universal method	There is only one scientific method	A single step-by-step method is used
46-Not used	Not used, we use observations	Not used, they follow a theory	Only the scientific method is used	Scientists use a step-by-step method	I only know of the scientific method
88-Used in some phases	Used e.g. during the design stage	Used when design-ing experiments	Scientists use various methods	Various methods are used with no elaboration	Different types of methods are used
131-Used throughout investigations	Used throughout research for accurate results	Used throughout research, it provides new ideas	Experiments are not only means used to generate knowledge	Other methods like observation and speculation are used	Scientists use a variety of valid methods
156-Used throughout investigations	Without them there is no progress	Without the two, there is no research	Different problems need different methods	Different types of methods are employed	There is no single, universal step-by-step method

The upper portion of the matrix shows how the five learners' conceptions varied in the 'laws and theories' aspect of the NOSI. The bottom portion summarizes responses from two NOSI aspects of the same five learners shown on the upper portion. The remaining three NOSI aspects investigated in the study are not shown on the table but follow the same format. The matrix analysis confirmed the nomothetic categorization done by the LUSSI and Probes, strengthening the validity of the LUSSI and Probes' instruments. As shown on the matrix, there is nothing to preclude looking for a relationship among all six NOSI aspects. Of the 15 learners (out of the 23 interviewed) classified by the LUSSI and probes' instruments as harbouring inadequate views, ten (10) were confirmed to display inadequate views in the Matthews sense by the matrix, for example; scientific laws are proven and absolute during interviewing. By inadequate views, Matthews (1998a) refers to the idea that individuals are not able to marshal evidence to support their own epistemological positions. This was on at least three of the explored NOSI aspects shown in Table 5.11. The remaining eight interviewed learners classified as harbouring both moderately adequate and highly adequate views were also categorized in the same way using the matrix.

The researcher with the help of a colleague first independently did the placement of each learner for each of the six explored NOSI issues. Each learner'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 learner on each of the issues. Consistency with which the learner expressed his/her ideas on the issue throughout the interview, the LUSSI and the probes was used as the basis for the placement. However, at times there was a challenge in some cases where learners expressed both an inadequate and informed view. Eventually the researcher reached consensus with the colleague and the self-contradicting responses were taken as inadequate views.

5.2.5 Application of the multidimension framework

The multidimension framework was employed after triangulating responses from LUSSI and probes questionnaires and from interviews to answer the research question: what are learners' understandings of the NOSI? As mentioned earlier, by this tool learners' views of

the NOSI are not treated as existing on a unidimensional continuum, but rather as multiple dimensions that are more or less independent. From the 25 learners who were sampled for interviewing as described in Chapter 3, two dropped out and eventually 23 learners were interviewed. The 23 learners' LUSSI, probes and interview responses showed that 15 of the learners harboured static, empiricist-aligned views of science on at least four of the six NOSI tenets. Their conceptions subscribe to such notions as: scientific observations and interpretations are objective and theory free, science is culture free, there is one method of science, scientific knowledge is sourced from observation and experiment only, scientific theories develop into laws, scientists are humans with extra-ordinary intelligence and that science is entirely empirically based knowledge. To Allchin (2011) and Clough (2004), these notions seem to be myths about the nature of science and NOSI. However, according to Deng et al.'s (2011) categorization; these are taken as naive views about the nature of scientific inquiry. The other 7 learners' responses were more of fairly constructive views of the NOSI on at least four of the six NOSI tenets. These views were neither empiricist-aligned nor highly constructivist-oriented. Only one learner showed desirable, contemporary, and highly adequate and largely dynamic, constructivist-oriented views of the NOSI when all the six tenets were considered. His conceptions subscribe to such notions as: scientific observations are subjective and theory-laden, scientific knowledge is a product of human creativity, imagination and serendipity, there is no one method of science, science is not culture free, and that science is just another humane enterprise. Deng, et al.'s (2011) multidimension framework considers these notions as informed conceptions of the NOSI.

Considering the other 144 learners who only completed the LUSSI and probes questionnaires, each individual learners' responses was considered on both instruments. Using the multidimension tool, a decision was made considering the six dimensions (tenets in this case). If a learner's views subscribed to notions that seem to be myths about the NOSI on at least four tenets then the learner would be said to harbour static and empiricist-aligned views. If a learner's views subscribed to notions that are neither explicitly empirically-aligned nor largely dynamic, constructivist-oriented views, then the learner's

conception of the NOSI were taken as fairly constructivist-oriented. If a learner views subscribed to notions of informed views on at least four NOSI tenets then the learner would be said to harbour desirable, contemporary, and highly adequate and largely dynamic, constructivist-oriented views. Results from such an analysis of this study are: 75 out of 144 learners (52%) harbour static and empiricist-aligned views; 58 out of 144 learners (40%) possess fairly constructivist-oriented; and 11 out of 144 learners (8%) harbour desirable, contemporary, and highly adequate and largely dynamic, constructivist-oriented views. Overall, the learners displayed inadequate conceptions of the NOSI.

5.3 Discussion

The study's first research question is; what are learners' understandings of the NOSI? This study has found that sampled learners held mixed NOSI views that ranged from inadequate (naive), moderately adequate (transitional) to adequate (informed) in all six NOSI aspects that were explored. The percentages though varied from one NOSI aspect to the other. Overall, 7 % of the learners harboured inadequate views, 82 % moderately adequate views and 11 % highly adequate views on closed responses. Interestingly, 32% of the learners harboured inadequate views, 49 % moderately adequate and 19% highly adequate views on open-ended responses. This finding is consistent with ones reported in a plethora of studies that assessed high school learners' nature of science views over the past six decades and few recent studies (see, e.g., Abd-El Khalick & BouJaoude, 1997; Aikenhead, 1973a, 1973b; Akerson, Buzzelli, & Donnelly, 2008; Constantinou, et al., 2010; Gilbert, 1991; Özdem, Çavaş, Çavaş, Çakıroglu, & Ertepınar, 2010; Songer & Linn, 1991; Tsai, 1998a; Tsai, 1998b; Tsai, 2000; Vhurumuku, et al., 2006).

The majority of the learners demonstrated inadequate understandings on: (a) laws and theories serving different roles in science; (b) observations being theory-laden; (c) scientists using a variety of methods to conduct scientific investigations; (d) scientists requiring accurate record keeping, peer review and replicability; (e) scientific knowledge being socially and culturally embedded; and (f) scientific knowledge being partly the product of human creativity and imagination.

As the results of this study show a reasonable proportion (15 %) of the sampled learners hold such acceptable NOSI views in all six aspects (a - f) stated above. In this regard then, this study confirms existing knowledge. This is consistent with prior research findings (e.g., Afonso & Gilbert, 2010; Akerson & Volrich, 2006; Şahin & Köksal, 2010). Also consistent with prior research findings is the finding that participant's NOSI views were not related to their gender (see, e.g., Lederman, 1992; Şahin & Köksal, 2010; Tsai, 2006; Tsai & Liu, 2005a; Vhurumuku, et al., 2006). The lack of association between gender and learners' understandings of the NOSI contradicts the finding of Saunders, Cavallo, & Abraham (1999) whose study although with College Chemistry students showed that epistemological beliefs were correlated with gender.

However, there was association between two variables, namely; the main effect for the school and learners conceptions of the NOSI. This is inconsistent with prior research findings where learners' natures of scientific knowledge views were not related to the type of school (e.g., Carey & Stauss, 1969; Dolan & Grady, 2010; Vhurumuku, et al., 2006; Wood, 1972). The fact that the type of school was not related to learners' NOSI understandings might point towards instruction being different in all types of sampled schools. In South Africa, former Model C schools are known to have more resources in terms of best facilities, best teachers and best educational opportunities for children when compared to Township and Suburban schools (South African Schools and Education System, 2010). Other attributes that characterized the participant's NOSI views are discussed under each NOSI aspect below.

Laws and theories serve different roles in science

A majority of the participants (62%) endorsed a hierarchical view of the relationship between theories and laws. Of the 62%, 18% of the participants advocated for a simplistic relationship between hypotheses, theories and laws. This finding is consistent with the findings of studies reported by Lederman and Abd-El-Khalick (2002) and Abd-El-Khalick (2006)'s study although it was with 153 undergraduate and graduate students in a mid-sized

Western State University. However, the simplistic, hierarchical notion is inappropriate for at least two reasons. According to McComas (1996), theories are inferred explanations for observable phenomena, whereas laws are statements or descriptions of the relationships among observable phenomena. A hypothesis, on the other hand, can either serve as a description of the relationship between a set of observable phenomena or as an inferred explanation for those phenomena. As such, a hypothesis, or set of hypothesis, can develop into a theory or a law. For example, most of the participants in this study were required to design and conduct a practical investigation where the kinetic molecular theory serves to explain phenomena that relate to heat and its transfers. However, the kinetic molecular theory can still be used to explain phenomena that relate to changes in physical states of matter, others that relate to rates of chemical reactions, to mention just a few. Thus, hypotheses explain relatively limited sets of observations in a certain field of scientific research, while theories often explain relatively huge sets of seemingly unrelated observations in more than one field of investigation (Lederman & Abd-El Khalick, 2002). In this regard then, this study confirms existing knowledge.

Participants seemed to ascribe a variety of meanings to the term such as "prove" which is crucial in assessing their NOSI views. The use of the *LUSSI*, both an open-ended and closed instrument in conjunction with Probes and individual semi-structured interviews in this study was pivotal in accessing the various meanings of the term within which they were used, and relating them to the participant's NOSI views. Laws cannot be 'proven theories', because in addition to the fact that these are different kinds of ideas, neither scientific hypotheses, nor theories or laws can be 'proved'. This holds irrespective of the amount of empirical evidence gathered in the support of one of the ideas or the other (Lederman & Abd-El Khalick, 2002). According to Popper (1963), a law can never acquire an absolutely proven status because for it to be 'proven', a certain scientific law should account for every single instance of the phenomenon it purports to describe all the time.

The naive view that theories become laws harboured by most of the participants in this study is also discounted by the history of science which is replete with examples where scientific laws have preceded the theories that pertain to their explanation. To mention just a few, Boyle's law which relates to the pressure of a gas to its volume, was formulated by Robert Boyle in the 1670s yet the kinetic molecular theory, which explains Boyle's law, was not developed by Rudolph Clausius and James Clerk Maxwell until the 1850s (Toulmin & Goodfeld, 1982). According to Mix, Farber and King (1996), it was not until 1915 that Mendel's laws were interpreted in terms of the chromosome theory, the results of studies conducted by Thomas Morgan and his co-workers yet Gregor Mendel had formulated his laws of inheritance in a paper which he presented in 1866. Another example is that of the law of universal gravitation and the laws of motion, formulated by Sir Isaac Newton in The Mathematical principles of Natural Philosophy, published in 1687, which were and are still widely used. Until this present day, no viable theory of gravitation, inertia or motion has been put forth (Dobbs & Jacob, 1995). This serves to explain that not all laws that are widely applied in our modern times have accompanying theories for their existence and explanations. Very few learners' responses showed such informed views on the differences between laws and theories or their role in science.

Observations being theory-laden

A reasonable number of the participants (26%) in this study portrayed scientists as being objective. Participants' responses elicited that scientists are objective; hence they always make theory-free observations. This finding is consistent with the majority of the studies reported in the literature. This objectivity is believed to allow scientists to set aside their personal prejudices, perspectives and beliefs as they engage in their work (Lederman & Abd-El Khalick, 2002). The idea that observations are independent of what the scientists themselves know, believe or how they view the world has been reported in studies with High School learners (Abd-El-Khalick, 2006). The interview responses reveal that the majority of the learners harboured inadequate views of the NOSI on this aspect by saying scientists use rules of logic and inference to formulate hypotheses or theories to explain the

phenomenon under investigation based solely on their objective observations. An example is learner L3SCInt12.

> L3SCInt12: Scientists' observations are not based on theory but logic and facts [...]. In the laboratory when we do investigations we have rules to follow just like scientists because we have laws and theories to confirm. Therefore observations are not theory-laden.

Lederman (2007b) has called such perception of the nature of scientific knowledge a naive view. This finding is consistent with prior research findings (see, Abd-El-Khalick & Lederman, 2000b; Lederman, 2007a) but inconsistent with results from Liang et al., (2008)'s study with preservice teachers across three countries. In this regard then, this study confirms existing knowledge. The above notions of objectivity have been discounted by many philosophers and historians of science. Kuhn (1970) for instance suggested that all scientific observations and interpretations are in some respect subjective. To account for what happens in science, Kuhn advanced the notion of 'paradigm'. Lederman and Abd-El-Khalick (2002) propose that for a scientist, a paradigm acts as a lens through which his /her observations are filtered. In a sense, the interpretations and explanations that scientists formulate are consistent with that paradigm. To Kuhn and his followers, this shift is not simple and such shifts Kuhn dubbed revolutionary. As the results of this study show a reasonable proportion (20%) of the participants believed observations and inferences are the same. Studies of learners' views or understandings of the NOS and NOSI that have been reported over the past 15 years (Abd-El-Khalick & Lederman, 2000a; Khishfe & Abd-El-Khalick, 2002; Lederman, et al., 2006) have shown that in many parts of the world, the majority of secondary school harbour such naïve views. In this regard then, this study confirms existing knowledge. However, the observations and inferences are different. Observations are descriptive statements about natural phenomena that are directly accessible to human senses (or extensions of those senses) and about which observers can reach consensus with relative ease (Liang, et al., 2008). Inferences on the other hand are logical interpretations derived from a combination of observation and prior knowledge. Interpretations explain the causes of what one observes.

Results from this study also show that some of the learners 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**.**

Scientists use a variety of methods to conduct scientific investigations

Learners in this study displayed naïve views on the methodology of scientific investigation. As can be seen from the results of this study, very few learners harboured these informed views. About 21% of the participants naively held the idea that there is an existence of "The Scientific Method": A recipe-like step-by-step procedure that all scientists follow and that guarantees developing claims about nature. This finding consistent with results from previous studies (Abd-El-Khalick, 2006; Dogan & Abd-El-Khalick, 2008; Liang, et al., 2006) and a possible source of the misconception might be the way scientific research has been reported in journals and books (McComas & Olson, 1998). In this study an interesting finding was that the teacher himself/herself is another source of this misconception. This was elicited by learners during interviewing:

> L1SAInt15: My teacher told us that for scientists to get results that will be recognized internationally by other scientists, one has to use the scientific method. Ever since I started doing Physical Science we have been following this method where you; observe, formulate a problem, formulate a hypothesis, design experiments to collect data, take relevant measurements, interpret results, form conclusions and report the results. These are the steps we follow and there are no other methods which I am aware of.

This is one example which makes an erroneous conclusion that "this is how science works". Thus, let it be understood that different kinds of questions suggest different kinds of

scientific investigations. There is no single universal step-by-step scientific method that all scientists follow. According to Liang et al. (2008) different scientific domains employ different methods, core theories, and standards to advance scientific knowledge and understanding. Scientists being human beings like any other and their approaches to problem solving ate the same as of other beings. Science is not the only way through which knowledge about the universe can be obtained. Very few learners showed such understanding in all three instruments: the LUSSI and Probes questions and interviews. Other methods like; speculation, library investigation, dream, observation, analysis, experimentation, serendipitous discovery and mere luck can also play a part. What many refer to as "the scientific method" (testing a hypothesis through controlling and manipulating variables) is really a basic description of how experiments are done (Banchi & Bell, 2008). Abd-El-Khalick (2006) for example found that the majority of high school students hold naive views of the nature of scientific observations. The *National Science Education Standards* (National Research Council, 1996) and *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) explicitly debunked this notion. There is no such method (Bauer, 1994).

Scientists require accurate record keeping, peer review and replicability

Basing on the nature of their work, scientists are a community of practice. "Scientists review and ask questions about the result of others' work...Science advances through logical skepticism" (National Research Council, 2000, p. 20). The results of this study fail to fully support that view scientific inquiry is embedded within a community. About 40% of the participants failed to realize that scientists require accurate record keeping, peer review and replicability. Learners from this study failed to realize that recognising when observations do not fit expectations is a critical part of progress in science. Anomalies spark more questions and drive further investigation. Since scientists who ask similar questions and follow similar procedures may validly make different conclusions; evidence, consistency and recognition of alternatives become associated elements regarding scientific processes. From the results presented in this study, very few responses pointed to this reasoning. Learners in this study also failed to realize that practices and standards for

developing and accepting scientific knowledge are established within these scientific communities. Because most of the learners' responses could not explicitly fit into issues such as rejection, ignoring the anomaly, acceptance with theory change and reinterpretation of data, most of their conceptions were found to be informed.

Scientific knowledge being socially and culturally embedded

Only a very small fraction of the sampled learners appear to perceive scientific knowledge as being socially and culturally embedded. A reasonable number of participants (38%) in this study harbour the notion that science is a search for universal truth and fact and is not affected by culture and society. 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, et al., 2004) has observed this could result from lack of clarity on the nature of scientific knowledge. The truth of the matter is that science is a human endeavour, and as such, it is subject to subjectivity (Banchi & Bell, 2008). As human beings, scientists are influenced by subjectivity and are inherently biased. An array of activities which researchers suppose are worth pursuing for example, scientific questions, the observations that count as data and even conclusions drawn by scientists are influence by social and cultural contexts. The idea that scientific knowledge is not socially and culturally embedded has been reported in studies with high school learners in Europe and Asia (Liang, et al., 2008). It is also consistent with studies done elsewhere (Abd-El-Khalick, 2006; Miller, et al., 2010) that some high school learners' habour naïve views on the nature of scientific knowledge.

Scientific knowledge is partly the product of human creativity and imagination

Results indicate that about a quarter of the participants (26%) elicited naive NOSI views by stating that scientists do not use imagination and creativity because imagination and creativity are in conflict with objectivity. In this situation the implicit messages carried by the learners' responses is that scientists do solely rely on logic and rationality. The results are consistent with studies done elsewhere (Abd-El-Khalick, 2006; Liang, et al., 2009;

2006; 2008) that some high school learners' habour naïve views on the creation of nature of scientific knowledge. Abd-El-Khalick (2006) says science is contrary to common belief, is not lifeless, rational and orderly activity. Science is thus a blend of logic and imagination. Scientific concepts do not emerge automatically from data or from any amount of analysis alone. Very few learners were found to hold such acceptable NOSI views on this aspect as: scientific concepts do not emerge automatically from data or from any amount of analysis alone; Scientists do a lot of thinking and imagination; scientists often use creative methods and procedures throughout investigations, bound only by the limitation that they may be able to justify their approaches to the satisfaction of peers. History of science is replete with examples where creativity is clearly evident as in Darwin's synthesis of a theory of natural selection from a wide variety of data and ideas, including observations from his voyage on the H.M.S. Beagle, his understanding of the geologic principles of Lyell, and even Malthus' theory of populations. The message inherent in the learners' interview responses appears to be that imagination and creativity are partially used during scientific investigations by scientists. The learners must be reminded that figuring out how theories and hypotheses can be put to test of reality is as creative as designing skyscrapers, composing music or even writing poetry.

5.4 Conclusion

The NOSI views of a majority of participants seemed to be fragmented and lacking a coherent framework. These views were compartmentalized with few or no bridging connections. This is inconsistent with results from *unidimension framework* (UD) studies (see, e.g. Özdem, et al., 2010; Songer & Linn, 1991; Tsai, 1998a; Tsai, 1998b). Although consistent with studies from the multidimension framework (MD) studies (see, e.g. Afonso & Gilbert, 2010; Bezzi, 1999; Tsai & Liu, 2005a; Walker & Zeidler, 2007), the results here show that; not only were participants' views fragmented and inconsistent, these views were also often not associated or reconciled with accurate understandings of the nature of scientific inquiry and practice. Many participants did not provide any examples from the history or practice of science to support or defend their NOSI views. Whenever they provided the examples, the participants gave no further elaboration or justification on all six

NOSI aspects. In addition to the participants not being informed about some of the NOSI aspects, the findings also point to the fact that some participants were being misinformed by their teachers especially on the ‘methodology of scientific investigation’ aspect. This study has revealed several substantial inadequate (naive) patterns in participants NOSI views which seem persistent to high school learners.

CHAPTER SIX

Teachers' conceptions of the nature of scientific inquiry

6 Introduction

This chapter describes and discusses the results of teachers' conceptions of the nature of scientific inquiry (NOSI). Data pertaining to the study's second research question is qualitatively analyzed, presented and discussed. This question is: what are teachers' conceptions of the NOSI? The sources of data are the probes and teachers' responses to interview questions. The five teachers' conceptions on the six NOSI tenets chosen for investigation in this study are presented and discussed. The presentation of results is organized around sub-headings based on the six major NOSI issue(s) raised in the probes and interviews. Teachers' open-ended responses to issues raised in the probes were analyzed and interpreted using the hybrid model produced after fusing the Ibrahim, Buffler and Lubben's (2009) coding model with Liang et al.'s (2009) rubric for the SUSSI instrument as mentioned in Chapter 3. Interview data was analyzed using a combination or "hybridization" of the processes of analytic induction (Murcia & Schibecci, 1999), sequential analysis (Harwell, 2000), and interpretational analysis (Gall, et al., 1996) as also descibed in Chapter 3. The thinking on one tenet by an individual is not the same with the thinking on the other and this agrees with the multidimension framework. Because individuals think of NOSI in various ways, an individuals conceptions of the NOSI was considered after eliciting his or her views on all the six tenets.

The hybrid model uses the inadequate/adequate categorization. Each of the teacher's conceptions on these six NOSI tenets was considered, and an overall decision made about the adequate or inadequate nature of a teacher's conceptions. The teacher would get 'an adequate' decision if he/she elicited informed views in at least four NOSI aspects. This is in line with the multidimension framework which assumes individuals think of the NOSI in various ways when different tenets are considered. This consideration resulted in placement

of the teachers along a normative map ranging from poorly and/ or inadequate (naive), moderately adequate (transitional), to highly adequate and/or extremely adequate (informed). This categorization of the teachers' views was used to triangulate the categorization of teachers NOSI conceptions based on teachers' responses to interview questions with results obtained from the Probes questionnaire. Results are presented and discussed in the following order: probes closed responses followed by probes open-ended and interview responses.

6.1 Results from the probes and interviews

In this section, results are considered for teachers' understanding of the nature of scientific inquiry based on probes' responses and interview results. The major findings from the *closed-ended* Probes' responses are summarized in Table 6.1. Each probe's open-ended responses are then corroborated and cross-checked with data from interview probes. Interview data is reported in verbatim.

6.1.1 Probes: teachers' responses to closed questions

As Table 6.1 shows, the teachers can be said to hold highly adequate conceptions on some NOSI issues and extremely adequate views on others. Four of the five teachers held similar conceptions on five aspects of the NOSI namely; laws and theories serve different roles in science, observations are theory-laden, scientific knowledge is socially and culturally embedded, scientists use a variety of methods to conduct investigations and scientists use human creativity and imagination to create scientific knowledge. All the five teachers acknowledged that scientists require accurate record keeping, peer review and replicability. The responses to probes 1 and 2 could be indicative of consistency in the way in which the teachers looked at scientific observations. Four of the teachers believed observations are based on theories. One teacher can be said to have disagreed with the rest.

Table 6.1: Summary of Probes Closed-ended responses (n = 5).

Probe	Choice	Description	No. Of Teachers
1	A	Laws and theories serve different roles in science	4
	B	No, laws and theories serve same roles in science	1
	C	I have another view which I will explain	0
2	A	Observations are theory-laden	4
	B	No, observations are not theory-laden	1
	C	I have another view which I will explain	0
3	A	Scientists use one method to conduct investigations	1
	B	No, scientists use a variety of methods to conduct investigations	3
	C	I have another view which I will explain	1
4	A	Scientists require accurate record keeping, peer review and replicability	5
	B	No, scientists do not require accurate record keeping, peer review and replicability	0
	C	I have another view which I will explain	0
5	A	Scientific knowledge is socially and culturally embedded	4
	B	No, scientific knowledge is not socially and culturally embedded	1
	C	I have another view which I will explain	0
6	A	Scientists use human creativity and imagination to create scientific knowledge	4
	B	No, scientists do not use human creativity and imagination to produce scientific knowledge	0
	C	I have another view which I will explain	1

6.1.2 Open-ended probe responses and interview results

The purpose of the open-ended response section was for teachers to explain the basis of their answers and eventually their choices. As mentioned, the framework for analyzing probes' open-ended responses followed a *hybrid model* produced after fusing the Ibrahim, Buffler and Lubben's (2009) model for coding probes with that of Liang et al.'s (2009)

rubric for scoring SUSSI open-ended responses as described in Chapter 3. The transcribed probes open-ended data was read looking for patterns, relationships and themes. Entries were coded according to identified patterning while keeping a record of what entries went with which element of the patterns. Frequencies of responses showing similar types of reasoning were identified. Examples of such coding from the ATLAS.ti version 6.2 program are provided in Appendices G and H. It is important to point out that for each of the explored NOSI issues the categories emerged from the ideas raised by teachers rather than from the prior ideas of the researcher. The sub-categories and clusters of responses formed for each probe from teachers' responses are the same as those used for analysis of learners responses described in Chapter 5. To ensure rigour in the analysis, the researcher asked a post-doctoral research fellow at the same institution with the researcher to re-code a section of his data based on categories defined for teachers' open-ended responses. Discussions with the post-doctoral research fellow led to consensus and agreement on the categorization.

Considering the responses given by the five teachers to the probes instrument items and interview probes, a summary of teachers' views on the selected NOSI aspects was constructed. This is presented as Table 6.2. As shown in this table, two aspects; 'the ways scientists validate new knowledge' and 'the social and cultural embeddedness of scientific knowledge' are combined into one "issue" called "the nature of scientific knowledge". The aspects of 'the methods scientists use to conduct investigations' and 'the generation of scientific knowledge' are also combined into one "issue" called "nature of scientific process". Generation of scientific knowledge here refers to how scientific knowledge is given birth to. It includes the question of the source of the knowledge. In this case it is includes the methods scientists use to come up with the new knowledge.

Table 6.2: Summary of teachers' conceptions on six selected NOSI issues

Teacher	NOSI views			
	Role of laws and theories in science	Nature of scientific observations and interpretations	Nature of the scientific knowledge	Nature of scientific process
Ranelo	Theories explain laws	Observations (Subjective)/ Interpretations (Objectivist)/ Inductivist/Realist	Logical skepticism/ Realist/social and culture free	Research methodologist/ instrumentalist/ verificationist/ Conventionalist
Hedwick	Theories explain laws	Subjective/ Inductivist	Logical skepticism/not social and culture free	Research methodologist/ Conventionalist
Jairos	Theories explain laws	Subjective/ Inductivist	Logical skepticism/not social and culture free	Research methodologist/ Conventionalist
Johnny	Realist/ Instrumentalist	Objectivist/ Realist	Logical skepticism/not social and culture free	Objectivist/ Falsificationist/ Realist
Booi	Realist	Observations (Subjective)/ Interpretations (Objectivist)/ Inductivist/Realist	Logical skepticism/not social and culture free	Research methodologist/ Conventionalist

In the sections below, the results for each NOSI tenet are presented and discussed. The order followed in the presentation and discussion is as follows: laws and theories serve different roles in science; observations are theory-laden; scientists use a variety of methods to conduct scientific investigations; scientists require accurate record keeping, peer review and replicability; scientific knowledge is socially and culturally embedded; and scientific knowledge is partly the product of human creativity and imagination.

Laws and theories serve different roles in science

On this NOSI tenet, based on responses to the open-ended probe question, three of the teachers, Ranelo, Hedwick and Jairos gave responses which can be described as highly adequate. This was in agreement with their saying scientific laws and theories serve different roles in science during the interviews. This is how Ranelo and Jairos answered the open-ended part of the probe:

PRLTST1 (Ranelo): Theories explain laws, for example, the kinetic theory of matter is a theory that explains Boyle's law about the relationship between pressure and volume.

PRLTST3 (Jairos): A theory explains the laws of science.

When asked the question: "What is the difference between a scientific theory and a law?" and to describe their views on the roles of scientific theories and laws the teachers explained: On this NOSI tenet, based on responses to the open-ended probe question, three of the teachers, Ranelo, Hedwick and Jairos gave responses which can be described as highly adequate. This was in agreement with their saying scientific laws and theories serve different roles in science during the interviews. This is how Ranelo and Jairos answered the open-ended part of the probe:

Tr1Int. (Ranelo): [...] basically a theory explains the law and the difference between the two is that the law will stand because that is what it is, for example, the law of gravitation but to explain the law of gravitation, you will need a theory behind it.

Tr3Int. (Jairos): [...] theories explain laws, for example, the Big Bang Theory is a theory to explain the expanding universe whereas Hubble's law shows that galaxies are moving apart. The gas laws show how gases behave and kinetic molecular theory of matter explains these observations.

Tr2Int. (Hedwick): […] scientific theories exist in the natural world and are uncovered through scientific investigations. Scientific laws are generalizable statements that have become consolidated by repeated successful testing whereas a scientific theories are a body of knowledge that seek to increase explanation of a major phenomenon of nature.

Though the views above are classified as highly adequate, they cannot be said to be extremely adequate in the sense that not all laws have accompanying explanatory theories. For example, to this date, no viable theory of gravitation, inertia or motion has been put forth (Lederman & Abd-El Khalick, 2002). The other two teachers, Johnny and Booi gave responses, which can be described as poorly inadequate or naive. The following was their response:

PRLTST4 (Johnny): Laws and theories are the same because they both are used as scientific facts.

PRLTST5 (Booi): Laws are verified theories.

From this, he two teachers can be said to have harboured inadequate conceptions. For Booi, there is a relationship between laws and theories; however, one simply does not become the other no matter how much empirical evidence is amassed. Teacher Booi's claim that "Laws are verified theories" is a common NOSI misconception (see, McComas, 1998).). During interviewing, Booi confirmed what he had said in the probe saying:

Tr5Int: (Booi): [...] scientific laws are more certain than theories because they are proven "true"; theories therefore can change when enough evidence has been generated yet laws are "absolute" through repeated testing [...]

Teacher Booi's view on this issue can be described as a misconception. According to Popper (1988, p. 25), "no rule can ever guarantee that a generalization inferred from true observations however repeated is true." Johnny had almost identical ideas to those of Booi but this was only elicited during interviewing. This was his response:

Interviewer: To you, what is the difference between a scientific law and a scientific theory?

Tr4Int: (Johnny): There is not much difference but there is a link here and there because I believe a law will not just come from the air but will come from some experimentation which develops from a theory [...]

Johnny's answer appears to be tainted with the realist conception of the roles of laws and theories in science. He believes there exists an objective truth about nature that is independent of one's thinking. He also believes some form of instruments must be used during experimentation to discover such objective truth. The two teachers assigned an inappropriate simplistic hierarchical notion relationship between theories and laws. As McComas (1996) puts it, theories and laws are different kinds of knowledge and cannot become the other. No questions about validity can be raised from this probe since no ambiguous responses were revealed.

Observations are theory-laden

All the interviewed teachers with the exception of Johnny were of the highly adequate view that scientific observations are theory-laden and necessarily selective. Three of the teachers Hedwick, Jairos and Booi wrote:

PObST2 (Hedwick): Observations are based on theories an individual knows. So we observe differently basing on what we know.

PObST3 (Jairos): Observations are based on theories. However, we choose what to observe, for example, during a practical investigation, we do not observe all.

PObST5 (Booi): Observations confirm theories and thus are limited to what we want to know.

The conception of 'selective' implicitly elicited in the teachers' responses here appears to be associated with observations being necessarily subjective. The four teachers believed there is some bias in observations. During interviewing, the teachers were further probed to

check if they stood by their word of scientific observations being theory-laden. Hedwick explained:

Interviewer: In the probes instrument you wrote, "Observations are based on theories an individual knows..."Can you explain further?

Tr2Int (Hedwick): With high school science, observations are really theory-based because you are trying to prove that what has been done is true or false. But when you are inventing something you need to look for an observation which somebody has actually missed. So you are trying to falsify a previous theory through a new observation. So observations are theory-laden.

Interviewer: Can two scientists' observations of the same event be the same?

Tr2Int (Hedwick): Observations of the same event are different because we are selective; we choose what we want to observe using our five senses. Since we choose differently, observations therefore differ.

Interviewer: Let us look at interpretations, should interpretations of the same observations be the same or different?

Tr2Int (Hedwick): Interpretations are supposed to be universal if we are using the same theories but most of the time we are informed by different theories therefore interpretations differ.

Tr3Int (Jairos): The interpretations are depended on the knowledge somebody has. Does he know the theory behind the practical? So, the interpretations differ depending on the prior knowledge of individuals involved.

It is not surprising to see that four of the teachers harboured adequate views on the aspect of observations being theory laden. As mentioned in Chapter 3, all the five teachers were subjected to NOSI one way or the other since they had taken a course incorporating

scientific inquiry in their post graduate studies. On this aspect, Hedwick's views can be described as are extremely adequate. Jairos's views can be said to be inductivist. Ranelo and Booi can be described as having contradicting ideas regarding 'observations and inferences'. Although the two believed observations are theory-laden, they were of the belief that interpretations of the same observations are the same. This is what they said:

Interviewer: Should interpretations of the same observations be the same or different?

Tr1Int (Ranelo): Interpretations should be the same; if individuals interpret things differently then there will be something wrong because they have to come to the same conclusions.

Tr5Int (Booi): Interpretations are the same because scientists are objective hence they are all looking for the same fact.

These responses show contradicting extremely adequate and naive views of the NOSI. Despite having revealed the idea that; scientists' disciplinary and theoretical commitments, beliefs, training, experiences and expectations influence their work when observing; the two teachers harboured the view that there exists an objective truth about nature that is independent of one's thinking. Teacher Johnny had a totally different view and saw observations and interpretations as objective. In the probes, when asked the question "Can different scientists make different observations on the same thing? He wrote:

PObST4 (Johnny): You observe with your five senses (i.e., sense of smell, look, taste, hear and/or feel).What you actually observe is what happens therefore scientists make the same observations from the same thing.

Johnny stood by his word and repeated the same thing during interviewing when asked the same question. When asked about interpretations, he said:

Interviewer: Let us look at interpretations; should interpretations of the same observations be the same or different?

Tr4Int (Johnny): Interpretations should also be the same. Isn't it that they are observing the same thing; they must come to the same conclusion.

Johnny's responses can be described as objective and realist. He believes scientific truths are created when scientists eliminate personal biases, a priori commitments, and emotional involvement. Such a conception is naive in that these same background factors cannot be totally eliminated and they form a mind-set that affects what scientists observe (and do not observe) and how they make sense of, or interpret their observations.

Scientists use a variety of methods to conduct scientific investigations

Four of the five teachers (Hedwick, Jairos, Ranelo and Booi) believed that scientists use a variety of methods to conduct scientific investigations. When responding to the probe related to this aspect, they wrote:

PMSCIT1 (Ranelo): A variety of methods are used. The procedure of an experiment depends on a question to be addressed. However, the scientific method must be used to check the conclusions.

PMSCIT2 (Hedwick): There are so many methods of doing investigations. Some discoveries are made by accident (e.g. penicillin). I understand the structure of benzene was discovered based on a dream.

PMSCIT3 (Jairos): There are several ways of conducting scientific investigations, e.g. speculation, experimentation, library investigations etc.

PMSCIT5 (Booi): Scientists use a variety of methods during investigations to arrive at the same conclusions.

These responses show highly adequate conceptions. However, of interest is Ranelo's response who believed other methods can be used to conduct investigations but components of the scientific method should be used to confirm the results. During interviewing Hedwick, Jairos and Booi maintained their position by giving more or less the

same responses they had given in the probes questionnaire. Ranelo qualified his probe response too when asked the question "what can you say about the methods scientists use in their investigations or experiments?" He said:

> Tr1Int (Ranelo): Scientists employ a variety of methods but for confirmation of results, scientists have to use an orderly step-wise procedure. Then they can be sure of their results after having followed a logical common method.

This response shows that Ranelo is also a conformist/ verificationist and objectivist. He believed other methods can be used to conduct investigations but components of the scientific method should be used to confirm the results. Johnny did not think that way. His probe response was:

> PMSCIT4 (Johnny): Scientists use one method of logical steps known as the scientific method to perform various investigations.

This view is categorized here as poorly inadequate (naive). The view was cross-checked and validated during interviewing and Johnny qualified his conception by further saying:

> Tr4Int (Johnny): Scientists need to prove each other incorrect in scientific arguments. For them to be able to do this the same method of scientific investigation should be used and there is only one method known for accuracy called the scientific method. I use this method with my learners as from Grade 10[...]

This response fits into Rudolph's (2005) description of the scientific method when he lamented that the more nuanced step-based accounts of scientific processes, when formalized for school curricula, risk getting altered and distorted into rigid steps. The idea that science is a linear process often portrayed in the science classroom by the scientific method is also raised by 85% of the teachers in a study by Abd-El-Khalick (2006). Johnny can be classified as being falsificationist and objective. In reality, there is no single universal step-by-step scientific method that all scientists follow. Several methods are employed.

Scientists require accurate record keeping, peer review and replicability

All the five teachers held the belief that, the scientific community is seen as an essential part of the scientific process, because scientists work in teams and require accurate record keeping, peer review and replicability. This is the only NOSI probe in which all the teachers both harboured informed views and showed agreed in between their open-ended probe responses and the interviews. Characteristic probe responses given by Ranelo and Hedwick are:

PWSVNKT1 (Ranelo): Scientists do not just make unfounded claims. Gaining consensus involves building justification for claims and negotiating meaning. Scientists validate their new knowledge by making use of accurate record keeping, peer review and replicability.

PWSVNKT2 (Hedwick): Scientists do require accurate record keeping and replicability. They have to provide evidence and consistency in their claims. That is the way they can determine whether certain knowledge is valid.

These are highly adequate views. They resurfaced during interviewing. When asked "how do scientists validate new knowledge?"Jairos said:

Tr3Int (Jairos): There are several acceptable philosophical practices and principles which make scientific knowledge valid, for example, practices like replicability and peer review. Science is not a solitary pursuit but a group of scientists have to approve of certain evidence for it to be credible scientific data.

These responses show informed views of the NOSI. They are however reminiscent of the assertion by the National Research Council (2000) which says, "Scientists review and ask questions about the results of others' work... science advances through logical skepticism" (pp.20). This shows that scientific inquiry is embedded within a community. Knorr-Cetina (1999) believes there are multiple communities within the broader community of science. Acceptable scientific knowledge is established within these communities by providing

balances and checks through development of certain practices and standards. Eventually, communication and peer review impact what and how science progresses.

Scientific knowledge is socially and culturally embedded

Four of the five teachers held informed views that science is part of social and cultural traditions. Scientific ideas are affected by their social and cultural milieu. Hedwick, Jairos, Johnny and Booi were of the opinion that scientific knowledge is not social and culture free. When responding to the probes item regarding this aspect, the four wrote:

> PNSKT2 (Hedwick): Science as a phenomenon is not conducted in a vacuum. Society and culture do influence research; for example, war-mongering cultures and nations like the United States of America invest and conduct research into weapons and so forth.

> PNSKT3 (Jairos): Science is everywhere and as such scientific ideas are affected by their cultural, social and political settings.

> PNSKT4 (Johnny): Everything in science is part of life so social issues affect science directly; in reality science aims to resolve societal and cultural problems.

> PNSKT5(Booi): Scientists' knowledge comes from what they believe in, i.e. their social and cultural locale; social issues affect science in a way that scientists find a need in their social life and try to fix that problem using science.

These responses are corroborated by the teachers' responses to the interview question, "Where do you think scientific knowledge comes from?" Jairos explained:

Tr3Int (Jairos): Science as a human endeavour is influenced by the society and culture in which it is practised. On one hand, in school science for example, politicians will always influence the design and contents of the science syllabus. They will also influence education, particularly science education. Society holds a particular idea like a science phenomena, for example, lightning. You find that some societies believe that lightning can be created by an individual to fight against one another. Social problems on the other hand determine the research to be pursued to solve those nagging societal problems, for example, nowadays there is so much expanded research on HIV and AIDS, global warming and the use of genetic engineering.

Booi concurred:

Tr5Int (Booi): As much as scientific knowledge aims to be universal and general, science is affected by social and cultural beliefs because science reacts to societal and cultural problems. Cultural values determine what science is conducted and accepted. Issues like the HIV and AIDS pandemic, use of non-renewable energy sources and famines has resulted in so much money being channelled into the research of HIV and AIDS, global warming and genetic engineering by politicians.

While these responses demonstrate informed views on this NOSI aspect, Ranelo did not think that way. He thought science is a search for universal truth and fact which is not affected by culture and society. When completing the probe item with reference to the nature of scientific knowledge, Ranelo wrote:

PNSKT1 (Ranelo): Scientific knowledge is not influenced by society and culture, but on facts. For example, lightning has the same effect no matter how it is produced and which culture one belongs to.

Ranelo's view can be described as "realist". His view is based on the idea that there exists an objective truth about nature that is independent of one's social and cultural affiliation. However, being realist does not mean that one is not informed. Within the science

education community this view is categorized as undesirable. During interviewing, Ranelo said:

> Tr1Int (Ranelo): Science is based on facts. Most of the time science proves social and cultural beliefs held by individuals wrong. In the olden times people believed that the sun moved around the earth but Science proved that it was the earth that moved around the sun even though the church was against that fact. Another example is that of lightning which has the same effect no matter how individuals believe it is produced. To me scientific knowledge is not socially and culturally embedded.

Ranelo's argument is characteristic of a realist epistemological and ontological position. However, science as an endeavour and phenomenon is not conceived and operated in a cultural and environmental vacuity (Inokoba, Adebowale, & Perepreghabofa, 2010). It is a social phenomenon greatly influenced by the prevailing cultural traits and worldview of a people such as their social values, priorities, ideas, skills ethics, perception of social reality and belief systems. Cultural values and expectations determine what and how science is conducted, interpreted and accepted. The history of science is replete with other examples on the social and cultural influence on science including the examples of Darwin and Galileo.

Scientific knowledge is partly the product of human creativity and imagination

With regard to this NOSI aspect, the five teachers' views fall into two categories .There is Hedwick, Jairos, Johnny and Booi whose views were largely constructivist and totally believed that scientific knowledge and truth are not fixed by nature but are also creations of the mind. In responding to the corresponding probe item, they wrote:

> PCSKT2 (Hedwick): Dalton used imagination when interpreting data to say matter is made up of atoms so scientists do use imagination and creativity when creating new knowledge.

PCSKT3 (Jairos): One has to be highly creative and imaginative to further pursue general views so imagination and creativity are used a lot by scientists in creating new knowledge.

PCSKT4 (Johnny): Scientists are the most creative and imaginative beings on this planet because it is of these two; imagination and creativity that they use very well and new knowledge is born.

PCSKT5 (Booi): By coupling imagination and creativity with experience and experiments scientists create new knowledge.

These views are categorized here as highly adequate. Through further probing and prompting, interesting responses were given by the teachers to solidify their views and positions. This is what Jairos said:

Interviewer: Do you think scientists use imagination and creativity when they do their work?

Tr3Int (Jairos): For anybody to come up with something recognizable or of academic stamina, one has to imagine things. When one has an idea, he has to be creative or have the notion, for example, let us talk about Boyle's apparatus, for him to come up with a U-tube and all those things he had to imagine things. He had to be very creative. The idea of trying to measure pressure was there. That was the idea, how can I measure pressure? Right....aah! Then he used his imagination and creativity to come up with what we call today-the Boyle's apparatus.

Interviewer: In your teaching of investigations how do you make sure these two constructs are infused?

Tr3Int (Jairos): It is a point of saying to the learners we know most of the time the expected or desired result but if it does deviate from the norm, that is, if you do get observations that are out of expectation do not be afraid to record what you have established because that is how science functions. There are no set of rules that if you actually follow the following steps you will actually end up at a particular result. For sure science does not operate like that.

Ranelo did not think that way. He did not see scientific knowledge as a product of imagination and creativity because both human creativity and imagination are in conflict with scientists' objectivity. This view can be described as "realist". Ranelo appeared to base his thinking on the belief that there exists an objective truth about nature that is independent of one's thinking. When completing the probes instrument, Ranelo wrote:

PCSKT1 (Ranelo): Scientists do not use imagination and creativity when creating new knowledge because the two interfere with objectivity and I do not use creativity and imagination at all as an individual.

During interviewing, when asked, "From what you do during Chemistry practical investigations, what can you say about the use of imagination and creativity in science?''Ranelo said:

Tr1Int (Ranelo): Scientists don't use imagination or creativity because they won't be able to prove what they have come up with. I do the same, I do not use it and I encourage my learners not to use it because it interferes with objectivity. Science is all about proving facts.

This response habours naive ideas about the NOSI. Ranelo's meaning of the term objective here appears to be the same as that for the term real. To Ranelo, if an idea cannot be proven then it is not scientific and not real. Ranelo has to be reminded that scientists do not solely rely on logic and rationality. In fact, creativity and imagination could be the major source of inspiration and innovation in science. They permeate the ways scientists design their

investigations, choose the appropriate tools and models to gather data, and analyze and interpret results.

6.1.3 Application of the multidimension framework

The multidimension framework was employed as an interpretive lens to answer the research question: what are teachers' understandings of the NOSI? As mentioned earlier, by this tool teachers' views of the NOSI are not treated as existing on a unidimensional continuum, but rather as multiple dimensions that are more or less independent. Two of the teachers Ranelo and Johnny held poorly adequate views on at least four of the six NOSI issues. They have inadequate views on the 'ways scientists validate new knowledge' and 'the social and cultural embeddedness of scientific knowledge'. The two teachers subscribe to such notions as: scientific observations and interpretations are objective and theory free, science is culture free, there is one method of science, scientific knowledge is sourced from observation and experiment only, scientific theories develop into laws, scientists are humans with extra-ordinary intelligence and that science is entirely empirically based knowledge. According to the multidimension framework, such conceptions are considered to be static, objectivist/ empiricist-aligned views. To Allchin (2001) and Clough (2007), these notions are myths about the nature of science and NOSI. However, according to Deng et al.'s (2011) categorization; these are taken as naive views about the nature of scientific inquiry. Booi subscribes to notions that are neither explicitly empirically-aligned nor largely dynamic and constructivist-oriented. They were taken as fairly constructivist-oriented. He displayed moderately adequate views on all issues except 'role of laws and theories in science' and 'the nature of scientific interpretations'. He also believed that scientific knowledge was obtained through a variety of methods. Jairos and Hedwick were categorized as holding highly adequate views in all six NOSI aspects. They subscribe to such notions as: scientific observations are subjective and theory-laden, scientific knowledge is a product of human creativity, imagination and serendipity, there is no one method of science, science is not culture free, and that science is just another human enterprise.

6.2 Discussion

When all six NOSI aspects are considered for each teacher, this study has found that the sampled teachers held mixed NOSI views that ranged from poorly adequate through moderately adequate to extremely adequate. This finding is consistent with the majority of earlier studies. Studies of teachers' views, conceptions or understandings of the NOSI that have been reported over the past 20 years (Abd-El-Khalick, 2006; Dogan & Abd-El-Khalick, 2008; Erdoan, 2004; Kahyaolu, 2004; Liang, et al., 2006; 2008; Yakmaci, 1998) have shown that in many parts of the world, the majority of secondary school teachers show inadequate NOSI understandings. Abd-El-Khalick (2006) for example found that the majority of high school teachers hold inadequate views of the nature of scientific observations and inferences. Teachers in this study have also displayed such inadequate conceptions of the nature of scientific inquiry. They also subscribe to the notion that scientific observations and interpretations are objective and theory free, science is culture free, there is one method of science, scientific knowledge is sourced from observation and experiment only, scientific theories develop into laws, and that human values and beliefs do not influence the scientific endeavour. Allchin (2001) describes such understandings as NOSI misconceptions. The fact that teachers believe that scientific theories develop into laws has been reported in studies with high school teachers in Europe (Lederman, 2006a).

The results of this study are also consistent with studies done elsewhere (Abd-El-Khalick, 2006; Liang, et al., 2006; 2008) which found that some secondary school teachers' habour constructivist views of science. As the results of this study show two of the sampled teachers hold such acceptable NOSI conceptions as: scientific observations are subjective and theory-laden, scientific knowledge is a product of human creativity, imagination and serendipity, there is no one method of science, science is not culture free, and that science is just another humane enterprise. In this regard then, this study confirms existing knowledge.

This study's finding that some teachers harbour moderately adequate views of the NOSI is consistent with the finding of Liang et al. (2008) whose study although with pre-service teachers showed that teachers views on certain NOSI tenets can be categorized as fairly constructivist. In South Africa institutions of higher education incorporate inquiry components differently in their in-service and pre-service teacher education programmes. These programmes are assumed to be an important factor in determining the level of understanding of a teacher's conceptions of the NOSI. The fact that teachers' conceptions of the NOSI differ might point towards instruction on inquiry differing during in service teacher education programmes. This could be true given that the teachers did different courses at different institutions.

Two of the teachers, Johnny and Booi appeared to believe in simplistic hierarchical relationship between theories and laws. This is consistent with results from a study conducted by Abd-El-Khalick and BouJaoude (1997) with 20 inservice secondary science teachers in Lebanon, which found that science teachers gave a simplistic hierarchical relationship between theories and laws. Though the views of the other three teachers, Ranelo, Hedwick and Jairos are classified here as highly adequate, they are not extremely adequate in the sense that contrary to the beliefs of these teachers, not all laws have accompanying explanatory theories. Dobbs and Jacob (1995) point out that to this day, there is no viable theory of gravitation, inertia or motion that has been put forth. As they point out Newton wrestled with this challenge for the greater part of his life but was not successful in formulating such a theory.

The NOSI aspect of observation and inferences produced interesting results from the sampled teachers. Not only were teachers' views fragmented and inconsistent, but the views were often not reconciled or associated with adequate conceptions of scientific knowledge and practices. Ranelo and Booi for example held same contradicting views regarding 'observations versus inferences'. The two teachers agreed that observers must have prior conceptual frameworks with which to perceive and describe their observations. However, they believed inferences are objective which is contradictory. It is this fluidity

and lack of coherence of views which makes these findings interesting and significant. Interesting, in that questions are raised about the views the teachers put across to their learners when teaching practical investigations and significant in that very few studies have reported such findings. Several studies (see, e.g. Abd-El Khalick & BouJaoude, 1997; Aikenhead, et al., 1989) have reported that teachers habour misconceptions (e.g. on theory-laden nature of observations). However very few studies have found about teachers views existing with such contradictions. Johnny who is an outright realist and objectivist who believes observations are not theory laden but the act of inferring is objective. This is contradictory because the background and experience of an observer provide the basis for the inferences the observer makes. The observer can never be fully objective. Multiple perspectives contribute to valid multiple interpretations of observations.

The aspect *scientists use a variety of methods to conduct scientific investigations* confirmed one of the most widely held inadequate or naive ideas about science - the existence of a universal, step-wise ‘‘Scientific Method”. Interestingly, this study had one teacher who harboured this view. The other teacher-Ranelo believed scientists can use all other methods they can come up with but at the end, the steps of the “Scientific Method” should be used to verify and confirm results. The National Science Education Standards (National Research Council, 1996) and Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993) have for long debunked this notion. There is no such method (Bauer, 1994).). Such naive patterns are highly unlikely to be attributed to chance but it is most likely that these teachers have been *explicitly* exposed to these naive ideas about the scientific knowledge, for example, as shown by Ranelo’s argument. This is difficult to understand given that the teachers were exposed to aspects of scientific inquiry in their post graduate studies. This could raise questions about the content of the courses.

The five teachers investigated in this study did not have total agreement on all of the explored NOSI tenets. However, they all appeared to agree that science advances through logical skepticism. The teachers saw the generation and advancement of scientific knowledge as being achieved within a framework of ‘community of practice’. The message

inherent in the teachers' interview responses appears to be that through review and asking questions about the results of others' work, scientific inquiry is embedded within a community. Scientists strive to increase objectivity through peer review and other self-checking mechanisms. This NOSI view is also under researched regardless of the fact that it is one of those aspects set forth in general terms by Joseph Schwab five decades ago (Schwab, 1962). To the best of the researcher's knowledge, there are very few studies that have examined secondary science teachers' conceptions of this NOSI aspect. Indeed, only a handful of studies (see, e.g. Schwartz, et al., 2008) have examined the views of science teacher conceptions of NOSI aspect and found inconsistent results.

Although the majority of the teachers (four out of five) viewed scientific knowledge as being subjective to a certain degree, one of the teachers did not see it that way. These results would be inconsistent with results from a study conducted on Turkish teachers by Macarolu, Taþar and Cataloglu (1998) who found that their participants to believe that scientific knowledge as being subjective to a certain degree. As a human endeavour science is influenced by the society and culture in which it is practised. Topical issues like HIV and AIDS, global warming and genetic engineering are getting well researched because of their impact to different societies and cultures. Liang et al. (2008) sum it all by asserting that cultural values and expectations determine what and how science is conducted, interpreted and accepted.

Intricately linked to the subjectivity of science is the use of imagination and creativity in scientific investigations. One teacher argued that if imagination and creativity were to be used in science, then science loses it worth of being a body of facts. To this teacher, science is proven truth and scientists have to prove each other wrong if they do not agree with each other. Through use of imagination and creativity, this would not be possible. What a naive and realist argument put forth by this one teacher. As a word of caution, Bell, Maeng, Peters and Sterling (2010, p.11) hint "scientists do not solely rely on logic and rationality." Because science is a blend of logic and imagination, creativity becomes a major source of inspiration and innovation in science. Similar and consistent findings have been found in

other studies (see, e.g. Abd-El-Khalick, 2006; Bell, et al., 2003; Mackay, 1971). Scientists have to think and be creative like an artist would create an artifact out of wood or stone or a musician compose music or a poet write poetry when inventing hypothesis or theories to imagine how the world works.

6.3 Conclusion

The teachers' NOSI views were found to be fluid and lacked coherence. Although on some NOSI tenets, all participants expressed some views that were consistent with current acceptable conceptions they also displayed inadequate views of some NOSI aspects. Aspects on which misconceptions were shown are: the role of laws and theories in guiding scientific research, the theory-laden nature of observations, and the existence of a universal, step-wise ‘‘Scientific Method”.

CHAPTER SEVEN

Teachers' instructional practices

7 Introduction

This chapter presents and discusses the results on teachers' instructional practices when teaching investigations. The focus is on research question 3, "What is the nature of teachers' practices of inquiry when teaching practical investigations?" The focus was on determining the extent to which teachers practice inquiry oriented instruction when they teach investigations in Grade 11 Physical Science. For purposes of organization of data and presentation the following questions are asked:

1. How do Grade 11 teachers teach investigations?
2. To what extent do the teachers practice *open-ended* inquiry when teaching investigations?

The data is treated both quantitatively and qualitatively. This data was obtained from; lesson observations, interviews of teachers and learners and learner and teacher completion of the LPCI questionnaire. As already explained in Chapters 1, 2 and 3, this study sought to explore and understand the nature of the teaching practices of five, South Africa Grade 11 Physical Science teachers when teaching investigations. Within that effort, it also aimed to determine the extent to which the teachers' practices of inquiry were *open-ended* (Hegarty-Hazel, 1986). Open-endedness is measured here by the degree or latitude given to learners by the teacher to: ask or frame questions for investigation; design and conduct investigations; collect their own data; interpret results; and draw their own conclusions. As already explained in Chapter 2, the Hegarty-Hazel (1986) model was used to describe the nature of teachers' practices of inquiry when teaching practical investigations. The choice for this model by Hegarty-Hazel (1986) was based on the fact that it elaborates level 2 by dividing it into levels 2a and 2b, thus simplifying the discrimination between the levels of inquiry. For level 2a, the apparatus are given whereas the apparatus are not given for level

2b. This is crucial as it points to the explicitness of the type of inquiry being practiced in a given classroom.

Results are presented and discussed in the following order: lesson observation; researcher ratings; interview results; learners' responses to the LPCI; correlation results; and teacher responses to the TPCI.

7.1 Lesson observation results

The following are vignettes from the observation for the second lesson (the practical investigation) for Ranelo, Hedwick, Jairos, Johnny and Booi respectively:

Case 1: Ranelo

01.45. Ranelo introduced the lesson by giving a brief history of Robert Boyle and his invention. He then proceeded to inform his class that they will be investigating Boyle's law and their interest most lies in the relationship between pressure and volume. The theoretical relationship, $p \alpha 1/V$ is mentioned by one learner after Ranelo had asked for it.

4:24. During the preliminary discussion, the teacher delves into the issue of variables. The class discusses about the dependent, independent and controlled variables.

6.12. Ranelo picks up a Boyle apparatus and demonstrates to the class how the apparatus is used.

8.41. After demonstration, Ranelo instructs the learners to get into their usual groups (7 groups each averaging five learners) and proceed with the experiment. No worksheet is given to the learners. Learners get into groups and get along with the investigation. All groups are busy and every group member is observed having an active role as the investigation is conducted.

18.31 The teacher calls the groups to order and says "let us remind ourselves once again how a science report is written". The teacher asks for the format and all the learners in the class gave a chorus answer, they all shouted; 'investigative question, hypothesis, variables, apparatus, design/procedure results, interpretation of results, conclusion.'

19.56. Most groups except one had finished collecting data when teacher interjected and are now working on the investigative report as a group.

23.06. All groups are now working on the investigative report. One group has an interesting investigative question which reads, "Grade 11 learners want to know what the relationship between pressure and volume is if temperature remains constant".

25.27. In one group learners are arguing; three learners are saying we have dependent, independent and 'constant' variables whilst the other two are saying it's 'controlled' and not 'constant' variables. In all groups, learners are using their home language during discussion as they continue writing up the individual investigative report.

80:00. All groups inform the teacher that have not finished writing up the individual reports and the teacher says they should hand in the reports the next day first thing in the morning for marking.

Case 2: Hedwick

0.05. Hedwick commenced the lesson by saying learners were not suppose to sit down but move straight away to their work benches situated at the back of the classroom laboratory. Whilst learners are busy getting their full-scales and jotter books to write down notes, Hedwick gives a rundown of confirmatory colours from the qualitative analysis learners should expect to obtain as they do the experiment (s).

0.32. She says "From yesterday you know that if the reaction is releasing Bromine and Bromine is going into the non-polar layer we are going to expect a yellow colour. If we get a pinkish colour then iodine has gone into that layer. If the layer does not change colour, then nothing has happened, ok! Chlorine will make the colour stay the same because nothing is going to displace Chlorine." The teacher then informs the learners to move on to their working benches for the practical.

1.47. Learners move into groups of four which are randomly distributed and they form 8 groups. Hedwick then says, "Ladies we are going to start, we want to see whether Chlorine water will react with potassium iodide. We gonna put in potassium chloride as well but we do not expect any reaction between chlorine and chlorine. Ah…hhh, so potassium bromide and potassium iodide. So nominate one member from the group to come and collect the reagents […]."

3.32. Learners from each group then collected the reagents and followed instructions given on a worksheet. Examples of the steps are: pour 2ml of xylene into each of the three labelled test tubes; add 2ml of potassium chloride to the first tube, potassium bromide to the second tube and potassium iodide to the third tube; then add chlorine water, shake and observe; repeat the above steps using bromine water and iodine water.

12.47. Learners discuss their results as they continue with the investigation. Discussions are in English since the class is multiracial.

13.22. Teacher then stops group activities and discusses expected results after addition of chlorine water to the first batch of three labelled test tubes and their contents. Hedwick also interjected after addition of bromine water to next batch of labelled test tubes (18.27) and after addition of potassium iodide to the last batch of labelled test tubes (24.39) to demonstrate and discuss the expected colour changes. This concluded the first part of the investigation.

30.12. The second part of the investigation involved the reduction of copper oxide with hydrogen gas. The apparatus were assembled for the learners by the lab technician prior to the lesson and again learners had a worksheet with instructions which they methodologically and precisely followed.

56:39. All groups were done with the second part of the investigation and they went back to their desks. Teacher informs class that conclusions and lab reports were to be done individually and the class was supposed to hand in the report after 10days.

Case 3: Jairos

0.15. Jairos introduced the lesson by saying learners were to get into their groups and only group plans were suppose to be taken out of their bags. Teacher then proceeded checking on each of the groups' plans.

1:39. Other groups took the opportunity to refine their investigative plans before the teacher got to them to check on the feasibility of their plans. Those groups which the teacher had approved of their plans were asked to commence with the practical.

3.30. Of interest is one group which brought additional material, a big shopping plastic bag and a hair dryer to act as a balloon. When the teacher asked the group "how are you going to measure the volume?", learners in the group failed to come up with a convincing answer and they said, "Don't worry sir, you shall see".

10.02. Learners continued working in their groups discussing at each stage code-switching between Zulu (a local language) and English and the other way round.

65:23. After doing the practical most groups except two had about 15mins to spare which they used to discuss how they were going to present their results.

80:00. Teacher informs class that conclusions and lab reports were to be done individually and the class was supposed to hand in the report after two days since it was a Friday.

Case 4: Johnny

0.27. Johnny commenced the lesson by distributing worksheets with detailed instructions for the investigation. The worksheet has five well-laid steps namely: design a plan (step 1) where the hypothesis was given; use the apparatus (step 2); obtain the results (step 3); interpret results (step 4); and conclusions (step 5).

1.31. Johnny gave a step-by step-description of what the learners were suppose to do and this took 15minutes.

16.36. Thereafter, the teacher put the learners in groups of fours and distributed the Boyle's apparatus. Learners were told not to complete the worksheets yet but use rough paper for recording results. Learners began working on the investigation.

45:39. After all groups had finished doing the investigation, the teacher guided the learners in completing the worksheet step-by step and emphasis was that learners had to complete the sections in pencil. The 2- period lesson ended when learners were moving to the last step of making a conclusion. Learners were told to submit reports for marking the next day.

Case 5: Booi

0.09. Booi introduced the lesson by informing his learners that they were going to do an investigation on Boyle's law. After writing the theoretical relationship of Boyle's law, $p \alpha 1/V$ on the chalkboard, Booi discussed the relationship between pressure and volume with his class.

1:07. Booi then went on to talk about the conditions needed for the relationship to hold emphasizing on constant temperature.

3:26. The teacher then drew a table of 2-rows and 2-columns and instructed his learners to take out notebooks to record their results in groups. Booi informed the learners to copy the table he had drawn on the chalkboard. He then asked his learners which was the independent variable between pressure and volume. The class remained quiet and he told the class that volume was the independent variable because it is the variable which was being manipulated. Booi then wrote "volume/cm^3" in the first column and "pressure/kPa" on the second column.

4.12. Booi then went on to write 10, 20, 30, 40 and 50 under the volume column and immediately instructed his learners to move into usual groups. There were 7groups averaging 5learners. He then distributed a worksheet with an introduction, problem statement and what was expected of the learners to do. Furthermore, he moved from group to group demonstrating how the learners were supposed to make readings using the Boyle's apparatus.

7.26. In groups learners start conducting the steps on the worksheet and as demonstrated by the teacher and make recordings.

10.22. As the learners are working in their groups they are using their home language during discussion. The teacher moves from group to group and says "I expect you to take between 10-15minutes to collect your results.

13.05. In one group, there was a decreasing trend in pressure readings and after the third reading one learner in the local language told others they had to repeat and discard this reading because the reading did not conform to the pattern hence there was an anomaly. Other group members agreed and the group repeated the procedure.

23.47. After all groups have finished collecting data, the teacher says "let us quickly look at the points you need to put in the report." He then wrote; investigative question, hypothesis, variables, apparatus, design procedure, observation, data, analysis and interpretation, conclusion, evaluation. The teacher quickly ran through what he expected under each sub-heading of the report. The worksheet also listed these.

78.23. Booi then asked the learners to complete the group report. He says, "Go and complete the report as a group after which all group members should copy from that report."

80:00. Booi then told his learners to submit individual report after two days.

Lesson observation data and the vignettes above; appear to show that, the five teachers practiced inquiry in three different and contrasting ways. Jairos and Ranelo allowed their learners to frame research questions which are a potential resource for teaching and learning of investigations. The two teachers also allowed their learners to engage in critical assessment and justification of appropriate procedures. Both teachers (Jairos and Ranelo) also tried by all means to transfer decision-making to learners and ensure their learners developed confidence and investigative skills.

In contrast, Johnny and Hedwick did not allow their learners to frame research questions but gave research questions to their learners. The two (Johnny and Hedwick) gave the learners step-by-step procedures (which they designed) to follow based on the scientific method.

Booi who falls somewhere in-between the two groups of teachers described so far allowed his learners to frame research questions but did not allow his learners to engage in critical assessment and justification of appropriate procedures. There was evidence of scaffolding (Vygotsky, 1978 as cited in Hackling & Fairbrother, 1996) to support learners as they worked through the decision making steps of the investigation in Jairos' and Ranelo's classes. Analysis of observation results shows that observation results appear to be supported by the inquiry ratings done on each of the teachers by the researcher using the modified version of the Campbell et al. (2010) instrument as shown on Table 7.1.

7.2 Results from researcher ratings

The LPCI was adapted as an analytic tool for analysis of teachers' practices of inquiry as explained in Chapter 3. Some sections of the analytic tool, for example, the *conducting investigations* and *collecting data* categories fit well into the Hegarty-Hazel's (1986) model

of inquiry by posing statements that differentiate the level of inquiry being practiced in different classrooms. Before the researcher could go ahead and use the analytic tool, the adapted tool was given to three researchers (one post-doctoral research fellow, a doctoral student and a master's student) all working in the field of scientific inquiry to rate. As explained in Chapter 3, this data was based on three video lessons of three teachers (one video lesson per teacher). Inter-reliability coefficients that resulted from this process are presented below.

7.2.1 Inter-rater reliability

Inter-rater reliability coefficients were calculated for each of the five sections using STATA (Integrated Statistical Software package for data analysis, management and graphics). The following Kappa (κ) coefficients were obtained: asking questions/framing research questions (0.947); designing investigations (0.939); conducting investigations (0.971); collecting data (0.956); and drawing conclusions (0.971) (see, Appendix J). This was taken to signify consensus among the three researchers. Having sought consensus, the researcher went ahead to analyse the rest of the lessons using the analytic tool. Table 7.1 gives results for the researchers' ratings.

Table 7.1: Ratings for each teacher on each of the five inquiry dimensions

Analytic tool for Analysis of Teachers' Practices of Inquiry

Ratings and written descriptions from an observation of practical investigation lessons for the five teachers

LPCI Ratings: Rating ⟶ Never occurred to Almost always

0 ⟶ 1 ⟶ 2 ⟶ 3 ⟶ 4 ⟶ 5

Item #	Criteria	Ratings					Comments
		Ranelo	**Hedwick**	**Jairos**	**Johnny**	**Booi**	
A	Asking questions/framing research questions: in the science classroom						
A1	Teacher formulate questions which can be answered by investigations	4	3	5	3	4	Johnny gave a hypothesis and never talked of research questions. The other four did.
A2	Teacher research questions are used to determine the direction and focus of the lab	4	3	5	2	4	Johnny never talked of a research question, practice not evident in the other four classes
A3	Teacher believes learners framing their own research questions is important	4	3	5	3	5	Evident in how Jairos structured his lessons. Booi and Ranelo took time to do this.
A4	Time is devoted to refining teacher questions so that they can be answered by investigations	4	2	5	2	4	Only evident in Ranelo, Booi and Jairos' classes.
B	Designing investigations: in the science classroom						
B1	Teacher gives step-by-step instructions before learners conduct investigations	4	1	5	4	3	Evident in Hedwick and Johnny's investigation class. Not seen in Jairos' class.
B2	Teacher designs procedures for learner investigations	4	2	4	1	3	Evident in Johnny's investigation class
B3	Teacher allows learners to engage in the critical assessment of the procedures that are employed when they conduct investigations	4	2	5	2	1	Evident in Jairos and partly in Ranelo's investigation classes. For the other three classes, learners were not given chance
B4	Teacher allows learners to justify the appropriateness of the procedures that are employed when they conduct investigations	4	2	4	2	1	Evident in Jairos and partly in Ranelo's investigation classes. For the other three classes, learners were not given chance
C	Conducting investigations: in the science classroom						
C1	Teacher conducts procedures of an investigation	4	4	4	2	4	Evident in Hedwick, Booi and Johnny's investigation classes
C2	The investigation is conducted by the teacher in front of the class	4	4	5	4	4	Jairos never did this. Booi and Ranelo demonstrated initially.

C3	Teacher allows learners to actively participate in investigations as they are conducted	4	4	5	4	4	Jairos' learners were actively participating.whe compared to the other four classes
C4	Teacher believes each learner has a role as investigations are conducted	4	4	5	4	4	All the five teachers ensured each learner had a role to play.
D	Collecting data: in the science Classroom						
D1	Teacher determines which data to collect	4	4	5	2	2	The template Johnny gave and the table drawn on the chalk-board by Booi suggest this.
D2	Teacher informs learners to take detailed notes during each investigation along with other data they collect	4	4	4	2	2	Jairos, Ranelo and Hedwick's learners were seen taking notes as they conducted the investigation.
D3	Teacher ensures learners understand why the data they are collecting is important	4	4	4	3	3	Teacher-learner questions promoted this act as evident in Jairos, Ranelo and Hedwick's classes.
D4	Teacher allows learners to decide when data should be collected in an investigation	4	3	5	2	2	Booi and Johnny were prescriptive yet Jairos and Ranelo gave lee-way for this to happen in their classes.
E	Drawing conclusions: in the science classroom						
E1	Teacher allows learners to develop their own conclusions for investigations	4	4	5	4	4	All five teacher s allowed for this to occur.
E2	Teacher gives allowance for learners to consider a variety of ways of interpreting evidence when making conclusions	4	5	5	2	4	Johnny's learners were limited and the other four teachers allowed this to occur.
E3	Teacher gives room for learners to connect conclusions to scientific knowledge	4	5	4	4	5	All five teachers allowed for this to occur.
E4	Teacher allows learners to justify their conclusions	4	5	5	4	4	All five teachers emphasized for this in learners' reports.

The researcher ratings presented in Table 7.1 are also supported by interview data as the researcher shall later show. The scores from Table 7.1 were transformed into a bar graph, Figure 7.1 for purposes of clarity and elaboration. As shown on Figure 7.1, Jairos and Ranelo have total scores of 94 and 80 respectively, implying that the nature of instruction in their laboratories generally is perceived as more open-ended inquiry compared to Johnny's 56. Hedwick and Booi have total scores of 68 and 67 respectively. It can be said that Johnny's practice is more on the closed inquiry side compared to Jairos whereas Hedwick and Booi's practice is more of medium inquiry.

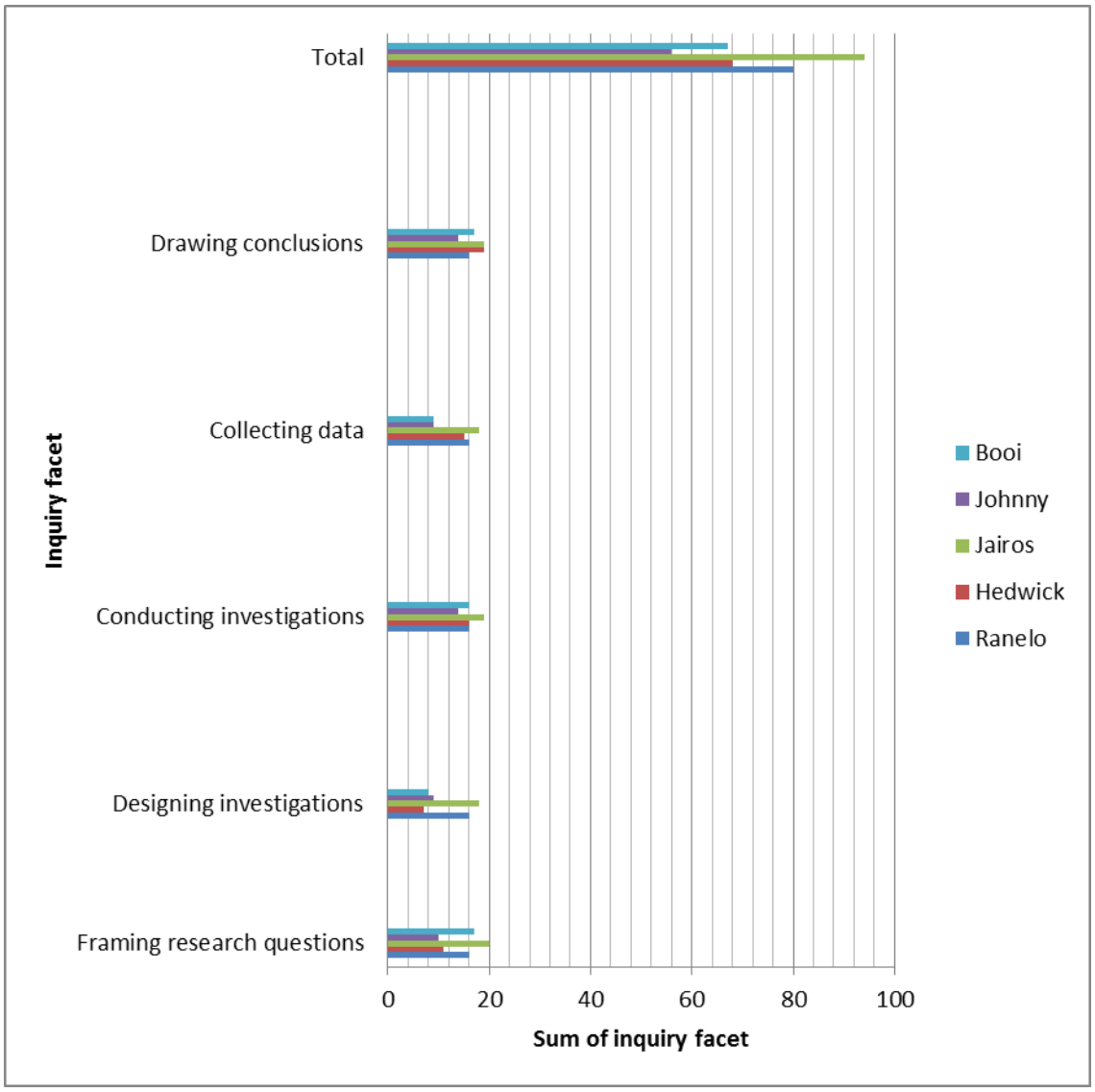

Figure7.1: A graph showing the researcher inquiry ratings for the five teachers' practices

On at least four of the five facets, Johnny's scores are lowest followed by Hedwick, Booi and Ranelo's. Johnny's and Booi's lower level of inquiry teaching is further indicated by the fact that they provided a template for data collection and Johnny went further and gave the learners the variables on graph axis. Both Johnny and Booi even told and determined for their learners the data to collect. It looks like Johnny and Booi were merely interested in the confirmation and verification of Boyle's law. Their interpretation of the NCS appears to

be that by 'doing inquiry' learners will learn about the nature of scientific inquiry (Vhurumuku, 2011).

Johnny and Booi provided tables to record the observations, measurements, or data. This type of *cookbook* activity (Jenkins, 1998) provides step-by-step procedures and follows a linear path to a solution. However, interestingly, for some time, Johnny's learners were captured on camera discussing issues which were not even related to the practical they were doing, for example, discussing politics, or plans they were making for the coming weekend and many other things not related to the practical. Johnny struggled to maintain discipline in the class because he did not want learners to move to the next step unless he told them to do so. After completing a step, most of the time the learners were unoccupied.

Hedwick and Booi had moderate levels of learner direction in three aspects of scientific inquiry: allowing learners to ask questions; to draw conclusions and conduct investigations (Carnes, 1997; Deters, 2004; Kang & Wallace, 2005). Jairos and Ranelo on the other hand had higher levels of learner direction in all five aspects of scientific inquiry: allowing learners to ask questions; to determine which data to collect and to design a procedure (Carnes, 1997; Deters, 2004; Kang & Wallace, 2005).

7.3 Teacher and learner interviews

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 each teacher's pedagogical philosophical position on teaching science (Miller, 2008) in order to get insights into their instructional practices. Each of the five teacher's philosophy on teaching science is described. This is followed by five assertions covering each of the five facets of inquiry characterizing the five teachers' practices. In describing the five teachers' practices using assertions, the researcher also reflects on some aspects from lesson observations and analysis of curriculum materials.

Teaching philosophy. Asked about their philosophy of teaching science, the five teachers had this to say:

Ranelo: It is to make sure that the teaching is as effective as possible. Learners should be able to leave the class not same when they entered the classroom. This will help them see the value of and improved interest in science. They will be able to realize their goals, their ambitions hence they chose the subject – Science.

Hedwick: Eh...hh, I use learners' previous knowledge based on the theory of constructivism which says learning is based on what we already know.

Jairos: [...] I centre my teaching on the constructivism approach which is learner-centred and the teacher is a facilitator. Learners come into groups and deliberate on the problem at hand and then the teacher will actually give direction especially where the kids are totally wrong through probing to give them direction but not giving them everything per se [...]

Johnny: I actually follow what is known as the scientific method. I introduce my learners to the scientific method in Grade 10, which is where you have your aim, investigative question hypothesis, procedure and so forth. They are actually familiar with the scientific method of presenting a write up or of conducting an experiment.

Booi: My philosophy is that learners have to get the basic knowledge about science. I would not mind starting them in the very, very simple Chemistry then move on to the complex.

Assertion 1: Learner questions play an important role in meaningful learning and scientific inquiry and are a potential resource for both teaching and learning.

Jairos began teaching the practical investigation section with the understanding that it is important for learners to frame their own questions. He believed formulation of a good question is a creative act, and at the heart of what doing science is all about. He said:

> The questions should basically be framed by learners according to NCS, and it works on progression for the FET phase, i.e. Grade 10, 11 and 12. In grade 10 learners must actually be given everything through discussion, the hypothesis, the investigative question and the learners will just be filling in on the spaces provided on the template report. In Grade 11, we must discuss with the learners and come to an agreement about the investigative question through probing. Then Grade 12 that is when we leave the learners to be on their own and must have their own investigative questions and design. For my learners especially grade 11 and 12, I do not differentiate them; I treat them on the same footing ... ...I centre my teaching on the constructivism approach which is learner-centred and the teacher is a facilitator and learners come into groups and deliberate on the problem at hand and then the teacher will actually give direction especially where the kids are totally wrong through probing to give them direction but not giving them everything per se...

Classroom observations also confirmed this practice. Jairos was seen giving a lot of time to his learners to refine their questions during the pre-lab session and delving more on discussing acceptable investigative questions during the post-lab session. This practice was confirmed by the learner interviews. One of the learners reported, that learners in Jairos's class were involved in formulating research questions. She said:

> L2SCInt11: [...] in groups, we look at the problem posed to us and in groups we share ideas and come up with an investigative question which we will investigate.

As with Jairos, Ranelo also believed that good science investigations begin with a clear and well formulated question which will enable the investigator to plan a procedure to be followed (Ramnarain, 2011). In the interview, Ranelo explained that he supports learners in formulating the investigation question by asking them to "spell out exactly what these variables are" and when necessary he would "intervene and ask them to rethink it". This is what he said:

> Researcher: When doing investigations in your science classroom, who frames the questions?

Ranelo: I pose a problem and tell the learners to come up with their own questions and they should consider all the variables for the investigation.

Researcher: How do they do this?

Ranelo: Usually it is as a group I tell them to throw ideas around so that they come up with an investigative question which they are all proud of and which includes all variables under investigation.

During the pre-lab lesson, not much of this practice was evident. Ranelo looked at ideal and real gases and spent the better part of the lesson solving problems involving Boyle's law. However, during the practical investigation, Ranelo's learners spent a great deal of time refining investigative questions they were throwing about. Ranelo also took some time during the post-lab lesson reading out good investigative questions from learner's individual marked reports and those questions which he said were not good giving reasons in the process. This practice was confirmed by the all four learners who eventually were interviewed from Ranelo's class. One learner said:

L2SAInt16: Usually we devise the questions in groups and there are times we do it in pairs depending on the investigation. After the lesson (s), we go home and refine the question (s) individually because we hand in individual reports.

In contrast, Johnny formulated investigative questions for his learners suggesting that learners' framing their own questions was not important. As the analysis of curriculum materials showed, Johnny had a worksheet which stated that the learners were investigating Boyle's law. Under step 1, the worksheet stated the following hypothesis: "At constant temperature a fixed mass of gas has a volume which is inversely proportional to the pressure exerted on it". Learners were simply required to follow the step by step procedures and arrive at confirmation of Boyle's law. He expressed his beliefs about learner formulation of investigation questions saying:

Johnny: [...] you know, usually these kids don't have a lot of experience because of many reasons. Major one being that aah, the syllabus is just too long. You can't do practicals as many times as you want otherwise you might fail to analyze them. You see what I mean! So I give them the questions but otherwise with experience they can actually formulate their own investigative questions.

This was confirmed by all the five learners interviewed from Johnny's class who said their teacher always framed questions for them. Their role was to answer the given problem. When asked the question, "When doing investigations in your science classroom, who normally formulates the questions?"Two learners said:

L4SDInt9: We get them from the teacher.

L2SDInt7: Usually Sir gives us the question on a work sheet.

The focus on the need to clarify variables in the investigation question also arose during one of Booi's class observations. The excerpt below is from an exchange which took place in Booi's class where a practical on Boyle's law was observed, and provides an example of how the teacher, by employing probing questions, enabled the learners to think through more clearly the relationship between the variables in the investigative question.

Booi: Okay, can one group tell us the investigative question they have come up with? We can have so many questions as long as they mean the same thing. [Haibo - not his real name] What does your group have?

Haibo: [Not her real name] Does an increase in pressure result in an increase in volume?

Booi: No! Can anyone from the group help?

Zinja: [Not her real name] Does an increase in pressure result in a decrease in volume if the temperature remains constant?

Booi: Yes, you see now. The controlled variable is also included in the question. This is now perfect. Don't forget your question should be in a question form and should have a question mark. Another question [...]

By discussing the investigative question, Booi encouraged the learners to articulate and clarify their thinking. The probing questioning forced learners to reflect on what they had said and rethink the investigative question they had formulated. This was crucial since an investigative question which is poorly formulated will lead to invalid results. All five learners interviewed from Booi's class agreed to the practice that; time is devoted to refining learner questions so that they can be answered by investigations. During interviewing, when asked the question, "When doing investigations in your science classroom, who normally formulates the questions?" One learner said:

L3SEInt21: We discuss possible investigative questions as a group and the teacher helps us to refine them.

As with Ranelo and Johnny, Booi looked at ideal and real gases in the pre-lab lesson and spent the better part of the lesson solving problems involving Boyle's law. Booi did not spend much time on research question during the post-lab lesson. However, Hedwick was mum on the investigative question during the pre-lab session, the practical investigation and the post-lab lesson. Only the worksheet she had prepared for the learners stated that the learners were supposed to come up with an investigative question for the practical. She did not put much emphasis on the investigative question. All the five learners interviewed from her class agreed that they formulate the investigative question individually as they prepare the practical report. One learner said:

L3SBInt3: I do formulate my own questions, at times I get questions from textbooks and from the internet as well.

Evidence above suggests the sampled five teachers' practices of inquiry regarding this scientific inquiry dimension are substantially different.

Assertion 2: By gradually shifting to a more learner-directed approach, teachers can develop comfort, transferring decision making to learners and teachers can see the inquiry process modelled and build learners' skills.

A pattern evident in the data was an increased engagement of Jairos' learners in critical assessment of the procedures that they employed when conducting investigations. Jairos emphasized learner justification of the appropriateness of the procedures. His comment on his handling of the design stage of practical investigations was that:

> Jairos: [...] my learners must come with their own design and they bring their design to me for verification and correction and the correction is on probing basis. I will be asking them why did they choose this method, what is the advantage of doing that and what if this problem comes up, to enlighten them and for them not to be blinkered.

Indeed, Jairos used questioning as a support strategy in guiding learners when planning how to conduct the investigation. This was revealed by all five learners interviewed from Jairos' class confirming this teaching approach. This often resulted in learners rethinking and reconsidering their original plan. When asked, "How do you conduct/handle the designing stage of the investigation?" One learner from Jairos's class said:

> L1SCInt10: We do it in groups. We select one of us to lead and we come up with the design which we take to the teacher for marking. The teacher usually asks us questions so that we can justify the procedures and when he is convinced we know what we want to do and it will give reliable results, then he gives us the go ahead to conduct our design.

Ranelo is the other teacher who fairly allowed learners to engage in the critical assessment of the procedures that are employed when conducting investigations. Though he initially performed a demonstration to show how the Boyle's law apparatus works, learners were seen discussing the procedures they were going to employ. When asked, "how do you handle the design stage of practical investigations", he said:

> Ranelo: In Grade 10, we give them the whole scenario as to what is supposed to be done. There is an investigative question, hypothesis, all three types of variables, the method, the observations, the results, the interpretation and the conclusion. That is all given to them in a template worksheet and theirs is to complete it. In Grade 11, I tell them you are now used to investigations so I will only come in when it is necessary, surely I believe you know what is suppose to be done. Then in Grade 12, I just give the scenario and they have to pick up the necessary equipment.

Classroom observations confirmed this practice but it was only seen in the practical investigation. During the pre-lab lesson, as with Booi and Johnny, Ranelo looked at ideal and real gases and spent the better part of the lesson solving problems involving Boyle's law. During the post-lab lesson Ranelo seldom talked about the design stage. However, all four learners interviewed from Ranelo's class agreed with their teacher thereby confirming the practice. When asked, "How is the designing stage of the investigation handled in your science classroom?" One learner said:

> L1SAInt15: The teacher leaves it to us and in groups or pairs depending on the activity we come up with plausible designs with the help of the teacher when need arises.

This shows Ranelo gradually shifted to a more learner-directed approach by transferring decision-making to learners. He made an effort to build learners' skills. As was seen in the lesson observations, for Johnny and Hedwick, the learners were not engaged in critical assessment of procedures. Instead they were given step-by-step instructions in a worksheet. Johnny and Hedwick gave a rationale for this practice. They said:

Johnny: I roughly do the same thing you saw me doing today. Like um...mh, I obviously put learners into groups, then of course after setting up the work stations, I send them to their workstations and I give them instructions as to what are the expectations there. Then of course I follow up to see if there is any progress or lack of it [...]

Hedwick: I run my investigations like you saw me doing today. I have a worksheet for the learners which have some specific and explicit steps to follow. After briefing them on the expectations of the investigation, they move to the work benches and get along with it.

Both teachers acknowledged to the fact that they design procedures for learner investigations. The worksheets and learners' reports also supported this. During the interviews all five learners from each teacher's class confirmed this practice by Johnny and Hedwick. When asked, "How is the designing stage of the investigation handled in your science classroom?" Two of the learners, one from each class said:

L3SDInt8: We get the design from the teacher; the truth is we just get worksheets with instructions to follow.

L1SBInt1: Usually we get the procedures from the teacher. She gives us a worksheet with well laid steps like add $2cm^3$ of this and that in this test tube or this and that test tube...therefore the teacher designs the investigation for us.

In the pre-lab lesson, Johnny focused on ideal and real gases and spent the better part of the lesson solving problems involving Boyle's law. Hedwick on the hand was busy solving and balancing oxidation and reduction (redox) practice problems with her learners. Both teachers did not set aside time to further talk or discuss about the design stage. In the post-lab lessons both teachers focused on the marks awarded to each learner and the impact of the investigation on the learners' school-based assessment mark. The educational value of this approach was questionable, as when the findings disagreed with the theory provided by the textbook, learners often fudged their data in order to get the expected results

(Viechnicki & Kuipers, 2006, p. 115). Booi's practice as seen in the lesson observation was not very different from that of Johnny and Hedwick. The slight difference in Booi's worksheet is that it did not have very explicit steps as of the other two but he eventually demonstrated the procedures moving from group to group showing the learners what to do. When asked how he handles the design stage of the investigation, Booi said:

> Booi: Basically I design a worksheet with procedures but I do not make steps too explicit, then I help the learners along each procedure. They usually do investigations in groups so I help the groups throughout the investigation.

All learners interviewed from Booi's class concurred with and confirmed to this practice. When asked how the design stage of investigations is handled in the science classroom, one learner (L2SEInt20) said "the teacher will show us how to do it and we write the methods in our own words."

As with Johnny and Hedwick, Booi did not shift to a more learner-centred approach. On this scientific inquiry dimension, the three teachers' laboratories were more traditional since learners were not responsible and autonomous (Hegarty-Hazel, 1986; Vhurumuku, 2011).

Assertion 3: Providing learners with an opportunity to do hands-on science does not necessarily mean they are doing inquiry because not all hands-on activities are inquiry oriented

Jairos allowed learners to actively participate in investigations and to go through procedures on their own. This appeared to be in line with his beliefs about what it means to *do* scientific inquiry for the NCS, Learning Outcome 1. He said:

> Jairos: [...] the South African science curriculum assumes that by "doing inquiry" learners will come to understand the nature of scientific inquiry. This assumption is achieved not by following the rigid steps of the scientific method for example, though I acknowledge the relevance and importance of the steps. In my teaching

> of investigations, I emphasize on the principle being investigated as well as the reasoning behind designing and performing a scientific investigation. To achieve this, I subject my learners to an increased level of learner direction; allowing learners to ask questions, to determine which data to collect or designing a procedure.

On the contrary, Johnny gave his learners what questions to answer, what materials to use, and how to go about solving the problem. He appeared to be a strong believer in following the scientific method. He noted:

> Johnny: [...] this meant instilling process skills linked with the scientific method and hence I introduce these learners to the scientific method at Grade 10... I actually follow what is known as the scientific method, which is where you have your aim, investigative question, hypothesis, procedure and so forth. They are actually familiar with the scientific method of presenting a write up or of conducting an experiment.

Ranelo's emphasis was on learners gaining understanding rather than just right answers. He allowed learners to go through procedures he partially produced and the learners had to do the rest for themselves. He allowed learners to actively participate in the investigation as it was conducted. He believes he is an effective teacher, who can inspire and influence learners through expert and referent power but not coercive power. He also believed he empowered learners and get them do things which they did not think they were capable. He commented:

> Ranelo: [...] as you saw during the investigation, I wanted my learners to improve on their skills and sights. After I got them started, I neither let them flounder nor prematurely offered assistance. I also probed and asked incessant 'why questions' to groups which called for my assistance to unmask and discard tidy explanations [...]

Booi and Hedwick's practices regarding the conducting investigations dimension were similar. Both teachers provided structured investigations. They gave learners the apparatus

to use and how to go about solving the problem. In other words, they provided step by step procedures and followed a linear path to a solution without much thought and purpose (Anderson, 2007; Kim & Tan, 2010). Booi is a strong convict of the teaching through concrete-to representational-to abstract sequence of instruction yet Hedwick believes in utilizing learners' prior knowledge during instruction. During interviewing, they said:

Booi: I start from the simple then move on to abstract. Like you saw in the investigation, I made it simple for them since steps were provided and they knew what they were suppose to do then they had to make meaning with their findings, you see [...]

Hedwick: You saw that in the pre-lab lesson, I spent much time solving the redox problems. I wanted them to identify the oxidant, oxidizing agent, reductant, reducing agent as well as balance the equations. In the practical, I wanted them to identify these [oxidant, oxidizing agent, reductant, reducing agent] using the knowledge they know.

The two teachers (Booi and Hedwick) appear to harbour a myth about inquiry based learning which states 'doing hands-on science is the same as doing inquiry (Llewellyn, 2002). Interestingly, while the five teachers' practices appeared to be in contrast; they all allowed learners to work cooperatively in groups, fostering a sense of community. For all the five classes, each learner had a group role, for example, keeping time, taking temperature or pressure readings, or operating the Boyle's apparatus. The learners themselves from all the five classes appeared to hold notions that working in groups allowed them to share ideas. Learners from Jairos, Hedwick and Johnny's classes commented:

L1SCInt10: [...] group work is the best for suggestions and improvement. We get in groups to share ideas. You put your own ideas and you listen to what the other colleagues say and it makes you have a different view of the concept. We understand the concepts more when working in groups.

L2SBInt2: Working in groups helps because not everybody understands the concepts of some practicals so the peers will help you answer certain questions you have that the teacher cannot answer at that stage.

L2SDInt7: We conduct investigations as groups and it is so helpful doing it in groups because we are able to share ideas like they say two heads is better than one. Doing it as individuals, we would not understand the same way we do as we are in groups.

However, with verificationism as the objective, it is noteworthy asking what it is that Johnny, Hedwick and to a greater extent Booi expected their learners to share? The investigation was just a matter of following the steps provided by the worksheet. There is an issue here of whether the learners actually practiced inquiry or merely followed a cookbook recipe?

Assertion 4: Providing learners with the opportunity to decide when and how data should be collected is important and allows learners to filter the vast resources to find the relevant information that they need for accuracy.

Jairos, Ranelo and Hedwick acknowledged that learners should understand why the data they collected was important. Consequently, the three teachers gave learners significant latitude to decide on when and what data should be collected and how to record the data. The three teachers also encouraged learners to take detailed notes during each investigation. When asked the question, "How is data collected in your classroom during investigations", the three said:

Jairos: I tell them [learners] to organize themselves but also ensuring all learners take part in the investigation so that not even one of them in a group is idle. I tell my learners, you have the investigative question, which is your focus, go ahead and collect the relevant data to answer it and I emphasize on repeated measurements so that their results are reliable.

Ranelo: I tell my learners that because they have had time to conceptualize the problem, the honours is on them to decide on when, what and how data is collected and ponder on why they are actually collecting the data.

Hedwick: As you saw the other day, the worksheet has questions which they have to answer so basically I leave it to them [learners] to decide which data to collect or not. My learners are free to collect data which they think will address the questions.

Classroom observations were consistent with what the teachers said and all learners interviewed from the three teachers' classes concurred with their teachers' practices regarding data collection. For example, from each of these three teachers' classes, one learner said:

L2SCInt11: As a group during the planning stage we ask ourselves questions, for example, what are the variables we are interested in? We then discuss how we are going to record results, that is, the format of the table (s). We put it on paper then take it to the teacher for validation. Once the teacher says it is fine then we proceed.

L2SAInt16: We always do investigations as a group, so within our group we discuss and agree on what variables should be included in the table of results. We assign one scriber to write down the results as others are busy reading instruments or measuring physical quantities [...]

L4SBInt4: We take a lot of notes during the investigation so that we are able to write informative investigation reports afterwards. So in my group everyone records the results. Before we go home we compare what we have so that we are on the same page because we were working in a group and to make sure that we do not get confused.

In contrast, Booi provided learners with tables of results and Johnny went further and provided learners with tables, graphs with labelled axis indicating the variables to be included in the laboratory report and emphasized which data the learners were suppose to

collect. This appeared to be in tandem with both teachers conviction (expressed in the interview) that learners should:

> Johnny: [...] actually read off instruments and write the data on tables. That is usually how data is collected. They tabulate their information and enter the data which they collect from the experiment [...]

> Booi: [...] collect the data which enables them to get the right answers. I make sure I give them an outline of the table of results that they have to complete and when I am sure they have the correct data then they finish off on their own.

Classroom observations and learners marked reports confirmed this practice. All interviewed learners concurred to this practice. When asked, "How do you collect data during investigations?" one learner from Johnny's class responded:

> L1SDInt 6: We are usually given a worksheet with table of results and graph templates with labelled axes so we just follow the instructions, complete the tables and draw the graphs.

When asked the same question, a learner from Booi's class said:

> L5SEInt23: Recording depends on what the practical is all about. Let us say it was about chemical decomposition. We just write yes or no to the questions given on a worksheet. If it was a Physical Science investigation on pressure and volume, eeh...hh that is, Boyle's law, the teacher gives a table where we would record readings of pressure and volume.

Johnny and Booi filtered the vast resources they had provided for the learners. Learners did not get the opportunity to find the relevant information that they needed for accuracy but instead the teachers did it for them.

Assertion 5: Learners need to learn how to process sources of information to make thoughtful decisions about their measurements and link them to their hypotheses.

All five teachers allowed their learners to develop their own conclusions for investigations. Jairos, Ranelo, Johnny and Booi also gave room for learners to connect conclusions to the kinetic theory of matter whilst Hedwick gave her learners room to connect conclusions to essential ideas about redox reactions. The five teachers approach to drawing conclusions was summed up by Jairos who said:

> Jairos: Group work is basically on the design process up to the conducting of the practical, thereafter learners work individually for the analysis, and interpretation. If there are graphs and conclusions, they must work on their own. That is the inter-arrangement which we give, but basically we find out that group work continues to the end of the practical and this you see it in their laboratory reports [...]

This was confirmed by the learner interviews. During interviews, learners from all five classes indicated that the teachers allowed them to develop their own conclusions for the investigations. When asked, "How do you come up with conclusions?" One learner from Hedwick's class and another from Ranelo's class said:

> L3SAInt 17: After getting results, the teacher says 'now that you have results from the investigation, using the results and your opinions what patterns and trends do you obtain from them'. Then we make up our individual conclusions.

> L3SBInt3: The conclusions, ah...h, we do them individually. The teacher says we must look at our results and derive the conclusions for ourselves.

> Researcher: Where and when do you come up with the conclusions?
> L3SBInt3: We usually try to do it in class but we are allowed to finish at home after the investigation.

For the ‘drawing conclusions’ dimensions, all teachers as explained above did well on all aspects except that Johnny limited his learners by not allowing them a variety of ways of interpreting evidence when making conclusions. The template for the investigative report designed by Johnny gave no room for additions or subtractions. When asked during interviewing if this had no negative impact on learners seeking patterns and trends, and generalizations in terms of simple principles, he said:

> Johnny: Providing a guide like this will help since learners will not have room to waffle but the conclusions reached are reasonable answers to the focus question of the investigation.

The other issue which raises eyebrows is the practice by Booi where learners write a group report and then each member of the group copies from that. A learner from Booi’s class commented:

> L4SEInt22: We write one report in a group and then every group member copies from that and we get the same mark.

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

The succinct remarks on the teachers’ philosophy of teaching science and the five assertions are that; Jairos believed school Chemistry has the potential for productive inquiry (produce scientific knowledge like professional Chemistry). He therefore practices what he believes. For Johnny, the development of learners’ understanding of the scientific inquiry was only important if it aided the school-based assessment (SBA) goal. He is a conformist to the scientific method. Hedwick and Booi’s views are that in addition to developing learners’ understanding of theory, investigations also serve the purpose of developing learners’ abilities to manipulate apparatus and chemicals. Ranelo is of the opinion that school laboratory work is not very different from the Chemistry practiced by the frontier scientists. He believes learners should not leave the laboratory the same way they entered, they should gain knowledge. 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. However, the number of observations one can make is limited because the curriculum prescribes that only two-lab-based investigations can be done in Physical Science, i.e., one in Physics and one in Chemistry per year. This has implications to those doing research in the area because more lab-based lessons are necessary for conclusive claims to be made about teaching behaviour and styles.

Table 7.2: Summary of observed teachers' instructional practices

Teacher	Framing/Asking questions	Planning and Designing investigation	Conducting and Collecting data/level of interaction	Conclusions and communication	Level of inquiry
Ranelo	-believes learners framing questions is a creative act	-more learner-directed approach	-doing hands-on is not inquiry/ high learner-learner interaction	-learners to filter vast resources	-Medium inquiry
Hedwick	-believes learners framing questions is not important	- more teacher-directed approach	-doing hands-on is inquiry/ high learner- learner interaction	-learners should process sources of data	-Low inquiry
Jairos	-believes learners framing research questions is heart of what doing science is all about	-inquiry process modelled	-not all hands-on activities are inquiry oriented/high learner - learner interaction	-learners should know when, why and how data is collected	-Very high inquiry
Johnny	-believes learners framing questions is not important	- more teacher directed approach	-scientific method/high learner - learner interaction	-learners should link measurements to hypothesis and get the right answer	-Very low inquiry
Booi	-believes learners questions are a potential resource for teaching and learning	- more teacher directed approach	Doing hands-on is inquiry/high learner - learner interaction	- learners should link measurements to hypothesis and investigative question	-Low inquiry

Table 7.2 shows that a high level of learner-learner interaction does not mean the teacher's instruction is of high inquiry. All five classes had high learner-learner interactions during the practical investigation. Learner-learner interaction can still be high but all what the learners will be discussing is verificationism (as witnessed in Hedwick and Johnny's classes). Learners can exchange ideas without necessarily engaging in the kind of discourse described as scientific argumentation (Reis & Roth, 2007; Roth, 2008; Roth & Lucas, 1997); for example, arguing about the merits and demerits of procedures, conclusions, hypotheses and so forth. This was found mainly to be the case in Johnny's and Hedwick's laboratory classes. For example, learners in Johnny's class were caught on camera happily discussing plans for the upcoming weekend which had nothing to do with the investigation. Learners in Hedwick's class were seen comparing qualitative colours in test tubes from the displacement of halides. They however would not engage in discourse about why their colours were different (due to the amount of reagent added or possible contamination). Such a discursive engagement is essential for learners (Rogoff, 1990; Wertsch, 1998) if laboratory inquiry is to be a cognitive apprenticeship into the practice of science (Rogoff, 1990, 2003; Sandoval & Reiser, 2004). This happens in the science class when the more knowledgeable and skilled teacher guides learners through the stages of the investigation when doing the investigations and learners are working with their peers.

As the summary table shows (Table 7.2), teachers' instructional practices range from very low inquiry (Johnny), through low inquiry (Hedwick and Booi) to medium inquiry (Ranelo) and finally very high inquiry (Jairos). The nomothetic categorization done here differs slightly from that done through teachers' perceptions of their instructions (TPCI). 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 multicase study in which 14 preservice secondary science teachers developed their own empirical investigations - from formulating questions to defending results in front of peers by Windschitl (2004) when developing folk "theories" of inquiry. The lesson observations suggest that the levels of inquiry in the teachers' laboratories are slightly lower than what some of the teachers' responses to the TPCI suggest. These disconnections are described by Tsai (2003a) and

Schwartz, Lederman and Crawford (2004) as epistemological gaps. For the categorization done in the present study, the placement is slightly different for three teachers (Johnny, Booi and Hedwick). It is different for Johnny who moves from low inquiry to very low inquiry. Booi and Hedwick shift from medium inquiry to low inquiry. It should be emphasized that the decision to place a teacher into a category (see, Table 7.8) is based on the criteria of how the teacher faired on all five aspects of scientific inquiry, frequent use of verificationism level of learner-learner interaction, teacher's philosophy regarding the teaching of science and use of practical work for understanding the nature of scientific inquiry.

7.4 Responses to the LPCI: Learners' perceptions of their teachers' instruction

In this section quantitative results from analysis of the LPCI questionnaire are described. The focus of the analysis was to determine learner perceptions of the extent to which they [learners] experienced inquiry during science lessons. It also provides an opportunity to compare the five teachers' practices.

Table 7.3: Descriptive statistics showing the variability for learners' scores on the LPCI

School	Sex	Mean	Std. Deviation	N
1 (A)	Male	56.25	5.817	12
	Female	60.96	6.677	23
	Total	59.34	6.704	35
2 (B)	Female	59.00	7.002	32
	Total	59.00	7.002	32
3 (C)	Male	55.05	5.052	20
	Female	56.46	4.644	24
	Total	55.82	4.829	44
4 (D)	Male	56.73	6.923	15
	Female	59.63	4.838	8
	Total	57.74	6.319	23
5 (E)	Male	54.67	5.630	12
	Female	56.29	6.182	21
	Total	55.70	5.950	33
Total	Male	55.64	5.750	59
	Female	58.37	6.327	108
	Total	57.41	6.250	167

As shown on Table 7.3, of the 167 respondents who completed the questionnaire, 59 were males (35.3 per cent) and 108 (64.7 per cent) were females. Concerning the variable gender, males had a mean score of 55.64 and standard deviation of 5.75 whereas females had a mean score of 58.37 and standard deviation of 6.33. Overall, the mean score for both males and females was 57.41 and standard deviation of 6.25. The LPCI scores show that there was little variation in the perceived levels of inquiry by learners on moving from one school to the next as shown on Table 7.3. In South Africa, only 30 percent of learners who complete school at the National Senior Certificate level sit for the Physical Science examination (South African Institute of Race Relations, 2012). Given this unpopularity, Physical Science class sizes vary from school to school.

Although the sample sizes per school were small and differed (ranging 23-44 learners), the average scores from school to school generally show little variation. A clearer picture of this variation is shown on Figure 7.2.

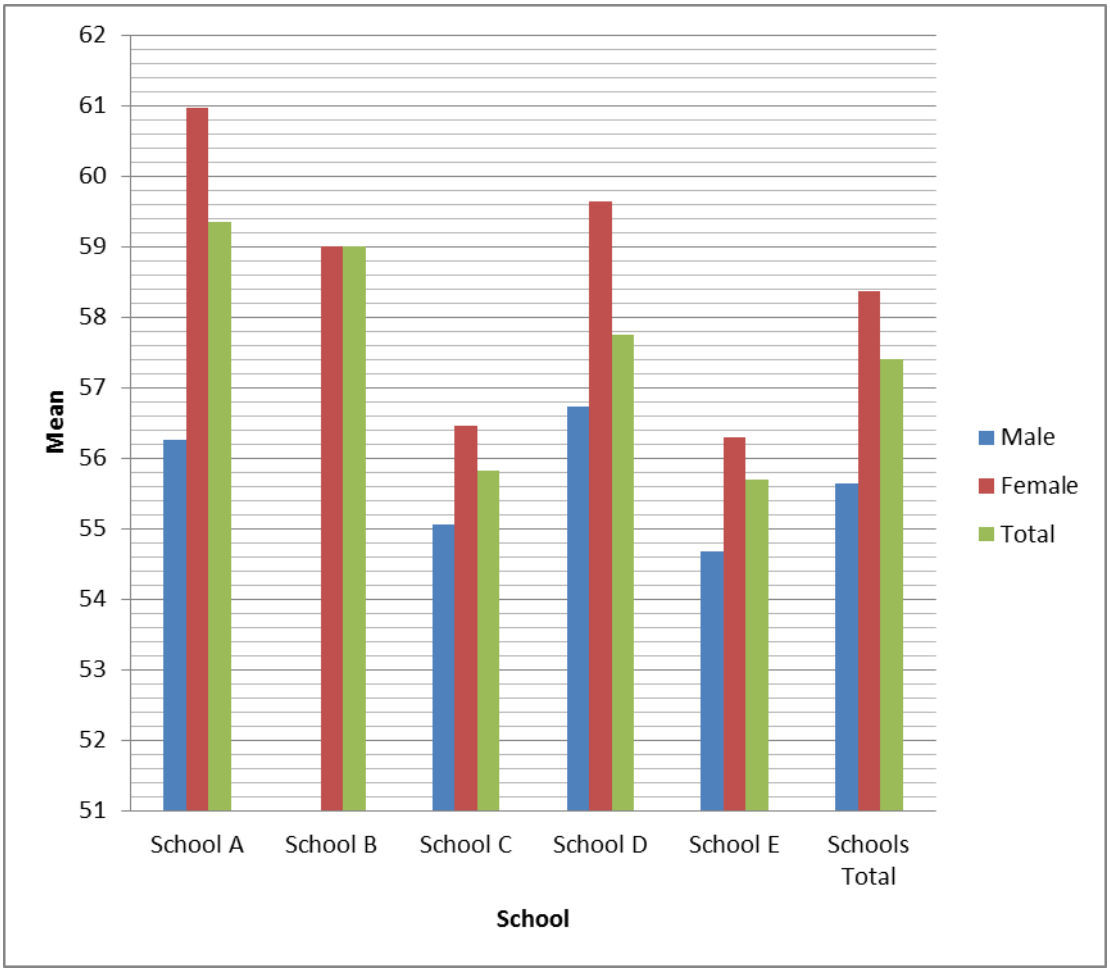

Figure 7.2: Variation of learners' gender scores on their perceptions of inquiry (LPCI) across the schools

Learners in schools A and D appear to have perceived higher levels of instructional practices of inquiry than learners from schools E, C and B. For males the differences across the schools is not quite so pronounced. Male learners from school D perceived higher levels of instructional practices of inquiry only slightly more than the rest of male participants across the schools. Overall, females appear to have perceived higher levels of instructional

practices of inquiry than males. Although the difference for schools C and E is small, there appears to be a discrepancy for schools A and D. Whether or not these differences were of statistical significance was determined only by performing a two-way between groups analysis of variance as explained below.

A two-way between-groups analysis of variance was conducted to explore the impact of sex and school on learners' perceptions of the extent to which they experience inquiry during science lessons, as measured by the LPCI instrument. Subjects were divided into five groups according to their schools (School A: 35 learners; School B: 32 learners; School C: 44 learners; School D: 23 learners; School E: 33 learners). There was a statistically significant main effect for sex [F (1, 158) = 5.68, p = .02]; however the effect size was small (partial eta squared = .035). Post-hoc comparisons using the Tukey HSD test indicated that the mean score for school A (M = 59.34, SD = 6.70), school B (M =59.00, 7.00), school C (M = 55.82, SD = 4.83), school D (M = 57.74, 6.32) and school E (M = 55.70, SD = 5.95) did not differ significantly from either of the groups. The main effect for school [F (4, 158) = 1.79, p = .13] and the interaction effect [F (3, 158 = .53, p = .66] did not reach statistical significance.

Though the results showed that there was a significant main effect for sex (sex: sig = .02), this meant that males and females differed in terms of their LPCI instrument scores. The value of partial eta squared which determines effect size is however small (.035) according to Cohen's (1988) criterion. This means that the actual difference in the mean values is very small. Mean scores for males is 55.64 and that of females is 58.37. The difference between the groups is therefore of little practical significance. What looks like an enormous difference on the plot only involves a few points difference. Reading across to the scale, the discrepancy for schools 1 and 4 is small (56.25 as compared with 60.95 for school A) and (56.73 as compared with 59.63 for school D). Thus when interpreting SPSS output plots, the reader is reminded to consider the scale used to plot the dependent variable.

To determine if there was a significant difference in the mean LPCI scores for males and females, an independent-samples t-test was conducted to corroborate and cross-check results from the two-way between-groups analysis of variance reported above. It was found that there was significant difference in scores for males and females in only two of the five inquiry facets/dimensions.

These are: [asking/ framing research question, for males (M = 10.58, SD =2.32) and females {M = 11.53, SD = 1.82; t (97.39) = -2.73, p = **.**01}; drawing conclusions, males (M = 12.07, SD =1.90) and females {M = 12.82, SD = 2.00; t (165) = -2.38, p = **.**02]. However, it was found that there was no significant difference in scores for males and females in the other three inquiry facets/dimensions. These are: [designing investigations, for males (M = 9.59, SD =1.65) and females {M = 9.79, SD = 1.90; t (165) = -.66, p = **.**28}s; conducting investigations, males (M = 11.25, SD =1.90) and females {M = 11.67, SD = 2.08; t (165) = -1.26, p = **.**30}; collecting data, males (M = 12.15, SD =2.25) and females {M = 12.56, SD = 1.98; t (165) = -1.22, p = **.**12}]. The magnitude of the differences in the means was very small (eta squared = **.**04 for asking/ framing research question; **.**003 for designing investigations; **.**01 for conducting investigations; **.**01 for collecting data; and **.**03 for drawing conclusions) for all five inquiry dimensions. *Note:* Effect size Eta squared: > **.**14 large; > **.**06 medium; < **.**01 very small (Cohen, 1988).

Since SPSS for Windows Version 16.0 does not provide eta squared values for t-tests, the values were calculated manually using information provided in the output (see Appendix I) using the formula for eta squared as follows:

$$\text{Eta squared} = \frac{t^2}{t^2 + (N1 + N2 - 2)}$$

where N1 = number of males; and N2 = number of females

7.5 Presenting the results from correlation

The relationship between school effect (as measured by LPCI scores from all learners in the 5 schools) and sex (as measured by male and female LPCI scores) was also investigated using Pearson product-moment correlation coefficient statistic. Preliminary analyses were performed to ensure no violations of the assumptions of normality, linearity and homoscedasticity. There was a weak, negative correlation between the two variables [r = -.18, n =167, p < .05] with sex being associated less with the type of school learners attended. For the other dimensions of instructional practices of inquiry, Table 7.4 shows where there was correlation and where there was not.

Table 7.4: Table of Correlations

Pearson Product-Moment Correlations Between Measures of Instructional Practices of Inquiry							
Measures	1	2	3	4	5	6	7
(1) Sex							
(2) School	-.176*						
(3) Sum 1	.222**	-.367**					
(4) Sum 2	.051	-.013	.182*				
(5) Sum 3	.098	-.124	.061	.188*			
(6) Sum 4	.095	-.030	.144	.113	.347**		
(7) Sum 5	.182*	-.081	.276**	.296**	.416**	.382**	

N = 167. Sum 1=Asking/framing research questions; Sum 2=Designing investigations; Sum 3= Conducting investigations; Sum 4=Collecting data; Sum 5= Drawing conclusions
*p<.05 [.*Correlation is significant at the 0.05 level (2-tailed)].
** p<.01[. ** Correlation is significant at the 0.01 level (2-tailed)].

Finally, using data from the LPCI instrument, standard multiple regression was performed mostly for determining the LPCI category (as an independent variable) that makes the strongest contribution to explaining the dependent variable (total score in this case), when the variance explained by all other variables in the model is controlled for. The standardized coefficient beta value gives this information. The higher the beta value of an independent variable the more the contribution. As shown on Table 7.5, sum 4 (collecting data) made the most contribution, followed by sum 1 (asking/ framing questions), then sum

3 (conducting investigations) and finally sum 2 (designing investigations) based on the sampled learners' responses.

Table 7.5: Table of Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	1.496E-14	.000		.000	1.000
	Sum 1	1.000	.000	.329	5.145E8	.000
	Sum 2	1.000	.000	.290	4.509E8	.000
	Sum 3	1.000	.000	.324	4.693E8	.000
	Sum 4	1.000	.000	.333	4.934E8	.000
	Sum 5	1.000	.000	.319	4.342E8	.000

a. Dependent Variable: Total Score

The Sig. values for all the five independent variables are less than .05 meaning all variables made a significant unique contribution to the prediction of the dependent variable (total score). Assumptions like outliers; normality, linearity, homoscedasticity and independence of residuals were checked and found not to have been violated before running the multiple regression procedure. As shown on Figure 7.3, the residuals are roughly rectangularly distributed, with most of the scores concentrated in the centre (along the 0 point). There is no systematic pattern to the residuals, for example curvilinear, or higher on one side than the other.

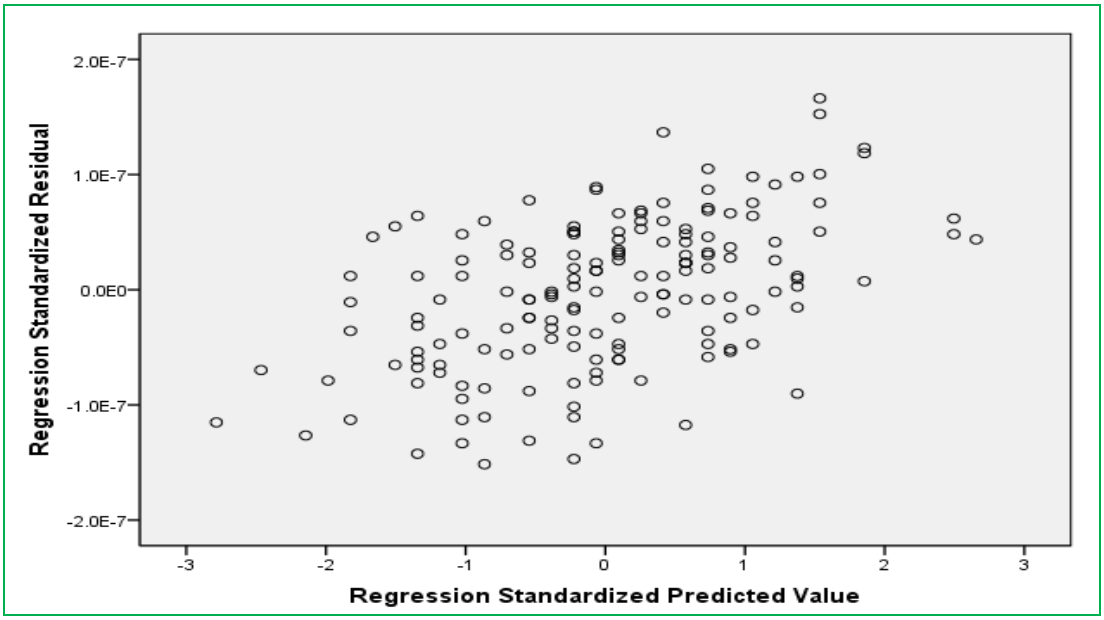

Figure 7.3: Residual scatterplot of the regression standardized residuals

Overall, the categorization of learners according to their perceptions of laboratory inquiry is shown on Table 7.6. Learners' scores from the LPCI instrument were categorized and mapped against a score range. Total number of learners per score range was converted into a frequency percentage thereby revealing the nature of inquiry most of the learners perceived they experienced.

Table 7.6: Categorization of learners according to their perceptions of laboratory inquiry (n = 167)

Score range	Number of learners per school per category					Total	Frequency as percentage	Nature of Inquiry
	School A	School B	School C	School D	School E			
20-40	0	0	0	0	0	0	0	Very low inquiry
41-60	2	2	1	0	4	9	5	Low inquiry
61-80	24	24	42	19	28	137	82	Medium inquiry
81-100	9	6	1	4	1	21	13	Very high Inquiry
Total	35	32	44	23	23	167	100	-------

As depicted on Table 7.6 and Figure 7.4, the majority of the learners perceived their teachers' practices to be mostly of medium inquiry levels when doing practical

investigations. The categorization done here differs slightly from that done through teachers' perceptions of their instructions (TPCI). Again, this is not surprising. Disconnections between what learners said they did, and what they were observed to be doing in classrooms were also found in a study of two seventh-grade science classrooms taught by two teachers in an independent school in a small urban community by Krajcik, et al. (1998). The lesson observations suggest that the levels of inquiry in the teachers' laboratories are slightly lower than what some of the learners' responses to the LPCI suggest. For the categorization done in the present study, the placement is slightly different for 4 learner classes (Schools B, C, D and E). It is different for School D whose class moves from medium inquiry to very low inquiry. Schools B and E classes shift from medium inquiry to low inquiry. School's C class moves from medium inquiry to very high inquiry It should be emphasized that the decision to place a school into a category (see, Figure 7.4) is based on the criteria of how the learners faired on all five aspects of scientific inquiry, frequent use of open-ended level of learner-learner interaction and use of practical work for understanding the nature of scientific inquiry.

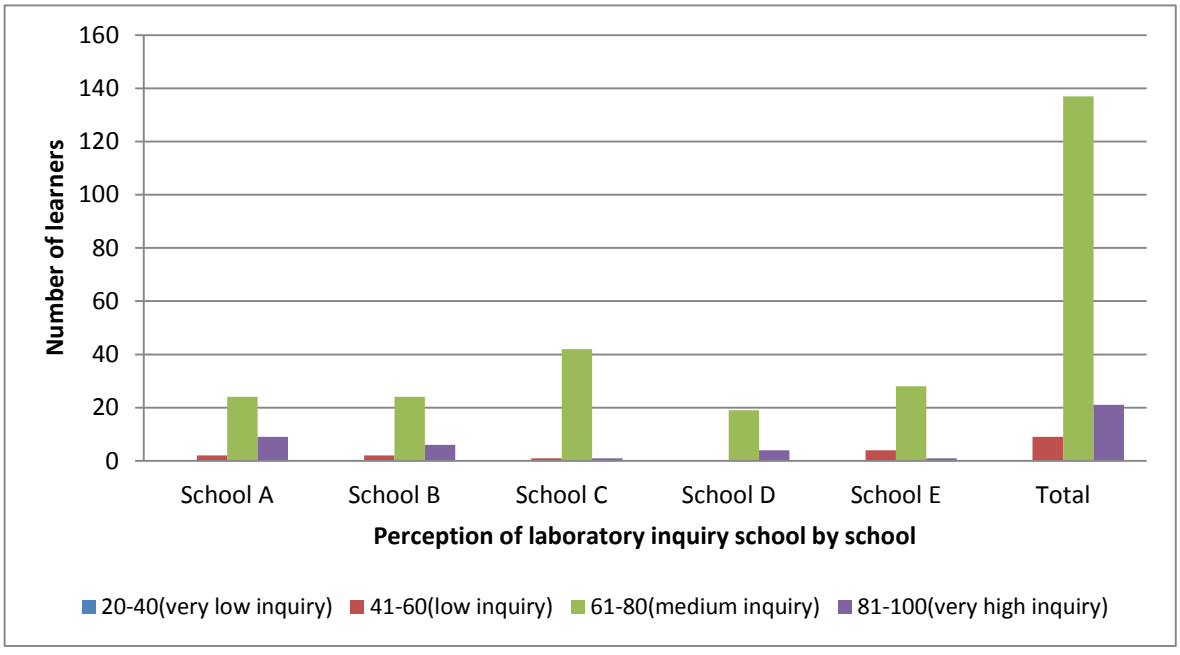

Figure 7.4: Categorization of learners according to their perceptions of laboratory inquiry school by school

7.6 Responses to the TPCI: 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 TPCI. The teachers can be placed into categories according to how they perceived their instruction when teaching investigations. Table 7.7 shows how each teacher rated his/her own instructional practice of inquiry dimension by dimension.

Table 7.7: Teachers' scores for each inquiry dimension

Teacher	Dimension/Score					
	Asking Questions	Designing Investigations	Conducting Investigations	Collecting Data	Drawing Conclusions	Total
Ranelo	16	12	18	16	15	77
Hedwick	12	8	17	17	17	71
Jairos	17	12	17	18	19	83
Johnny	11	10	12	12	16	60
Booi	15	6	16	14	19	70

Each dimension had a possible total mark of 20. As shown on Table 7.7 Jairos had the highest score of 83, followed by Ranelo, Hedwick, Booi and Johnny (who scored the least, 60) respectively. For easier comparison and clarity purposes, the scores were transformed into line graphs (see, Figures 7.5 and 7.6). Figure 7.6 shows the distribution of each teacher's TPCI scores for each dimension and the overall total score for each teacher.

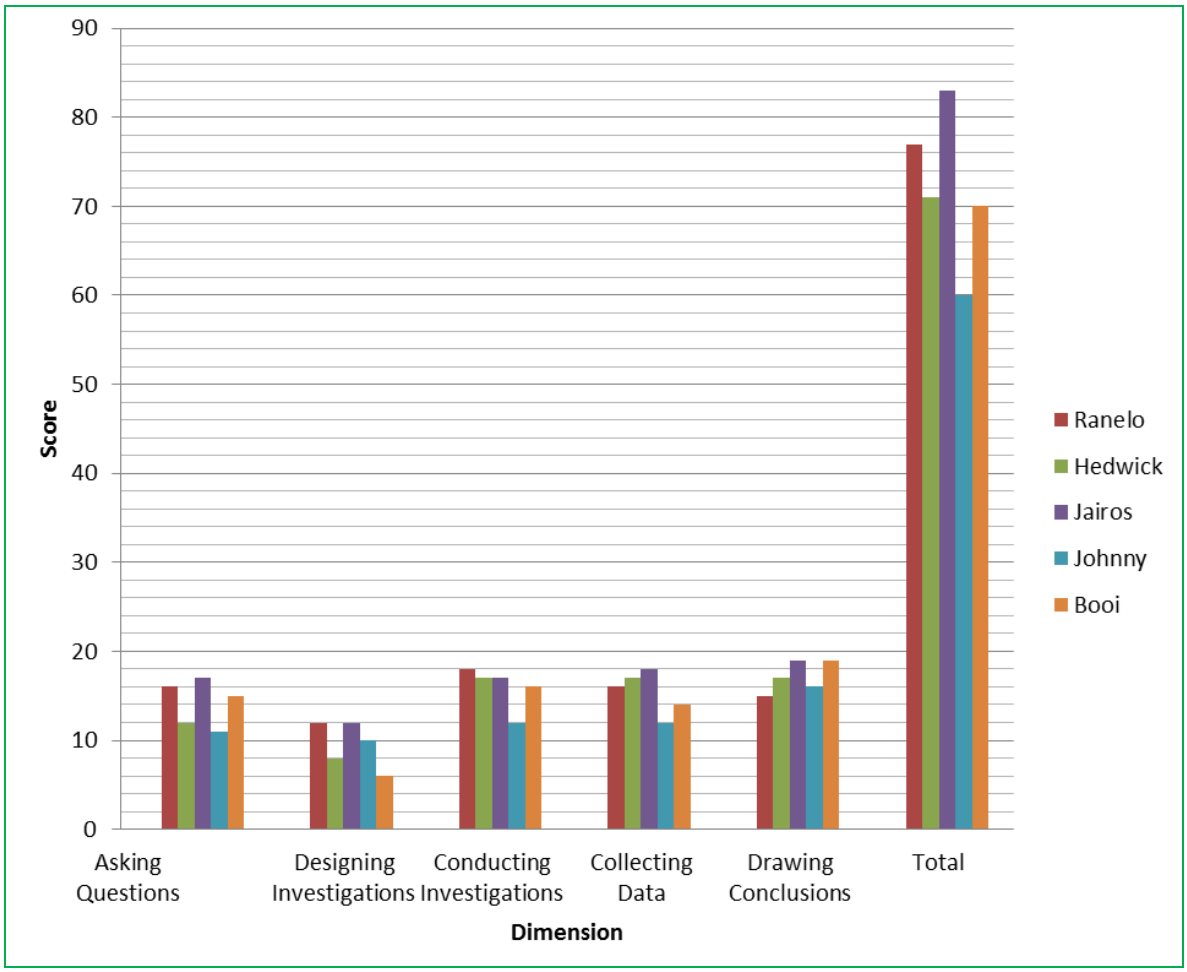

Figure 7.5: Teachers' perceptions of their practice of inquiry

As shown on Figure 7.5, Jairos perceived his instruction to be of high inquiry by giving himself high scores in at least four inquiry dimensions. Jairos's score for; the 'designing investigations' dimension is not that very high, but moderate. On the other hand, Johnny perceived his instruction to be of low inquiry because his scores were also low on at least four inquiry dimensions compared to the rest of the teachers. Figure 7.6 shows the distribution of each teacher's hierarchical arrangement of TPCI scores' dimensions according to the teachers' perceptions of their practice of inquiry.

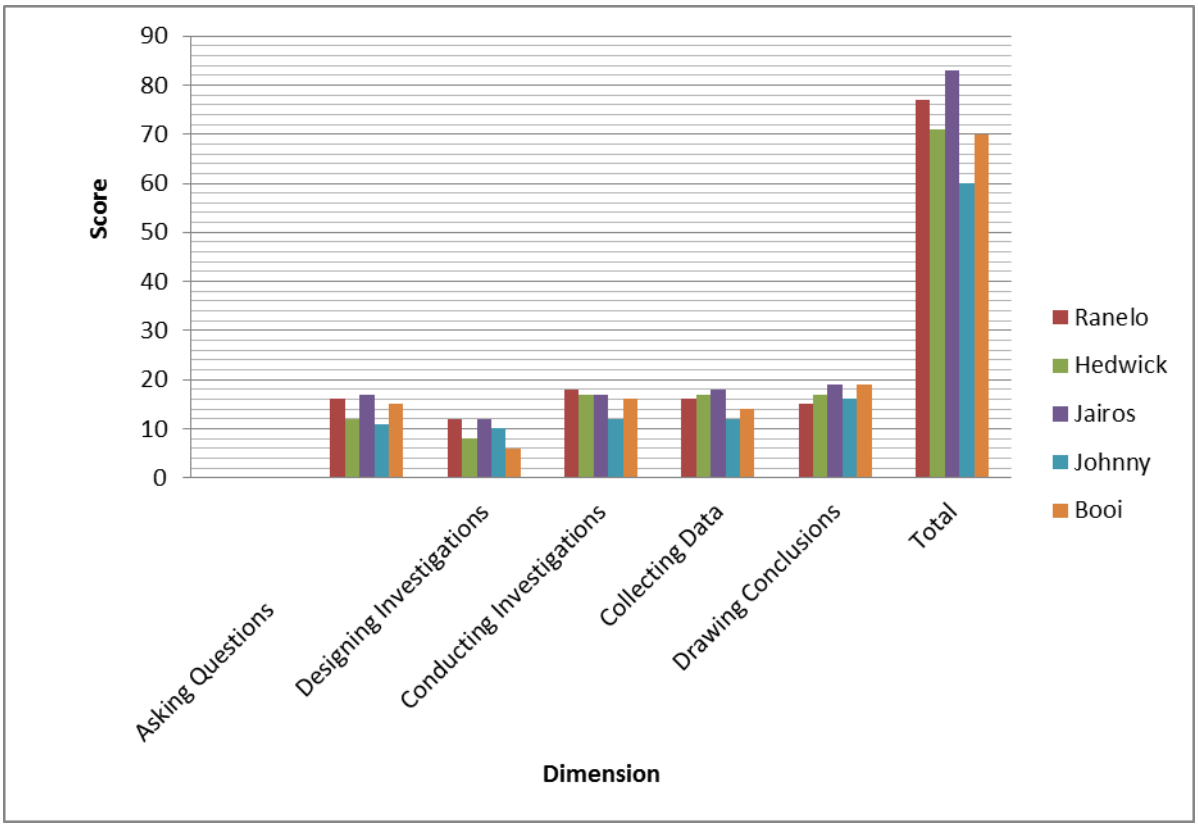

Figure 7.6: Hierarchical arrangement of dimensions according to teachers' perceptions of their practice of inquiry

For this sample of teachers, the least practised inquiry dimension is 'designing investigations' and it can be picked up from Figure 7.6 since it has the lowest scores. For all the five teachers who took part in this study, they rated themselves very low on this inquiry dimension/facet. What this entails is that teachers: mostly give step-by-step instructions before they conduct investigations; rarely give learners the opportunity to design their own procedures; deprive learners in engaging in critical assessment of the procedures that are employed when they conduct investigations; and seldom allow learners to justify the appropriateness of the procedures that are employed when conducting investigations. The commonest inquiry dimension is 'drawing conclusions' followed by 'collecting data' and 'conducting investigations' respectively. Teachers rated themselves high on these practices as can be picked from Figure 7.6. A practice is taken to be very

common if there is a high frequency (at least 3 teachers scoring above 15 out of a possible 20 in each inquiry dimension) of teachers indicating that they do what the item statement says often and almost always. The most common practices were from the 'drawing conclusions' and 'conducting investigations' inquiry dimensions and are that teachers:

- require learners to develop their own conclusions from investigations;
- allow learners to justify conclusions;
- require learners to conduct procedures designed by the teacher;
- require learners to actively participate in investigations as they are conducted;
- decide the data to collect for learners in an investigation.

Each teacher's total score was the mapped onto an inquiry continuum and Table 7.8 shows the TPCI score range and the nature of inquiry.

Table 7.8: Nature of laboratory inquiry as perceived by the teacher (n =5)

TPCI Score Range	Nature of inquiry	Teachers in score range
20-40	Very low inquiry	0
41-60	Low inquiry	Johnny
61-80	Medium inquiry	Booi, Hedwick, Ranelo
81-100	Very high inquiry	Jairos

A teacher's score below the theoretical midpoint of 60 (maximum =100, minimum = 20) was taken to mean that the teacher perceived his/her laboratory practice as of low inquiry or very low inquiry (Table 7.8). Scores above 60 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 = 72.2, median = 71.0, s.d. = 8.58). On the continuum of the nature of laboratory instruction, Jairos's instructional practice is the most inquiry oriented (most positive towards theoretical maximum) and Johnny's instructional practice is the least inquiry oriented (Figures 7.4 and 7.5). The other three teachers' instructional practices can be perceived to be of medium inquiry. As was with the case with

teacher probes, the small sample size (n =5) did not allow meaningful statistical exploration of relationships between TPCI scores and demographic variables.

7.7 A comparison of teachers' and learners' perceptions of the nature of laboratory inquiry

As shown on Figure 7.7, teachers' and learners' perceptions of the nature of inquiry in the schools are not completely different from each other. Teachers generally perceive their instruction to be of higher inquiry level compared to the way learners look at the instruction. Only at school D is the average learner's LPCI score (72.0) greater than the teacher's TPCI score (60.0). The gap between the two is widest for school C, teacher score (83.0) and learners' average score (70.0). For the other three schools, the average learner scores are almost equal to teachers' scores: for school A the teacher's score is 77 yet average learner score is 74; for school B the teacher's score is 71 and the average learner score is 72; and for school E both the teacher's score and the average learner score is 70. These gaps are in line with the findings of Tsai (2003a) who reports similar results in his study of Taiwanese learners and teachers. Both the teacher and the learners at schools A, B and E see the level of inquiry as medium and more or less to the same extent. The gap is very small at these three schools (Figure 7.7).

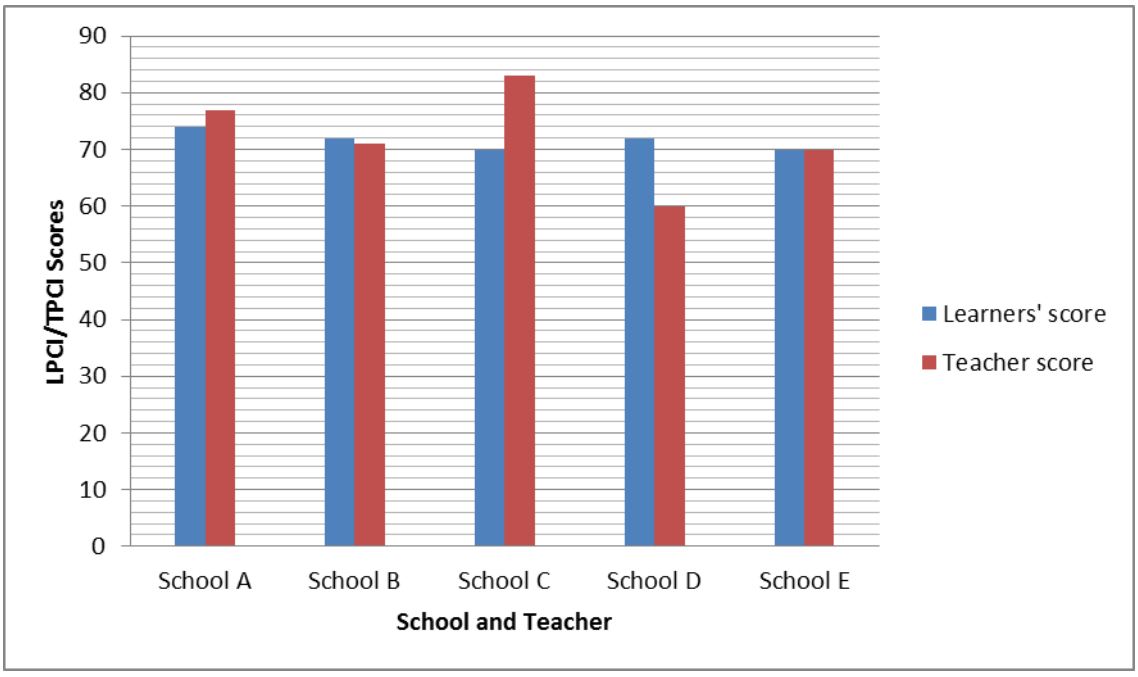

Figure 7.7: A comparison of teachers' and learners' perceptions of the nature of laboratory inquiry

For school C, the teacher perceives his instruction to be of very high inquiry whereas learners see it as of medium inquiry (according to the categorization done in Tables 7.6 and 7.8). For school D, the teacher perceives his instruction to be of low inquiry whereas learners see it as of medium inquiry. The difference in the larger sizes of gaps between learners' and their teacher's perceptions of the nature of laboratory inquiry at schools C and D and the smaller or no gaps at schools A, B and C are explained in the discussion below.

7.8 Discussion

This study used an adoption of Campbell et al.'s (2010) instrument to assess learners' and 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 the Campbell et al.'s (2010) instrument has been used in this way in the South African context. 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 Campbell et al.'s instrument can be used to assess teachers' perceptions of the nature of inquiry in science laboratories (Physics, Chemistry, and Biology). Research to further develop the Campbell et al.'s (2010) instrument for purposes of assessing teachers' perceptions of the nature of inquiry in science laboratories (Physics, Chemistry and Biology) is recommended.

The five teachers' profiles reveal a repertoire of divergent, contrasting and to some extent distinct instructional practices. On framing research questions, Jairos, Ranelo and Booi believed learners' framing their own research questions was important. When learners were formulating their own questions, the three teachers supported them in ensuring that the questions they posed were clear and investigable. The three teachers encouraged learners to refine their investigative questions through probing so that they could answer them by investigation. Support at this initial phase is critical as identifying a question plays an important role because it gives meaning and direction to what follows (Howes, Lim, & Campos, 2009; Kuhn, 2007). To the contrary, Johnny gave learners the hypothesis and never talked of investigative questions. Hedwick wanted to see the investigative question in the report but never talked about it throughout the entire practical investigation. What is evident appears to be that Jairos, Ranelo and Booi knew that good science investigations begin with clear and well formulated questions which enable the investigator (learner) to plan a procedure to be followed. Although investigative questions have their roots in the curiosity of learners (as mentioned in Chapter 2), they do not emerge spontaneously from learners (Chin & Osborne, 2008) and teachers have to employ strategies to elicit them (like what Ranelo, Jairos and Booi did). These findings suggest that teachers intervene in particular where learners formulate a question for an investigation involving the relationship between variables. This is consistent from an observation by Brook, Driver and Johnston (1989) who acknowledge that in formulating an investigative question, learners need to have a good grasp of the notion of a variable. Planning and designing an investigation requires explicit definition of the variable or variables which form the focus of the investigation and of other variables which need to be controlled.

The designing stage was approached by the five teachers differently. The new curriculum's emphasis on the investigative approach is in stark contrast to the traditional 'cookbook' approach to practical work seen in Hedwick and Johnny's classes where learners followed 'recipes' for the execution of procedures handed down by the teacher without much thought and purpose (Anderson, 2007; Kim & Tan, 2010). To Viechnicki and Kuipers (2006), the educational value of this approach is questionable. When the findings disagree with the theory provided by the textbook, learners often fudge their data in order to get the expected results. This was evident in Johnny's and Hedwick's learners marked practical investigation reports. "The investigative approach to practical work advocates greater learner autonomy, a notion that is promulgated in the South African curriculum" (Department of Education, 2002, p. 1). According to Black and Deci (2000), literature on learner autonomy is abundant, but there is no consensus on what this term means or implies. However, in the context of this study, learner autonomy is synonymous with independent learning where learners are able to work on their own with some guidance from the teacher as witnessed in Jairos and Ranelo's laboratory classes. Both Jairos and Ranelo surrendered much of the control of the learning situation in return granting learners the autonomy in doing investigations. Booi's practice regarding this dimension was in-between the practices of the other four teachers. Johnny and Booi were on one inquiry pole and Jairos and Ranelo on the other. These findings are consistent with findings from two relatively recent South Africa studies (Rogan & Aldous, 2005; Seopa, Laugksch, Aldridge, & Fraser, 2003) that highlighted the lack of learner autonomy in science practical work. The studies found out that practical work was still dominated by teacher demonstrations and a cookbook approach where learners merely followed the teacher's directions.

In conducting the investigation, although all five teachers allowed their learners to "manipulate apparatus and materials to make observations and measurements" (Corry, 2005, p. 64), Jairos's and Ranelo's learners were actively involved as they were driven by curiosity to answer their own research questions. By granting the learners autonomy in doing investigations Jairos and Ranelo surrendered much of the control of the learning

situation to the learners. This supports Billings (2001), who asserts that teacher "on-the-stage" teaching, as practiced by Johnny, Hedwick and to a larger extent Booi is the metaphor for the traditional passive learning. In contrast is the "learner-on-stage, which is the metaphor for learner-centred learning. Encouragingly, Jairos's and Ranelo' practices had some elements of this.

During the collecting data stage, Jairos, Ranelo and Hedwick's learners had the autonomy to choose the format in which they wanted to present their data. The teacher had a little hand in this. The three teachers (Jairos, Ranelo and Hedwick) ensured learners understood why they were collecting data. Johnny's learners were more concerned in completing the worksheet they had been provided with which was going to be part of the laboratory report. Booi's learners were more worried about completing the table their teacher had drawn on the chalkboard seeking patterns and trends, and generalizations in terms of simple principles. As mentioned before, the educational value of Johnny's and Booi's approach is questionable. When the findings disagree with the theory provided by the textbook, learners often tend to fudge their data in order to get the expected results (Viechnicki & Kuipers, 2006). In drawing conclusions from the investigation, learners from four classes (Jairos, Ranelo, Hedwick and Booi's classes) considered the "extent to which the conclusions reached were reasonable answers to the focus question of the investigation" (Department of Education, 2002, p. 17). However, Johnny's learners were more concerned in verifying whether the given hypothesis was true or false.

Another finding of interest from this study is that of disconnections shown by big differences in means between learners' and their teacher's perceptions of the nature of laboratory inquiry at schools C and D. While the lesson observations show the teacher at School C (Jairos) to be practicing very high level inquiry; his learners perceive the level of inquiry as medium. This could serve to confirm what Tobin and Fraser (1998a) have asserted about alpha and beta press (as discussed in Chapter 3). 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

learners). It is not uncommon for alpha and beta press to differ from each other. Equally interesting is the observation that although the sampled learners in school D on the average see instructional practice as of medium inquiry (mean score on LPCI = 72.0), the four interviewed learners from the same school did not view the instruction in exactly the same way (score range 60 to 80). According to Tobin and Fraser (1998) each learner has an idiosyncratic view (individual beta press) which could be the same or different from the class average (consensual beta press).

At school A both the teacher and the interviewed learners see the designing and planning phases of investigations as being more learner-directed and both acknowledge that not all hands-on activities are all inquiry, the gap is smaller. However, at schools B and E also both the teacher and the interviewed learners see doing hands-on as inquiry, but the gaps are also smaller. It is interesting to note that at these two schools [B and E], the level of learner-learner interactions (scientific discourse or argumentation as described by Rogoff, 1990, 2003; Wertsch, 1998) was observed to be generally low. At these schools [B and E], learners like their teacher also view practical investigations as providing the opportunity for them to experience inquiry in the "science lite" sense (Llewellyn, 2002) meaning inquiry is "soft science" hence investigations are designed to help them learn Physical Science by demonstrating or verifying theory. When describing the purpose of practical investigations one learner from each of these two teachers' classes said:

L1SBInt1: As you saw during the investigation, we wanted to verify the displacement reactions of the halides in solution and we managed to do it by checking on the colouring transferred to the non-polar xylene layer. We also verified the reduction of copper oxide with hydrogen gas and the principles behind this redox reaction we had discussed with the teacher in the pre-lab lesson.

L5SEInt23: The purpose of the investigation was to verify theory we had discussed in class about Boyle's law. After having solved a few problems of Boyle's law in the previous lesson, we wanted to verify if the theoretical relationship $p \alpha 1/V$ holds. From our results, we found that the relationship holds.

Inquiry as content should be elevated to the same level as knowing concepts, principles, and theories of life, Earth or the Physical sciences (Llewellyn, 2002). Inquiry is one more a strategy teachers can use, at the appropriate time, to engage learners in investigations and satisfy their curiosity for learning. At all five schools, the level of learner-learner interactions (each learner having a role as the investigation was conducted) was considerably high.

Overall, findings from this study show that teachers' practices varied from teacher to teacher and from one inquiry dimension to the other. Some teachers' practices were close to each other enabling the teachers to be categorized in one level of the openness to inquiry continuum according to Hegarty-Hazel's (1986) classification of inquiry levels. Basing on the findings presented above, it can be said that Jairos operated at level 2b on the openness to inquiry scale according to Hegarty-Hazel's (1986) classification of inquiry levels. Ranelo's practices are fairly "open-ended" hence it can be said he operated at level 2a. Hedwick and Booi's practices can be described belonging more on the "close ended" side of the scale. They practiced low inquiry, level 1. Johnny's practices can be described as largely "close-ended" as learners were asked to conduct the investigation based on specific instructions given on a worksheet. Johnny practised at the lowest level of inquiry, level zero (Hegarty-Hazel, 1986).

In each case, the practices appear to be guided by the teacher's philosophy of teaching science and interpretations of the NCS on teaching investigations. It also appears that even when the teachers believe in the goals and effectiveness of inquiry-based teaching, their practices maybe driven more by the prioritization of mastery of the subject matter than development of learners' investigative skills. The five teachers' practices as found in this study support Dai, Gerbino and Daley (2011) and Songer et al. (2003) who point out that curriculum realities and constraints limit teacher practices of open-ended inquiry. Johnny attests to this when he laments the lack of time for him to practice "full inquiry" leading him to do the minimum required to satisfy the NCS specifications on assessing practical

investigations. . As findings of this study show, for the sampled teachers the major focus is on content coverage and learner mastery of the subject matter. In this way they fail to make classrooms sites for higher levels of scientific inquiry.

7.9 Conclusions

The results from the observations of laboratory sessions and the teacher and learner interviews and questionnaires, reveal that the sampled teachers conducted laboratory instruction in ways which can be described as: mainly teacher-directed, with the teacher designing procedures for learner investigations. The teachers do not allow learners to engage in the critical assessment of the procedures that are employed when they conduct investigations but allows learners to actively participate in the investigations. The investigations are largely conformistic or verificationistic, aimed at verifying Physical Science knowledge, e.g. Boyle's law).

In conclusion, the level of inquiry in the sampled teachers laboratories can be described as generally low based on the following:

- It appears that curriculum and examination requirements limited learner autonomy.i.e. degrees of freedom or latitude given to learners to identify the materials to be used, plan and design their own procedures, identify the type of variables involved (control, independent, dependent), formulate a question or hypothesis, and determine how the variables can be manipulated, controlled, and measured (Chin, 2003).

- Some teachers failed to focus and support learners at the initial stages of framing or asking investigative questions. This initial phase is particularly important in that identifying a question plays an important role because it gives meaning and direction to what follows (Howes, et al., 2009; Kuhn, 2007).

- Learners 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 two classes did the teacher appear to encourage the kind of classroom discourse described as characteristic of the practice of inquiry (Rogoff, 1990, 2003; Wertsch, 1998).

- The teachers tended to encourage group activities but some teachers failed to monitor the groups and as a result group discussions were not focused and based on the practical investigation.

In sum, the five teachers varied considerably in how they attempted to engage learners in the active search for knowledge. Johnny and Hedwick advocated structured methods of close-ended inquiry (Banchi & Bell, 2008)) while Jairos and Ranelo strived to practice some form of open-ended inquiry (Bell, et al., 2005; Lederman, 2009). Booi's practices were in-between close-ended and medium inquiry. From this experience, the researcher learns that by simply asking learners to participate in some investigative activities, does not necessarily translate into their experiencing authentic inquiry.

CHAPTER EIGHT

Exploring interactions among the three investigated variables

8 Introduction

In this chapter results are presented and discussed from the exploration of interactions between: learners' NOSI conceptions and their perceptions of classroom inquiry; learners' NOSI conceptions and their teachers' NOSI conceptions and teachers' conceptions of the NOSI and their instructional practices. Quantitative and qualitative data are analyzed, presented, and discussed. This data is from; two questionnaires -the LUSSI and LPCI, probes, learner and teacher interviews, and classroom observations. The treatment of data is both exploratory and interpretive. The relationships among the investigated variables are related to the key aspects of the tenets of NOSI chosen for this study and to the theory on teacher instructional practices.

8. 1 The nature of interaction between learners' understandings of NOSI and their laboratory work experiences.

This section puts together the findings relating to the nature of interaction between learners' understandings of NOSI and and teacher instructional practices when teaching investigations. It focuses on learners' their perceptions of their experiences of inquiry. In doing so, it puts into test the validity of the assumption that, learners NOSI perceptions are related to their laboratory work experiences. It further tests the assumption that engagement of learners in laboratory activities can eventuate in the learners' picking up and building understandings of the nature of scientific knowledge and the processes of its development. This assumption is the basis of the so-called implicit approach to the development of learners' NOSI conceptions as promulgated by the NCS curriculum which inherently assumes that by "doing inquiry", learners come to understand NOSI.

The possible relationship between the two variables, learners' perceptions of their laboratory work experiences (as measured by LPCI scores from all learners in the 5

schools) and their conceptions of NOSI (as measured by the LUSSI instrument scores) was explored. Scatterplots were generated using SPSS for Windows (Version 16). Two scatterplots were produced, one for learners' laboratory work experiences against their understandings of NOSI (as measured by the LUSSI closed responses) and the other against their understandings of NOSI as measured by the LUSSI open-ended responses. As mentioned in Chapter 3, different scales were utilized to categorize learners' closed and open-ended responses although both address the same constructs for each explored tenet of the NOSI.

8.1.1 Closed LUSSI questionnaire versus LPCI

Figure 8.1 is a scatterplot of scores on learners' laboratory work experiences, as measured by LPCI total scores, and their understandings of NOSI, as measured by the LUSSI closed response scores.

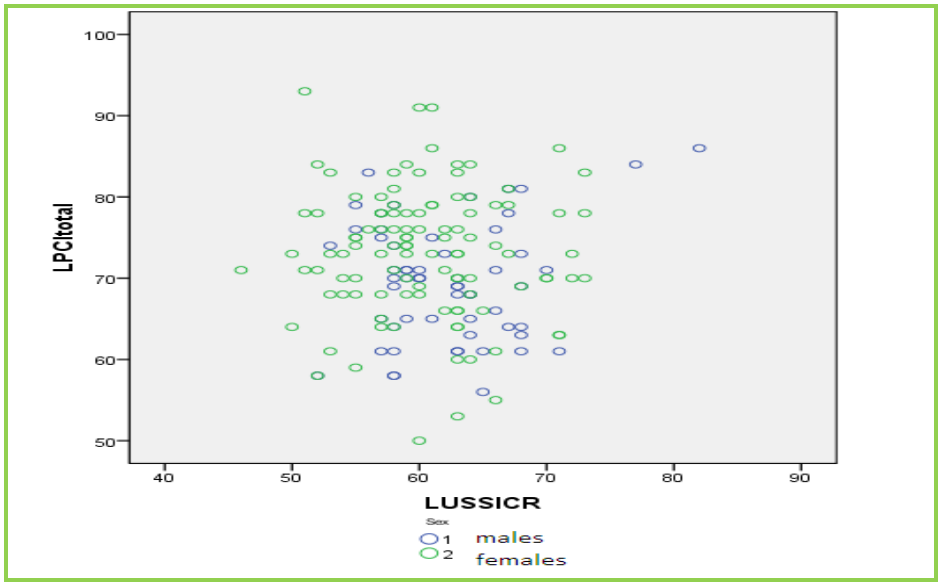

Figure 8.1: Scatterplot of learners' laboratory work experiences (as measured by LPCI total scores) and their understandings of NOSI (as measured by the LUSSI closed response scores).

As Figure 8.1 shows, there appears to be a very low correlation between the two variables. The basis of this claim is that data points are spread all over the place and mostly concentrated at the centre. The direction of the relationship between the variables is even difficult to tell due to the spread of the data points. There is no clear cigar pattern hence clear cut correlation between the two variables. Lack of correlation between the two variables ($r = -.004$, $p<.05$) was confirmed by computing the Pearson Product Moment Correlation Coefficient. As Table 8.1 shows, there was no correlation between learners understanding of NOSI, as measured by LUSSI closed responses, and learners' laboratory work experiences, as measured by the LPCI total scores.

8.1.2 LUSSI open-ended response scores versus LPCI

Scoring for learner LUSSI open-ended responses were obtained by categorizing responses as informed (3), transitional (2), naïve (1), or not classifiable (0) with the scores in brackets (Liang, et al., 2006). The LPCI response alternatives on the five-point bipolar Likert scale ranging from (1) never occurred (2) seldom, (3) sometimes, (4) often to (5) almost always were allocated scores from 1, 2, 3, 4 to 5, respectively. Scoring was done in reverse for statements representing non-inquiry or closed-inquiry laboratory. Figure 8.3 is a scatterplot of learners' laboratory work experiences, as measured by LPCI total scores, and their understandings of NOSI, as measured by the LUSSI open-ended response scores. As Figure 8.2 shows, there appears to be a positive weak correlation between the two variables. Data points of both male and female learners form a diagonal line which is not that distinctive from left to right. This suggests that respondents having a low understanding of the NOSI (shown on the horizontal, axis) experience low levels of inquiry (shown on the vertical, axis). On the other hand, learners perceiving high levels of inquiry have a high understanding of inquiry.

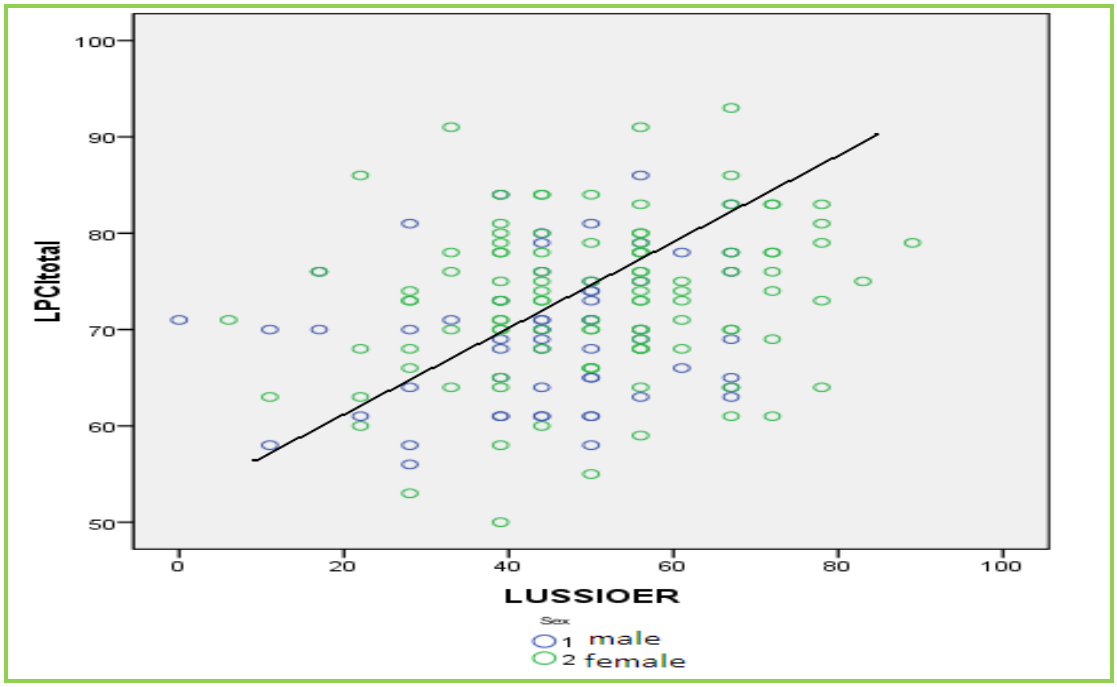

Figure 8.2: Scatterplot of learners' laboratory work experiences (as measured by LPCI total scores) and their understandings of NOSI (as measured by the LUSSI open-ended response scores).

A follow-up investigation on the relationship between learners' perceptions of laboratory work experiences (as measured by LPCI total scores from all learners in the 5 schools) and their understandings of NOSI (as measured by the LUSSI open-ended response scores) was carried out with the calculation of the Pearson product-moment correlation coefficient. This was deemed necessary in order to get a definitive answer since the scatterplot does not do so. Preliminary analyses were performed to ensure there were no violations of the assumptions of normality, linearity and homoscedasticity. There was a weak, positive correlation between the two variables [r = **.**236, n =167, p < **.**01] with high levels of perceptions of laboratory inquiry being associated with higher conceptions of NOSI.

Table 8.1: Table of correlations

Pearson Product-Moment Correlations Between Measures of learners' laboratory work experiences and their understandings of NOSI			
Measures	1	2	3
(1) Sex			
(2) LUSSICR	-.156*		
(3) LUSSIOER	.168*	.083	
(4) LPCItotal	.215**	-.004	.236**

N = 167; LUSSICR = LUSSI closed responses; LUSSIOER = LUSSI Open-Ended Responses; LPCItotal = LPCI total score

*p<.05 [.*Correlation is significant at the 0.05 level (2-tailed)].

** p<.01[. ** Correlation is significant at the 0.01 level (2-tailed)].

As discussed in Chapter 3, scoring LUSSI closed learner responses was done as follows: *strongly agree* = 1, *agree* = 2, *not decided* = 3, *disagree* = 4 and *strongly disagree* = 5 (Liang, et al., 2006). Items representing naive conception of science (negative Likert items) were scored in reverse. Learner LUSSI open-ended responses were scored as described in the preceding section. Of interest is lack of correlation between LUSSI closed response scores and LUSSI open-ended response scores yet both were measuring the same constructs on the instrument (Table 8.1). The only difference was that one set of questions was open and the other set closed (see Appendix A). The possible reason could be that when learners' completed closed or Likert-type questions they just ticked available options without putting much thought and reflections. This could raise questions about the validity of the closed items.

8.1.3 Interactions and gender

The variable, sex, correlated with the other three variables (LUSSI closed responses, LUSSI Open-Ended Responses and LPCI total score) [r = **-.**156*, n =167, p < **.**04; r = **.**168*, n =167, p < **.**03; r = **.**215**, n =167, p < **.**005] respectively (see Table 8.1 for correlations). Having found that sex correlates with all the three variables yet there was no correlation for the other variables among themselves (except between LPCI total score and LUSSI open-ended responses); a need arose to compare the strength of correlation coefficients for the

two separate groups (males and females) with learners' perceptions of laboratory work experiences (as measured by LPCI scores). Results from the split sample correlation to compare correlation coefficients are shown on Table 8.2.

Table 8.2: Table of split sample correlations

Sex			LUSSICR	LUSSIOER	LPCItotal
Male	LUSSICR	Pearson Correlation	1	.116	.160
		Sig. (2-tailed)		.382	.227
		N	59	59	59
	LUSSIOER	Pearson Correlation	.116	1	.192
		Sig. (2-tailed)	.382		.145
		N	59	59	59
	LPCItotal	Pearson Correlation	.160	.192	1
		Sig. (2-tailed)	.227	.145	
		N	59	59	59
Female	LUSSICR	Pearson Correlation	1	.110	-.029
		Sig. (2-tailed)		.256	.763
		N	108	108	108
	LUSSIOER	Pearson Correlation	.110	1	.214*
		Sig. (2-tailed)	.256		.026
		N	108	108	108
	LPCItotal	Pearson Correlation	-.029	.214*	1
		Sig. (2-tailed)	.763	.026	
		N	108	108	108

*. Correlation is significant at the 0.05 level (2-tailed).

As shown on Table 8.2, there was correlation only between learners' perceptions of laboratory work experiences (as measured by LPCI total scores) and their understandings of NOSI (as measured by the LUSSI open-ended response total scores) for females and r = **.**214* , n =108, p < **.**03 while for males there was no correlation. All other variables [understandings of NOSI (as measured by LUSSI closed responses) and learners' perceptions of laboratory work experiences (as measured by LPCI total scores)] had no correlation for both groups. According to Cohen (1988), r < **.**3 signifies a weak correlation and this explains why data points are spread all over and does not form a clear cigar pattern for male data points. This data suggests that for females harbouring fairly adequate views

of the NOSI does necessarily mean perceiving laboratory work experiences as highly inquiry oriented. The converse is also true in this instance. For males it suggests harbouring fairly adequate views of the NOSI does not necessarily mean perceiving laboratory work experiences as highly inquiry oriented.

To confirm the above findings one-way between-groups Multivariate Analysis of Variance (MANOVA) was performed to investigate sex differences in terms of learners' NOSI conceptions and laboratory work experiences. In the process, it was possible to determine if female and male learners differed in terms of their NOSI conceptions and perceptions of laboratory work experiences. Three dependent variables were used: LPCI total score, LUSSI closed responses and LUSSI Open-ended responses. The independent variable was gender. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted. There was a statistically significant difference between males and females on the combined dependent variables: F (3,156) = 2.64, p = **.**046; Wilks' Lambda = **.**95; partial eta squared = **.**05. When the results for the dependent variables were considered separately, the only difference to reach statistical significance, using a Bonferroni adjusted alpha level of **.**017, was LUSSI open-ended responses: F (1,158) = 1.83, p = **.**016, partial eta squared = **.**04. An inspection of the mean scores indicated that females reported slightly higher levels of laboratory work experiences (M = 55.64, SD = 5.75) than males (M = 58.37, SD = 6.33). Although statistically significant, the actual difference in the two mean scores was very small, fewer than 3 scale points.

As discussed earlier in Chapters 5 and 7, it was shown that about half of the learners (49%) hold moderately adequate views of the NOSI and also that most of them (82%) perceive the level of inquiry in their laboratory work to be medium. These results would imply a correlation between the nature of laboratory work experienced by the learners and their perceptions of the level of inquiry in their laboratory work. This would support the findings of Patel, et al. (2009) and Tsai (1998a; 2003a; 1999), which point towards some association

between learners' NOSI views and their perceptions of their laboratory work. Patel et al.'s work and Tsai's work suggest a relationship between holding informed views of the NOSI and high inquiry oriented instruction. The results in Chapters 5 and 7 appear to contradict the low Pearson correlation (r = 0.24) and (r = -0.004) between LUSSI open-ended total scores, LUSSI closed response total scores and LPCI total scores respectively as shown in Table 8.1. The low correlation coefficient suggests that learners NOSI views are at best only very weakly related to how they perceive the nature of inquiry in their laboratory work.

8.1.4 Interactions and interview responses

To get insights into the interaction between conceptions of the nature of scientific inquiry and perception of laboratory work, learners' responses to interview questions were analyzed. Of the 23 learners, 10 were classified from the LUSSI as holding inadequate (naïve) views, 8 moderately adequate (transitional) views of the NOSI and five as highly adequate (informed). Fourteen learners (9 harbouring inadequate views and 5 holding moderately adequate views) perceived experimentation as the source of scientific knowledge hence laboratory instruction becomes critical. Experimentation is one of the ways in which scientific knowledge is generated though not the sole method and is related to the processes of science (NOSI). Other methods like serendipity, dream, imagination and creativity, library investigations were mentioned by some learners in the moderately adequate and highly adequate view category. The idea of these methods being infused in instruction so as to help learners acquire or use them was mentioned by very few learners (4%) only in the highly adequate and extremely adequate categories when responding to the probes questionnaire. These same learners are also the ones who said the process of science is non- linear, complex, and contingent. This could be suggestive of learners' views of the methodology of scientific investigations in science being related to perceiving instruction as developmental. No patterns were found linking learners' understandings of the NOSI to perceiving instruction as conformist though a small number (3 learners) explicitly said so during interviewing. This is corroborative of the very weak relationship found between understandings of the NOSI and perceptions of instruction from the LUSSI and the LPCI.

Another interesting finding is that all interviewed learners managed to link use of group practical activities to the idea that science is a co-operative activity. They said this helped them share ideas and help peer review and replicate each other's work in the process. In responding to the question, "how do you do the actual investigation?" learner L2SCInt11 said:

> L2SCInt11: We do it as groups and observe what actually happens to the practical. Doing it as individuals, we would not do the same thing as we would when we are in groups because we share ideas; like they say two heads is better than one. It is so helpful doing it in groups.

The learners raised the fact that science is not a solitary pursuit and as such scientists work in a community of practice and validate each other's work. However, 40% of the sampled learners did not think scientists require accurate record keeping, peer review and replicability when completing the probes questionnaire. It could also be said that learners are aware of different and relevant pedagogy in the school context. If learners are aware of advantages of co-operative grouping strategies, it might make them interpret laboratory activities not as similar (regarding level of practice) to what scientists do but simply as "school science" as Chinn and Malhotra (2002) contend. This is because in school science learners are both cognitively and epistemologically limited unlike in authentic scientific inquiry. Some of the learners' responses were suggestive of learner awareness of the cognitive and epistemological limitations of school science. One of the learners had this to say:

> L5SCInt14: You see here at school, we lack the expertise and both resources and time to engage in real science. Most of the time, we perform confirmatory experiments to verify certain laws and theories and mostly we do these in groups so that we can help each other.

Learners' perceptions of the scientific value of practical activities organized by the teacher appear to be impaired and distracted by the nature of the NCS requirement in the sense that the two practical investigations they do are assessed and send to the District for moderation

and become part of the school-based assessment (SBA). The practical investigations contribute 40% to the Continuous Assessment (CASS) mark, which is school-based, meaning that this component has a huge weighting on the overall assessment. When asked, 'At what stage do the learners stop working as a group?' learners L1SCInt10 and L2SDInt7 expressed the sentiments of many of the learners when they answered:

L1SCInt10: After collecting the results, each one of us will be on his own since we will start working on our investigation reports which are marked. Our teacher says the results can be the same but everything else has to be different.

L2SDInt7: The teacher always emphasize that group work is up to the data collection stage, thereafter, everyone is on his/her own. The teacher also says since the reports are going to be taken to the District for moderation, they must not be the same though we are using the same results. At times it is confusing…

This impairment and distraction could mean that the nature of instruction itself is a possible factor responsible for the weakness of the learners' NOSI understandings-perception interaction. Learners in three of the five teachers' classes were concerned about how they went through the whole process of Physical Science practical investigations. They lamented the limitations they were given to ask or frame questions for investigation; design and conduct investigations; collect their own data; interpret results; and then draw their own conclusion. The learners believed scientists in authentic scientific inquiry, are not limited compared to their own practice. One learner said:

L3SDInt8: The way we do our investigations is completely different from that of scientists. As you saw we were more concerned with the confirmation of Boyle's law. However, when scientists like Boyle invented his apparatus, he had no yardstick. He tried his ideas several times until he came up with the Boyle's apparatus. That is the difference between our investigations and those of scientists. The focus of scientists is to solve real life persistent problems and ours is to confirm laws and theories.

This implies learners do see a difference between school and professional science. At this juncture, perceptions of instruction as: asking or framing questions for investigation; designing and conducting investigations; collecting their own data; interpreting results; and then drawing their own conclusions as well as understandings of the NOSI appear to be in concordance with the way "scientists ask or frame questions for investigation; design and conduct investigations; collect their own data; interpret results; and then draw their own conclusions". A possible explanation could be that learners' experiences with practical investigations from Grade 10 in which they start conducting investigations which are moderated by the District. At Grade 10 the learners start getting exposed to the format of presenting the practical examination report for assessment purposes. The learners see the same format of presentation in different textbooks and it is when the learners might develop notions that "real scientists take time to ask or frame questions for investigation; design and conduct investigations; collect their own data; interpret results; and then draw their own conclusions" and later present it in the same format. Such concordance could be suggestive of instruction influencing the interaction between learners' understandings of NOSI and perception of instruction. Learners' responses to interview questions suggest that the interaction between perceptions of laboratory instruction and understandings of the NOSI is not a straight forward affair but a complex entity that could be influenced 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.

The above results and evidence from the observations of laboratory classes, teacher and learner interviews suggest some weak interaction between teacher laboratory instructional practices (as demonstrated by learners' perception of their classroom inquiry) and their learners' understandings of the nature of scientific inquiry (NOSI). For only one teacher (Jairos), do the findings appear to give some weight to the existence of some interaction between learners' perceptions of laboratory experiences and their conceptions of NOSI. That interaction however is not a causal relationship. There is not enough evidence that being in a class where the level of instructional inquiry is low means holding naïve views of nature of scientific inquiry. For example, although learners from Hedwick's class practiced

low inquiry, most of her learners' conceptions of the NOSI ranged from mostly moderately adequate (transitional) views to highly adequate (informed) views. In very low inquiry, low inquiry and medium inquiry classes' (for example, Johnny, Booi and Ranelo's classes) learners were found who hold poorly adequate (naïve) views. Learners holding highly adequate (informed) views were also found in all the four classes.

8.2 The nature of interaction between learners' understandings of NOSI and their teachers' understandings of NOSI

The major issues discussed and summarized in this section relate to the question: What is the nature of interaction between Grade 11 learners' conceptions of the NOSI and their teachers' conceptions of the NOSI? Chapter 5 elicited and elucidated the learners' NOSI conceptions and Chapter 6 revealed and shed light on the teachers' NOSI conceptions. Focus is now on the interaction between the two variables (learners' and teachers' conceptions of the NOSI). As mentioned earlier, because of the small sample for teachers, the nature of interactions between these two variables is examined using only qualitative analyses of both learner and teacher response data.

Interactions between learners' conceptions of the NOSI and their individual teachers' conceptions of the NOSI was examined school by school. Each school's learners LUSSI open-ended response total scores were placed on normative maps alongside categories of NOSI views. The scores were converted into a bar graph. Figure 8.3 is a summary of the sampled learners' NOSI views. As mentioned earlier, the LUSSI open-ended response total scores were found to be statistically significant when correlated with other variables.

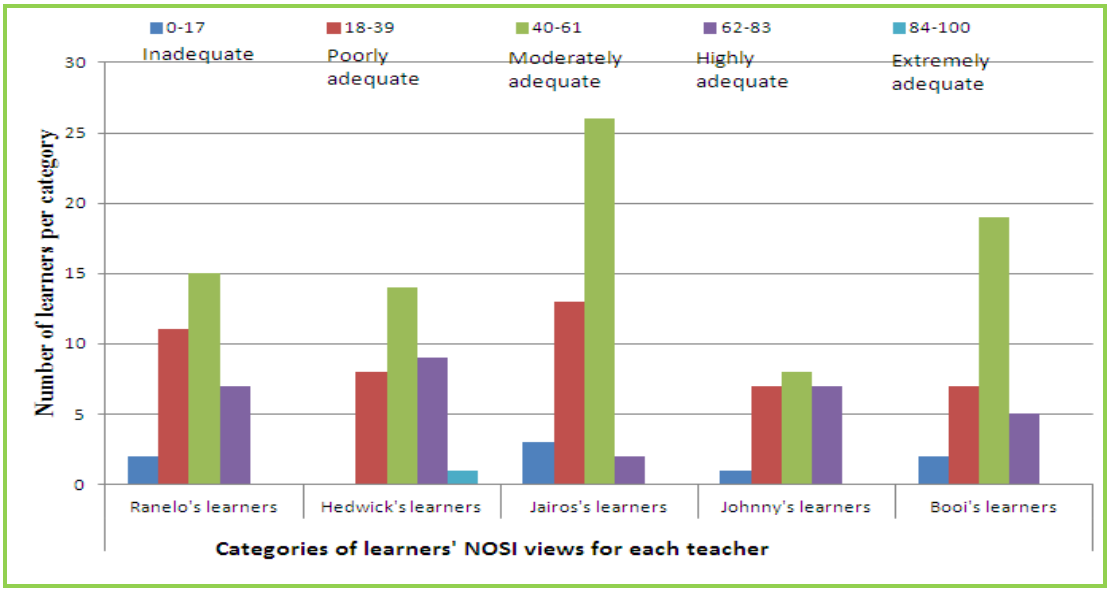

Figure 8.3: Categorization of learners' NOSI views (from open-ended responses) school by school

Though the moderately adequate views dominate, the whole spectrum of views harboured by the learners is clearly shown on Figure 8.3. Learners' NOSI views for each school were then matched against their teacher as shown on Table 8.3. Only the dominant learner NOSI views (the one with the highest frequency) are shown for each category on the table.

Table 8.3: Summary of observed teachers' and mapped learners' NOSI views

Teacher	Teachers' NOSI views category	Learners' NOSI views category (LUSSI closed responses)	Learners' NOSI views category (LUSSI open ended responses)
Ranelo	Poorly adequate (naive)	Moderately adequate	Moderately adequate
Hedwick	Highly adequate (informed)	Moderately adequate	Moderately adequate
Jairos	Highly adequate (informed)	Moderately adequate	Moderately adequate
Johnny	Poorly adequate (naive)	Moderately adequate	Moderately adequate
Booi	Moderately adequate (transitional)	Moderately adequate	Moderately adequate

As Table 8.3 shows, one teacher (Booi) and his learners can be said to harbour matching moderately adequate (transitional) views. One would be tempted to support Abd-El-Khalick, Bell and Lederman (1998) and Sarkar and Gomes (2010) and say there is a relationship between teachers' conceptions of NOSI and learners' understandings of NOSI. Such a generalization however is impossible given the sample size. It must also be borne in mind that the categorization for learners is based on only one instrument from a group of instruments used to elicit learners' conceptions of the NOSI. The categorization of learners' conceptions of NOSI is different from that coming out of the whole package of instruments used to draw these views including interviews. The other four teachers' conceptions of the NOSI mismatch with their learners' conceptions of the NOSI. It is more fruitful and perceptible to examine the nature of the interaction at the individual level of the teacher based on each of the six NOSI tenets explored. Meaning making and interpretation of the interaction can be done from the insights inherent in some of the teachers' and learners' interview responses and the observed lessons.

8.2.1 Results from interviews

Johnny appears to hold strong, naive realist views about scientific observations not being theory-laden and interpretations not necessarily being selective but objective. The following conversation elicits Johnny's standpoint.

Interviewer: Can different scientists make different or same observations on the same thing?

Johnny: You observe with your five senses (i.e., sense of smell, look and taste, hear and/or feel).What you actually observe is what happens therefore scientists make the same observations from the same thing.

Interviewer: Let us look at interpretations; should interpretations of the same observations be the same or different?

Johnny: Interpretations should also be the same. Isn't it that they are observing the same thing; they must come to the same conclusion.

Interviewer: When you are teaching practical investigations, what do you tell your learners about observations and interpretations?

Johnny: I tell them science is all about facts and is objective, you observe using all your five senses and the act of inferring is objective.

From the interview excerpt above, we would expect Johnny's learners to also harbour naïve realist and objective views if teachers' nature of scientific inquiry conceptions translates into learners' nature of scientific inquiry conceptions. Interestingly, there are learners in Johnny's class who elicited dynamic, constructivist-oriented views as opposed to their teacher's static empiricist-aligned views on this NOSI aspect. This group of learners saw observations being theory-laden and the process of making interpretations being selective. Two of Johnny's learners had this to say on observations and inferences:

L2SDInt7: When observing, for example, during a practical investigation, one applies scientific knowledge he or she already knows and this is informed by theories to make a better observation. Since we come from different backgrounds, our observations then differ.

L4SDInt9: We are informed by different theories, meaning our interpretations of the same events, for example, the same experiments differ because we use different background information and experiences as the basis for the deductions we make.

However, there are also learners in Johnny's class who harboured naïve views as their teacher. These learners saw observations not being informed by theory and saw interpretations as objective: Two of the learners said:

L1SDInt 6: Observations we make during a practical investigation are the same. They cannot be different because we will be looking at the same thing. So do scientists, they make the same observations from the same event.

L3SDInt8: Interpretations from the same observations are the same because science is about facts. Science deals with proving laws and theories. We are not allowed to use our background knowledge and beliefs when making interpretations from investigation results as this interferes with objectivity.

Though the other four teachers (Ranelo, Hedwick, Jairos and Booi) held adequately informed views on the observation NOSI tenet (as described in Chapter 6), the majority of their learners were found to harbour NOSI views which ranged from poorly adequate (50%), with a few learners' NOSI views found to be moderately adequate (11%) to highly adequate (13%) (as shown on Table 5.6 under the probes' results section in Chapter 5). Like some of their teachers (Ranelo and Booi), some learners had contradicting ideas regarding 'observations and inferences. Though the learners believed observations are theory-laden, they were of the belief that interpretations of the same observations are the same. These contradicting views were also harboured by learners from Hedwick and Booi's class. This shows that the teachers' NOSI conceptions do not match with their learners' NOSI conceptions at all.

A NOSI tenet which produced interesting findings worth noting is "the methodology of scientific investigations". Two of the teachers Ranelo and Johnny, gave insightful responses. When asked the question "what can you say about the methods scientists use in their investigations or experiments?" Ranelo said:

Ranelo: Scientists employ a variety of methods but for confirmation of results, scientists have to use an orderly step-wise procedure. Then they can be sure of their results after having followed a logical common method.

In a way, Ranelo is a verificationist and objectivist. Learner responses to the probes, LUSSI questionnaire and interviews probes from Ranelo's class were analyzed to see if the kind of reasoning elicited by Ranelo showed in some of his learners' NOSI views. Worth noting, there was none. Interestingly, similar reasoning to Ranelo's was found in responses by learners' in Jairos' class. The learner wrote:

PMSCIL 89: A number of methods can be used when conducting scientific investigations but at the end, the scientific method should be used to check if the answer is correct.

It should be remembered that Jairos himself had shown highly adequate views of this NOSI aspect. In contrast, Johnny believed scientists use only one method of logical steps known as the scientific method to perform investigations. He said:

Johnny: Scientists need to prove each other incorrect in scientific arguments. For them to be able to do this the same method of scientific investigation should be used and there is only one method known for accuracy called the scientific method. I use this method with my learners as from Grade 10[...]

Fascinating enough, two of Johnny's learners demonstrated the same kind of reasoning as their teacher during interviewing. When asked "What is your view about the scientific method as a way of doing investigations? The two learners responded:

L3SDInt8: To get results that will be recognized internationally by other scientists, you have to follow the scientific method so I think that is the only way you can do that; Yaah... there is only one method which is the scientific method, there is non-other; an another said:

L2SDInt7: I believe that is the only method because my teacher told me that there is only one method. Even if I wanted to find out if there are other methods, I am no longer interested because I was told this is the only method.

However, still in Johnny's class, two of the other interviewed learners harboured highly adequate (informed) views which were opposite of their teacher's and colleagues' views still on the same NOSI aspect. The two learners said:

L1SDInt 6: Scientists have no boundaries and are not limited, so with them using one method means they will not find solutions to their problems. They therefore employ different methods to solve their problems.

L4SDInt9: There is no one single solution to a problem, therefore scientists come up with many and different methods of conducting investigations.

Such matching and contradicting teacher and learner NOSI views were also found in the other four NOSI aspects namely: laws and theories serve different roles in science; scientists require accurate record keeping, peer review and replicability; scientific knowledge is socially and culturally embedded; and scientific knowledge is partly the product of human creativity and imagination. The above responses suggest lack of a simple and direct relationship between teachers' and learners' NOSI conceptions. Perhaps, such a relationship can only be contingent if the teacher pays explicit attention to developing learners' NOSI conceptions. The relationship between teachers' and learners' NOSI conceptions might be influenced by teachers' and learners' attitudes, values, assumptions, other beliefs and sub-beliefs all constantly interrelating and possibly fluctuating. This makes it difficult for the teachers' NOSI conceptions and learners' NOSI conceptions to be easily equated blow by blow. The results of this study therefore fail to fully support the idea that learners' conceptions of the NOSI are linked to their teachers' conceptions. The best that can be said is that the interaction between the teachers' NOSI conceptions and learners' NOSI conceptions is weak.

8.3 The nature of interaction between teachers' understandings of NOSI and their practices when teaching investigations

This study set out to addresses the question: What is the nature of the interaction among the teachers' understandings of the NOSI, and their instructional practices when teaching investigations? This section focuses on teachers conceptions of the NOSI and their teaching practices when teaching investigations. This study focused on teachers' teaching actions around laboratory activities during the teaching of investigations. The importance of the laboratory to science teaching was acknowledged. It was pointed out that first, lab activities are a central part of knowledge construction in science hence an essential area for identifying teachers' NOSI conceptions and underlying teaching actions. Secondly, the

centrality of investigations in school science teaching, and the importance of investigations in nurturing learners' ideas about the NOSI were recognized. The understanding of teachers' practices and perspectives when teaching investigations was done within these contexts.

As mentioned earlier, the small teacher sample made it impossible for any meaningful statistical testing to be conducted. An analysis is made of the interaction between teachers' conceptions of the NOSI and laboratory instructional practices as determined from interviews and lesson observations data. This analysis is purely qualitative and shows an interesting pattern. The pattern can best be represented in table form as shown on Table 8.4.

Table 8.4: Summary of observed teachers' NOSI views and their laboratory instructional practices

Teacher	Teachers' NOSI views category	Instructional practice (level of inquiry
Ranelo	Poorly adequate (naive)	Medium
Hedwick	Highly adequate (informed)	Low
Jairos	Highly adequate (informed)	Very high
Johnny	Poorly adequate (naive)	Very low
Booi	Moderately adequate (transitional)	Low

Examination of Table 8.4 shows that one teacher (Jairos) whose understanding of NOSI can be considered evidently highly adequate (informed) shows instructional practice which can also be described as of relatively high inquiry. The other teacher (Johnny) whose conceptions of NOSI can be considered poorly adequate (naive) shows instructional practice which can be described as very low inquiry. One would be tempted to support Sandoval (2005) and Schwartz, et al. (2004) and say there is a relationship between holding informed views about the NOSI and practicing more open-ended laboratory instruction and also say the interaction between these two variables exists. Existing in the sense that two out of five teachers have matching NOSI views and instructional practices. Another interesting point is that the categorization of teachers' instructional practices done by the

Teacher Perception of Classroom Inquiry (TPCI) instrument is not much different from that coming out of the lesson observations. If, as Fraser (1998a) suggested, teacher perceptions are a reliable indicator of their classroom practices, then the interaction of teachers' NOSI conceptions into practice can be taken as existing to some extent. Such generalizations however, are 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 from the observed lessons.

Ranelo, Hedwick and Booi appear to believe there is some bias in observations hence their responses to probes and interview questions were laced with the idea that observations are necessarily subjective. The three teachers said:

Ranelo: Observations are based on theories. However, we choose what to observe, for example, during a practical investigation, we do not observe all.

Hedwick: Observations are based on theories an individual knows. So we observe differently basing on what we know.

Booi: Observations confirm theories and thus are limited to what we want to know.

These views however appear to only feebly interact with instructional decision-making and eventual instructional practice. In their practices, Ranelo, Hedwick and Booi are seen to struggle against a frigid instructional milieu and still make decisions and do practices they believe can bring about learners' understanding of scientific investigations with little of their views about the NOSI being evidently practiced. Though the teachers were observed organizing group activities and encouraging learners to engage in scientific discourse (Driver, et al., 2000; Duschl, 2000), the highly adequate NOSI views the teachers hold on this tenet did not openly translate into level of inquiry they practiced as depicted by their instructional practices. The informed view regarding the observation NOSI tenet was not evident in the three teachers' practices at all. As discussed in Chapter 7, the three teachers' practices were guided more by their different philosophies of teaching science. For

example, there was little translation of the idea that scientific observations are theory-laden and necessarily selective into teaching practices. Evidence of this weak interaction also comes from the mismatch of practices and responses from Ranelo, Booi and Hedwick when it comes to the NOSI tenet of 'methodology of scientific investigation'. When asked the question "what can you say about the methods scientists use in their investigations or experiments?" The three teachers said:

Ranelo: Scientists employ a variety of methods but for confirmation of results, scientists have to use an orderly step-wise procedure. Then they can be sure of their results after having followed a logical common method.

Booi: Scientists use a variety of methods during investigations to arrive at the same conclusions. No single method is employed.

Hedwick: There are so many methods of doing investigations. Some discoveries are made by accident (e.g. penicillin). I understand the structure of benzene was discovered based on a dream. Many methods can be used as long as the scientists get a solution to their problems.

The three teachers' practices again are seen to be in contrast to what they said. Ranelo who can be said to be a conformist, verificationist and objectivist is seen doing exactly the opposite of what he alluded to in the probes questionnaire and interviewing. He does not bog his learners down to the scientific method. He allows his learners to: frame research questions which are a potential resource for teaching and learning of investigations; engage in critical assessment and justification of appropriate procedures and transfers decision-making to his learners. He also ensures his learners develop confidence and investigative skills. As a result, his level of inquiry is rated medium (see, Table 8.4). This is despite the fact that he believed the scientific method should be used to confirm results of an investigation.

Though Booi allowed his learners to frame research questions, he did not allow his learners to engage in critical assessment and justification of appropriate procedures. No varieties of methods were seen employed by Booi during his teaching of practical investigations. Learner interviews did not suggest he varied his teaching strategies either when it comes to practical investigations.

On the other hand, Hedwick who talked of many methods of doing investigations gave her learners step-by-step procedures (which she designed) to follow, based on the scientific method. The new curriculum's emphasis on the investigative approach is in stark contrast to the traditional 'cookbook' approach to practical work seen in Hedwick class where learners followed 'recipes' for the execution of procedures handed down by the teacher without much thought and purpose (Anderson, 2007; Kim & Tan, 2010). To Viechnicki & Kuipers (2006), the educational value of this approach is questionable. As pointed out earlier, when the findings disagree with the theory provided by the textbook, learners often fudge their data in order to get the expected results. This was evident in Hedwick's learners marked practical investigation reports. "The investigative approach to practical work advocates greater learner autonomy" (Department of Education, 2002, p. 1). This notion is promulgated in the South African curriculum. Hedwick advocated structured methods of close-ended inquiry (Banchi & Bell, 2008). From this observation; one can learn that simply asking teachers to engage learners in some investigative activities does not necessarily translate into their practicing high levels of open-ended inquiry. This confirms Hodson's (2001) observation that teachers do not do in laboratories what they say they intend to do. Thus, there is a mismatch between a teacher's rhetoric and classroom behaviour that can send mixed messages to learners. However, Jairos and Johnny had matching instructional practices and NOSI conceptions regarding the two tenets discussed above when teaching investigations.

Ranelo appears to also hold strong naive views about science as progressing through consensus and that scientists are not creative. He does not think that scientific knowledge is a product of imagination and creativity because both human creativity and imagination are

in conflict with scientists' objectivity. This realist view however appears to only weakly interact with his instructional decision-making and eventual instructional practice. When asked, "From what you do during Physical Science practical investigations, what can you say about the use of imagination and creativity in science?''Ranelo said:

> Ranelo: Scientists don't use imagination or creativity because they won't be able to prove what they would have come up with. I do the same, I do not use it and I encourage my learners not to use it because it interferes with objectivity. Science is all about proving facts.

Interestingly, Ranelo was captured on camera articulating the fact that his learners should use creativity and imagination so as to be able to justify their procedures and interpret their results and in so doing their investigative reports shall be informative. Ranelo said:

> Hey, class! Be creative and use your imagination. You need to be innovative in your investigations just like what scientists do ...your reports will tell if you have been creative or not."

The same contradicting issues are also raised and observed with teacher Hedwick. In responding to the probes questionnaire, Hedwick said "Dalton used imagination when interpreting data ... so scientists do use imagination and creativity when creating new knowledge". She reiterated the same informed view during interviewing. However, in her teaching of investigations, she did not even attempt to let her learners use imagination and creativity again confirming Hodson's (2001) observation that teachers do not in laboratories what they say they intend to do.

Relatively, only Jairos is seen giving the appropriate conditions that enable the practice of inquiry to flourish in the classroom. In his practice, he is to give learners a feel of inquiry, as he understands it. This is might be as a result of the fact that Jairos believes "the major characteristic of a scientist" is "the practice of the inquiry approach". At least he attempts to make his learners ask or frame research questions for investigations, use tools, collect data,

analyze data, process answers and explain, predict and communicate results as well as identify assumptions and use of logical and critical thinking (Songer, et al., 2003). As the teachers' instructional practices and the interview transcripts suggest, teacher instructional practices appear to be a balance between their own philosophy of teaching science, the nature of the curriculum, assumptions, beliefs or sub-belief system, or even attitudes. Some of the teachers' NOSI views, however, (e.g. Jairos's) appear to filter onto the practice.

The findings from this study suggest that the translation of a teacher's NOSI views into instructional decision-making and practice suffers from some other external influence(s) such as; the teacher's philosophy of teaching science, the nature of the curriculum, assumptions, beliefs or sub-belief system, or even attitudes. The translation of teachers NOSI views into instructional practices is difficult to concretize because of these intervening variables or barriers. The fact that some constraints sort of "inhibit" the translation of teacher NOSI views into practice is not surprising. These constraints, according to Martin (1999), have an influence on teacher decision-making and instructional practice. When asked to explain why he does not allow his learners to design an investigation on their own which is the advocacy of open inquiry, Johnny said:

> ...the syllabus is just too long. You can't do practicals as many times as you want...There is no time otherwise you won't cover the whole syllabus by the end of year.

This is an interesting observation signifying the lack of apparent association between teacher views of NOSI and teacher instructional practice. If a teacher's NOSI views are to be translated into practice, internalizing informed views of nature of scientific knowledge becomes a necessary condition for instructionally addressing nature of scientific knowledge (Abd-El-Khalick, 2005).

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 (Gallagher, 2006; Vhurumuku,

et al., 2006) that a teacher harbouring constructivist (highly adequate) views of the NOSI teaches in ways that are completely different from one holding poorly adequate or empiricist views. The fact that a weak relationship was found between teachers' conceptions of the NOSI and their teaching practices appears to give support to this assertion. This result supports the finding of Odgers (2003) who found that teachers' views of science were not strongly related to their teaching practices. In the current study, teachers harbouring both inadequate and moderately adequate views were found to teach in ways, which were designed largely to prepare learners for School-Based Assessment (SBA) tasks. For example, two teachers said:

Johnny: I emphasize more on the scientific method because the District officials want to see the step-by-step format when they are moderating learner practical investigation reports for SBA marks.

Booi: The Department of Education requires the investigation reports to be in the scientific method format as shown in most textbook hence as you saw in my execution of the practical, I tried by all means to follow that and ensure learners will do likewise when they write their reports which are taken to the District offices for moderation.

However, the SBA focus of instruction was slightly weaker in the classes of the teachers holding highly adequate NOSI views, for example, that of Jairos. Not only were teachers' views fragmented and inconsistent, but the views were often not reconciled or associated with descriptions of scientific knowledge and practices.

8.4 The nature of interaction between and among learners and teachers' understandings of NOSI and their practices when teaching investigations

Despite the fact that the NOSI views of a majority of learners' seemed to be fragmented and lacking a coherent framework, it is worth noting that the learners as discussed in chapter five appear to engage quite meaningfully with the

philosophical, methodological and epistemological aspects of the nature of scientific inquiry. When compared with their teachers, it was interesting to find out that in many NOSI aspects, the learners harboured informed views whilst their teachers, for example, Ranelo and Johnny possess naïve views. This is quite unique as other research including from developed countries such as the USA, Australia and Canada indicate the preponderance of naive views of the nature of science and/or scientific inquiry. Teachers were also found to be agents of naïve views. The following excerpt attests to this.

> L1SAInt15: My teacher told us that for scientists to get results that will be recognized internationally by other scientists, one has to use the scientific method. Ever since I started doing Physical Science we have been following this method where you; observe, formulate a problem…

Such naive patterns are highly unlikely to be attributed to chance but it is most likely that these teachers have been *explicitly* exposed to these naive ideas about the scientific knowledge, for example, through introspection of Ranelo's argument on the notion of one method of science. However, some of the teachers informed views (e.g. Jairos and Hedwick's) of the NOSI were seen to be translated into learners' NOSI conceptions especially regarding the use of imagination and creativity in scientific investigations and the social and cultural embeddedness of scientific knowledge. The interactions were looked at in a reciprocal manner and from the evidence gathered, there is no single instance where learners' NOSI conceptions were seen to be informing teachers' NOSI views and instruction. However teachers' NOSI conceptions were found in some instance to influence how they plan and teach scientific investigations. For example, Ranelo does not include issues of creativity and imagination when planning and teaching scientific investigations. Looking at interaction among all the three variables, it was found that the relationships are weak and not even simplistic but quite complex. A question then is raised "Is enough happening to improve understanding of the NOSI?" Findings from this study suggest that not enough is being done to improve both teachers' and learners' understanding of the NOSI. The source is traced back to countless

issues bombarding the state of science education in South Africa which according to Kriek and Grayson (2009) is a cause for concern. Considering troubles of South African science education as highlighted by Robinson (1999) in the introductory chapter, explicit programmes about the NOSI need to be introduced in university programmes which are the only institutions of teacher training after the closure of teacher training colleges.

8.5 Discussion

This study set out to investigate the relationships between' learners' NOSI conceptions and their perceptions of classroom inquiry; learners' NOSI conceptions and their teachers' NOSI conceptions and teachers' conceptions of the NOSI and their instructional practices. The analysis of the gathered data, suggests that such relationships are far from being direct or simple. The results from this study do not fully support the assumption that such relationships might actually exist.

The results of this study do not fully support the idea that learners' NOSI views are linked to their perceptions of laboratory instruction. This is in contradiction to the findings of Patel, et al. (2009), Songer and Linn (1991) and Tsai (1998a; 2003a; 1999) who found that constructivist (informed) learners tend to see their laboratory work as doing science compared to empiricists (naïve conceptions). This is despite the fact that quantitative results produced from the relationship between learners' laboratory work experiences (as measured by LPCI scores from all learners in the 5 schools) and their conceptions of NOSI (as measured by the LUSSI open-ended response scores) show a low or weak correlation. Additionally, analyses of learners' interview scripts fail to fully support the NOSI conception's and perception linkage. The low correlation coefficient suggests that learners' NOSI views are at best only very weakly related to how they perceive the nature of inquiry in their laboratory work. This would agree with the findings of Saunders, et al. (1999) and call into question the assumed association between learners' NOSI views and perceptions of laboratory instruction.

What this could mean is that the way the learners reflect on their laboratory work experiences and the way they look at NOSI might not be related to each other. There is also the possibility that the results of the current study are influenced by the small samples of learners taken from each school at least for the quantitative data. This calls for a need for more studies in examining this relationship with larger sample sizes. The weak relationship between learners' NOSI conceptions and their perceptions of laboratory inquiry could also be suggestive of some variables interfering with the relationship. Learners' responses to interview questions and classroom observation data suggest that the interaction between these two variables is not a straight forward affair but a complex entity influenced by another factor or other factors. These factors might include; the nature of laboratory instruction (which in this case is the object of perception) and the nature of curriculum- the fact that investigations are assessed might be of importance.

Questions arise about whether the results obtained here would be similar with other disciplines, e.g. Biology. It would also be interesting to investigate the relationship between learners' NOSI views and their perceptions of laboratory inquiry in Biology. In his doctoral study, Schwartz (2004) showed that the science epistemological views of practising scientists did not differ according to the scientists' disciplines or investigative approaches, but showed variations that depended on the individual scientist's context and experience. Could it be the same for South African secondary school learners?

An interesting finding from this study is that there was a stronger correlation between learners' laboratory work experiences (as measured by LPCI total scores) and their understandings of NOSI (as measured by the LUSSI open-ended response total scores) when females only were considered. The correlation was almost non-existent for males. In other words female learners reported slightly higher levels of laboratory work experiences compared to their male counterparts. This raises the issue of why females and males should perceive the same laboratory classes differently? These results however, contradict the findings of other studies (Burkam, Lee, & Smerdon, 1997; Cheung, 2009; Vhurumuku, 2011) which showed no diffferences in the way males and females perceived their

laboratory classess. This calls for further investigations. As mentioned earlier, this study was based on a relatively small samples, it is recommended that more studies with larger samples be done in order to help clarify the issue of whether a linkage actually exists between learners' NOSI views and their perceptions of laboratory inquiry and whether gender is an issue here. There is need to utilize both quantitative and qualitative methodology to fully understand these interactions.

A careful study of the theory and practice of science education reveals numerous instances where invalid assumptions have been used and/or taken on faith as true. One such assumption is that teachers' conceptions of the NOSI are related to their learners' conceptions (Lederman, 1992). The findings of this study do not support the association between teachers' conceptions of the NOSI are related to their learners' conceptions. It appears that learners do not necessarily learn through "osmotic flow" from their teachers. Overall, it was found that there was a mismatch between learners' and teachers' NOSI conceptions except for a few instances. The interaction between learners' and teachers' NOSI views was found to be weak.

It is not surprising that the majority of the learners in this study were found to harbour NOSI views which were fragmented and lacked a coherent framework. These views were compartmentalized with few or no bridging connections. Not only were learners' views fragmented and inconsistent, the views were also often not associated or reconciled with acceptable or desirable conceptions of NOSI. The learners harboured inadequate views such as: scientific observations and interpretations are objective and theory free, science is culture free, there is one method of science, scientific knowledge is sourced from observation and experiment only, scientific theories develop into laws, scientists are humans of with extra-ordinary intelligence and that science is entirely empirically based knowledge. These findings are consistent with findings from studies around the world(Lederman, 1992; Lederman, 2007a) which have consistently shown that high school learners harbour largely inadequate (naive) views about the NOSI. Most of the teachers in this study were found to harbour some NOSI views which can be described as fluid and

lacking coherence. Some of their views were in contrast with desirable and contemporary views such as: scientific observations are subjective and theory-laden, scientific knowledge is a product of human creativity, imagination and serendipity, there is no one method of science, science is not culture free, and that science is just another human enterprise.

As mentioned some previous studies (Bosman, 2006; Yerrick, Ambrose, & Schiller, 2008) have pointed towards teachers' harbouring of highly adequate (constructivist) views as meaning engaging in teaching practices that are also constructivist or open-inquiry oriented. The results of this study do not fully support that this. Teachers' understandings of the nature of scientific knowledge have been said to be the most important factors in governing teachers' instructional decisions (Barak & Shakhman, 2008; Lederman, 1992) and action agendas. They are said to ultimately determine the nature of instruction the teacher will put into practice (Mohamed, 2006; Richardson, Anders, Tidwell, & Lloyd, 1991; Schraw & Olafson, 2002). However, from this study, it would appear that teachers significantly alter the implementation of their curricula to be in congruency with their own teaching contexts and their philosophies of teaching (Blumenfeld, Krajcik, Marx & Soloway, 1994). This study shows that teachers' NOSI views only weakly translate into, or influence their instructional practice.

In their review of studies of teachers' understandings of the nature of scientific knowledge, Abd-El-Khalick and Lederman (2000b) and Lederman (1992), have suggested that the translation of teachers conceptions of the NOS and NOSI into classroom practices is constrained by such variables as pressure to cover content, resources, examinations and motivational requirements. Findings from this study seem to support results from these studies. From interviews and classroom observations, two main constrains which came out so clearly are the nature of the curriculum and the nature of instruction. Abd-El-Khalick and Lederman's argument is based on the pre-supposition that such a translation must necessarily result in teacher practices that promote desirable learners NOSI conceptions (informed or contemporary understandings). Another interesting finding from the observations is that irrespective of the teacher's NOSI understandings being inadequate or

highly adequate teachers were also found to be using two strategies of laboratory instruction. Both strategies did not appear to raise the level of inquiry. One way was the teacher starting by giving learners practical investigation activities and then following it up with discussion of the theory behind the practical or experiment. Booi and Johnny used this strategy. The other strategy is that the teacher would start by discussing the theory and doing some problem solving behind the investigation and then asking the learners to do the practical. Jairos, Ranelo and Hedwick used this strategy. Teachers using either of the strategies appeared to be convinced that it was the best way to prepare learners for the SBA tasks. In either case, however, the appeared to be no direct link to the teachers' NOSI conceptions.

Teacher instructional practices and his/her understandings of the NOSI cannot easily be equated blow by blow. While it is true to say that learners experience what the teacher practices (plans, organizes and implements) the effect of that practice might vary from one learner to the next. Learners 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 learners do and experience is actually a direct result of the teacher's actions. This is a further complication in the teacher instructional practice, learner experiences and teachers' conceptions of the NOSI equation. The divide line between what the teacher does (the instructional practice) and what the learners actually experience as a result of the instruction is a minuscule and also difficult to locate and concretize. Interviews and classroom observations showed that for most of the teachers, their own laboratory practices were divorced from their views of nature of scientific inquiry and from both their learners' perceptions of inquiry and conceptions of NOSI. This supports the growing body of research (Gess-Newsome & Lederman, 1995b; Smith & Neale, 1989) which indicates that the relationship between teachers' conceptions of NOSI and their classroom practice is far from being understood.

8.6 Conclusion

The findings of this study reveal that interaction among learners' NOSI conceptions and their perceptions of classroom inquiry; learners' NOSI conceptions and their teachers' NOSI conceptions and teachers' conceptions of the NOSI and their instructional practices appears not to be simplistic but quite a complex system. The complex system appears to be brought about by the interplay of a set of variables such as; 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 learners and teachers (Songer, et al., 2003). This creates a complication which goes beyond the scope and argument raised in this exploratory thesis.

CHAPTER NINE

Conclusions, Implications and recommendations

9 Introduction

This study set out to investigate the interactions among: learners' NOSI conceptions and their perceptions of classroom inquiry; learners' NOSI conceptions and their teachers' NOSI conceptions and teachers' conceptions of the NOSI and their instructional practices teaching investigations. Within that effort the study also sought to unveil, and illuminate the sampled school teachers' and learners' conceptions of the NOSI. Additionally, the study sought to investigate the nature of teacher instructional practices when teaching investigations. It examined the extent to which teachers practiced scientific inquiry when teaching investigations. Of interest was the NATURE of interactions among/between the three investigated variables; learners' conceptions of the NOSI, teachers' conceptions of the NOSI and teacher instructional practices when teaching investigations.

The pieces of evidence gathered suggest that the interactions between and among the investigated variables are either non-existent or weak. It was found that the interactions were far from being a direct or simple straight forward affair, but a complex entity influenced by other factors in the instructional environment. These factors include: the nature of curriculum, pressure to cover content, examinations, assessment demands, motivation, materials, learning orientation, and the nature of instruction. In this concluding chapter, the major findings, conclusions, implications and recommendations of the study are summarized. Limitations of the study are also highlighted.

9.1 Conclusions

Learners NOSI conceptions

Analysis revealed that learners hold inadequate views on some NOSI aspects and extremely adequate views on others. This study has found that sampled learners held mixed NOSI

views that ranged from inadequate (naive), moderately adequate (transitional) to adequate (informed) in all six NOSI aspects that were explored. The percentages though varied from one NOSI aspect to the other. Also consistent with prior research findings is the result that participant's NOSI views were not related to their gender (see, e.g. Lederman, 1992; Şahin & Köksal, 2010; Tsai, 2006; Tsai & Liu, 2005a; Vhurumuku, et al., 2006). The lack of association between gender and learners' understandings of the NOSI from this study contradicts the finding of Saunders, Cavallo, & Abraham (1999) whose study although with College Chemistry students showed that epistemological beliefs were correlated with gender. Examples of learners' NOSI views which were inadequate subscribe to such notions as: scientific observations and interpretations are objective and theory free, science is culture free, there is one method of science, scientific knowledge is sourced from observation and experiment only, scientific theories develop into laws, scientists are humans with extra-ordinary intelligence and that science is entirely empirically based knowledge. However, some learners' views were adequate and subscribe to notions such as: scientific observations are subjective and theory-laden, scientific knowledge is a product of human creativity, imagination and serendipity, there is no one method of science, science is not culture free, and that science is just another humane enterprise. Learners' views were 'internally' inconsistent, fragmented and fluid. Very few or no connections seemed to bridge their conceptions.

Teachers NOSI conceptions

Overall, the teachers' NOSI views were found to be fluid and lacked coherence. Although all participants expressed some views that were consistent with current acceptable conceptions of NOSI, some held inadequate (naive) views of some NOSI aspects, including the role of laws and theories in guiding scientific research, the theory-laden nature of observations, the existence of a universal, step-wise ''Scientific Method" and the relationship between categories of scientific knowledge. One teacher, Johnny, was found to hold naïve views of science in at least four NOSI tenets. Then there is Ranelo who did not think that scientific knowledge was a product of imagination and creativity because both

human creativity and imagination are in conflict with scientists' objectivity. This view can be described as "realism". Ranelo was found to base his thinking on the belief that there exists an objective truth about nature that is independent of one's thinking. This made Ranelo a realist. Overall, two of the teachers, Ranelo and Johnny, were considered to hold more static, objectivist/ empiricist-aligned views as they held poorly adequate views on at least four of the six NOSI issues except 'ways scientists validate new knowledge' and 'the social and cultural embeddedness of scientific knowledge' for Johnny. Booi was considered fairly constructivist. He displayed moderately adequate views on all six issues except 'role of laws and theories in science' and 'the nature of scientific interpretations'. He also believed that scientific knowledge was obtained through a variety of methods hence classified as a research methodologist. Jairos and Hedwick were categorized as holding more dynamic, relativist/constructivist-oriented views as they held highly adequate views in all six NOSI aspects.

The observation and inferences NOSI aspect produced interesting results from the sampled teachers. Not only were teachers' views fragmented and inconsistent, but the views were often associated with adequate conceptions of NOSI and scientific practices. It is this fluidity and lack of coherence of views which makes these findings interesting and significant. In addressing the study's second sub-research question which says; what are teachers' understandings of the NOSI?

Overall, this study found that sampled teachers held mixed NOSI views that ranged from static, empiricist-aligned views, fairly constructivist views to dynamic, constructivist-oriented views when all six NOSI aspects are considered.

Teacher instructional practices

Findings from this study show that teachers' practices varied from teacher to teacher and from one inquiry dimension to the other. Generally, the five teachers were found to practice low levels of scientific inquiry based on the following:

- learner autonomy was limited by the nature of the curriculum and assessment requirements;
- failure by teachers to focus and support learners at the initial stages of investigations;
- learners rarely allowed to engage in the kind of laboratory interactions which can be described as promoting scientific argumentation;
- failure by teachers to monitor the groups though teachers tended to encourage group activities. As a result group discussions were not focused;
- learners rarely allowed to engage in the kind of laboratory interactions which can be described as promoting scientific argumentation; and

Overall, the five teachers varied considerably in how they attempted to engage learners in the active search for knowledge; Johnny and Hedwick advocated structured methods of close-ended inquiry (Banchi & Bell, 2008) while Jairos and Ranelo strived to practice some form of open-ended inquiry (Bell, et al., 2005; Lederman, 2009). Booi's practices were in-between close-ended and medium inquiry

From Chapter 7, the succinct remarks made by the teachers' on their philosophy of teaching science and from the generated five assertions are; Jairos believed school Physical Science has the potential for productive inquiry (produce scientific knowledge like professional Chemistry). As a result, only one teacher (Jairos) therefore practiced what he believes and preaches. For Johnny, the development of learners' understanding of the scientific inquiry was only important if it aided the school-based assessment (SBA) goal. He was found to be a conformist of the scientific method. Hedwick and Booi's views are that in addition to developing learners' understanding of theory, investigations also serve the purpose of developing learners' abilities to manipulate apparatus and chemicals. This the two teachers executed with pride. Ranelo was found to be of the opinion that school Physical Science laboratory work is not very different from the Physical Science practiced by the frontier scientists. He believes learners should not leave the laboratory the same way they entered, and as a result they should gain knowledge. 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.

The gaps between some teachers' and learners' scores were found to be very small and in line with the findings of Tsai (2003a) who reports similar results in his study of Taiwanese learners and teachers. Basing on the findings presented in Chapter 7, Jairos operated at level 2b on the openness to inquiry continuum according to Hegarty-Hazel's (1986) classification of inquiry levels. Ranelo's practices are classified as fairly "open-ended" hence it can be said he operated at level 2a. Hedwick and Booi's practices can be described belonging more on the "close ended" of the continuum and practiced low inquiry, level 1. Johnny's practices can be described as largely "close-ended" in which learners were asked to conduct the investigation based on specific instructions given on a worksheet. Johnny practised at the lowest level of inquiry, level zero (Hegarty-Hazel, 1986).

Interactions among the investigated variables

From Chapter 8, it was found that the interactions among the three investigated variables: learners' understandings of the NOSI and teachers' instructional practices; the nature of interactions between learners' and teachers' NOSI understandings were far from being a direct or simple straight forward affair, but a complex entity influenced by other factors. The best that can be said is that the interaction between the teachers' NOSI conceptions and learners' NOSI conceptions is weak.

While there is a plethora of variables (nature of curriculum, pressure to cover content, motivation, materials, learning orientation, nature of instruction, guidance etc.) that might influence the interactions, classroom observations and interviews pointed to the nature of laboratory instruction (which in this case is the object of perception) and nature of curriculum as the two most common intervening variables possible of weakening the interactions. In sum, the three interactions were found to be weak and there appears to be not enough bases to give credence to the purported linkages. In this way, the study contributes to the conceptions-practice nexus body of knowledge by having employed

quantitative and qualitative methods to understand the purported linkages assumed in literature.

9.2 Recommendations for teaching and learning

If it is accepted that teachers' use of inquiry oriented instruction can be translated into desirable NOSI conceptions among the learners, then there is need to think about reforming the nature of practical work assessment in South Africa's Physical Science at FET level. The teachers observed in this study tend to concentrate only on those activities they know will contribute to the school based assessment (SBA) and the end of year final mark. Should not different practical work assessment models be tried? Bennet and Kennedy (2001) have reported the use of teacher based assessments and visiting examiner approach as possible alternatives to the end of year examination. Is not it high time South Africa thinks along the lines of Bennet and Kennedy's suggestion to improve what learners will take from practical investigations? Moving instruction from a focus on school based assessment (SBA) to an inquiry oriented one might be helpful in the implicit translation of learners' laboratory experiences into more desirable NOSI conceptions. This might help learners to make connections between their own laboratory experiences and the real nature of professional science. Many of the learners in this study did not see what they were doing in their laboratories as the real practice of science. To these learners school science is school science and what the professional scientist did something completely different. Unfortunately some teachers also subscribe to this view. As Chinn and Malhotra (2002) purport, school science inquiry and professional science inquiry may be different but both teacher instructional practices and curricula should be constantly reviewed and reformed in a way as to narrow the gap. This point also holds true for the South African school science education. Teacher instructional practices by South African teachers and the curricula should be reviewed constantly to ensure that what the learners do in school science is closer to professional science. Teacher education preparation programmes in South Africa should equip students with techniques and strategies to narrow between school science inquiry and professional science inquiry. However, as mentioned in the introductory chapter, the South African curriculum assumes that by doing scientific investigations, learners will come

understand the NOSI. As a result, teacher training which is being undertaken by universities due to closure of teacher training colleges seems not to be explicitly addressing the NOSI in their courses. One way would be for South African universities' pre-service and in-service teacher education programmes to change beliefs about the purposes of school science laboratory work. As Lederman (2009) 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.

Given the contrast between this study's teachers, one wonders what it is that can be done to encourage the teachers like Johnny to be more like the Jairos teachers in existing schools? The organisation of workshops and in-service teacher training programmes specifically focusing on curriculum interpretation and improving teacher practices of inquiry can go a long way towards redressing problems of low inquiry in science laboratories. At the same time, such efforts should not be oblivious to the fact that teachers like Jairos can do more to make classrooms sites for higher levels of inquiry, if fewer constraints are placed upon them by the curriculum realities and examination demands. Are examinations and other forms of assessments not impediments to teacher practices of more open-ended inquiry? Should science curricula, such as the NCS of South Africa not be revised for purposes of giving teachers more space to practice open-ended inquiry? Furthermore, the NCS requirement that says only two practicals are assessed per grade level might be sending wrong signals to teachers and teacher practices of more open-ended inquiry therefore it must explicitly be stated that teachers need to do more than just two assessed laboratory investigations per grade level. The organisation of workshops and in-service teacher training programmes specifically focusing on curriculum interpretation and improving teacher practices of inquiry can go a long way towards redressing the identified problems**.**

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 learning understanding of the NOSI, 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 learners and the teachers in the present study have also been identified world wide as threats to the practice of inquiry (Abd-El-Khalick, et al., 2004; Keys & Bryan, 2000; 2001). 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 South Africa that it is not just the practice of inquiry, which is under threat, but also the very existence of laboratory instruction.

Furthermore, if learners doing investigations is to become widespread in South African classrooms, the nature of the support the teacher offers to learners has to be properly defined in the curriculum documents so that learners retain autonomy over the investigations. The five teachers in this study varied considerably in how they attempted to engage learners in the active search for knowledge. From this experience, we learn that simply asking learners to participate in some investigative activities does not necessarily translate into their experiencing of authentic inquiry. It is important for science teacher education programmes (both pre and in-service) to equip teachers with the requisite knowledge and skills for them to engage learners in authentic inquiry activities. While teachers might be aware of curriculum goals and intentions, they might not have the knowhow to translate those goals into instructional action. Science teacher education programmes need to emphasize teaching investigations in ways that explicitly promote learners understandings of the NOSI. This entails exposing teachers to both the NOS and NOSI. Teachers can only practice authentic inquiry if they understand the NOSI. As Cochran-Smith and Lytle (1999) recommended, in-service science teacher training programmes should ensure teachers are taught how to interpret one's own practice and the practices of others. This can go a long way towards making assumptions explicit, and making classroom sites for inquiry.

Additionally, in line with trends in contemporary science education, the Physical Science curriculum needs to be re-examined with the objective of making the NOSI an explicit curriculum goal. This necessitates a reform of the curriculum content. As Abd-El-Khalick

and Lederman (2000a) have recommended, making the teaching of the nature of science and NOSI an explicit curriculum goal can result in improvements of learners' nature of science and NOSI conceptions. Such a reform will have implications for South African science teacher education. For example, the teaching of the nature of science and NOSI is an implicit rather than explicit curriculum goal in most if not all of teacher education institutions. Pre-service and in-service teacher education programmes in these institutions are tailor-made to suit the science curriculum whose goals regarding the teaching of the nature of scientific inquiry are implicit.

Results from this study also give us very strong messages on the theory and practice of science education. The message inherent in the learners' and teachers' interview responses appears to be that the practice of scientific inquiry is being hindered by a plethora of factors amongst them: the nature of the curriculum, the nature of instruction, availability of resources, constraints placed on teachers and too much emphasis on SBA tasks and examinations. This is sad for science education especially as science educators from around the world are producing reports pointing towards this scenario and it continually becomes a global feature. As Duschl (in Abd-El-Khalick, et al., 2004) observed, this could result from lack of a clearly formulated policy about the form of scientific inquiry to be given emphasis in the classroom. Scientific inquiry remains implicitly infused in the South African Physical Science curriculum and pedagogical practices. With this in mind, is it not high time that scientific inquiry is made explicit in the curriculum?

It was evident from the study results that learners and teachers struggled with the distinction between 'observation and inference' and 'laws and theories'. Moreover, no distinction is made anywhere in the curriculum between 'observation and inference' and 'laws and theories'. The existing Physical Science textbooks present observation as a step of practical activities. However, nothing is found in the curriculum regarding the difference between observation and inference. The South African NCS curriculum does not portray the distinction between observation and inference well, though it presents the collection of data as an important step of investigation. The distinction is neither comprehensible

between laws and theories, though most of the investigations suggested by the curriculum investigate generalized relationships, observed or perceived, of natural phenomena under certain conditions (scientific laws). There is no discussion on how to make observations and inferences from the execution of investigations. There is also no discussion on how theories explain laws. This study recommends that explicitness in distinguishing between constructs which make up scientific inquiry tenets is needed in textbooks which are recommended by the South African curriculum.

9.3 Recommendations for future research

A possible area of research is to look with a critical eye at the various intervening variables that were found to influence the relationships between the explored variables: learners' and teachers' NOSI conceptions and teacher instructional practices when teaching investigations. An investigation into one or several of these variables and comparing it (them) with informed NOSI understandings would greatly inform the planning of systemic efforts to address teacher understandings by taking into account extant strengths, if any, of South African Physical Science teachers and/or teacher preparation programmes in relation to NOSI.

The chapter on teachers' instructional practices (Chapter 7) of this thesis attests to the usefulness and niftiness of the Campbell et al.'s (2010) instrument in this study in that it enabled both learners' and teachers' perceptions of their classroom inquiry (their practice of inquiry) to be elicited. Research to further develop the Campbell et al.,'s instrument for purposes of assessing learners' and teachers' perceptions of the nature of inquiry in science laboratories (Physics, Chemistry, Biology) is recommended.

Because of the small teacher sample size it was not possible to get meaningful statistical information about the relationships between demographic variables and teachers and learners' NOSI conceptions. Research continues to look into this relationship and it would be interesting to find out if any relationships exist within the context of the South African educational system. South African FET teachers come from two main sources. Degree

holding teachers are from the South African universities, and teachers from the rest of Africa mainly Zimbabwe, Ghana, Kenya, Malawi and Nigeria It might be interesting to find out whether the instructional practices of these teachers are different from each other.

While a distinction has been made here between NOS and NOSI within the context of the laboratory, it is important to note that in the literature (see, for example, Bell, et al., 2000; Clough & Olson, 2004; Lubben, Campbell, Buffler, & Allie, 2004; Matkins & Bell, 2001) this distinction fails to be that clear cut especially when the issue of what would constitute the tenets of each of these constructs is considered. It will be interesting to examine that relationship within the context of theory lessons an aspect this study has not explored.

This study has not been able to fully explore the relationship between teachers and learners' NOSI conceptions. A number of people have recommended that such a relationship be investigated (Anderson, 2002; Grandy & Duschl, 2007; Keys & Bryan, 2000; McNeill, et al., 2005). It will be interesting to examine that relationship within the context of the laboratory. No attempt was made to explore the learners' and teachers' conceptions of NOSI in the *argumentative resource* (AR) framework which suggests that views of scientific knowledge should be seen as discursive achievements (Roth & Lucas, 1997) that are illustrated through argumentative resources drawn in practice. This can be a subject for further research. It could also be interesting to find out how the Physical Science teachers conduct their theory lessons and what effect this might have on learners' NOSI understandings.

This study has not been able to fully explore the relationship between gender and NOSI conceptions. A number of people have recommended that such a relationship be investigated (Burkam, Lee, & Smerdon, 1997; Cheung, 2009; Vhurumuku, 2011). It will be interesting to examine that relationship within the context of the laboratory. This can be a subject for further research.

9.4 Limitations of the study

There are several limitations to this study. First, the sample was selected and recruited from references and prior contacts. They are not necessarily representative of other teachers and learners within their broad disciplines, specialty areas, or practices who utilize similar pedagogic approaches. There are myriad practices within the broad inquiry practices that are not represented in the present sample. For example, the actual discourse in laboratories when teaching investigations was not investigated. Furthermore, the participants were conveniently and purposefully selected based on specific criteria of expertise. One limitation of this study, therefore, is that the results cannot be generalized and are not representative of the general teacher and learner population. The results are limited to this group of teachers and learners. Caution should be exercised when attempting to extrapolate any of the findings to other populations.

Second, the different numbers of participants within the classes (between 23 and 44 learners per class), as well as the small total sample size for teachers (N = 5), made statistical use for identifying trends problematic. For the reason that this study is exploratory and descriptive in nature, general patterns emerging were elicited through qualitative methods. Differences are therefore based on relative comparisons and in few cases only as a follow up to statistical significance where a relevant statistic was utilized. In addition, the study was not designed with a control group. The low sample size and lack of a control group may raise questions about power and type II error.

Thirdly, the researcher was the main instrument of data analysis. In this way, results as well as analysis are a product of the researcher's interpretation of the data. The interpretation was based on the researcher's knowledge and experience in science and science education. The theory-laden basis for the investigation is a recognized limitation as well as strength. Additionally; the detailed quotations and associated discussions of the results expose the researcher's rationale. This information may help the reader assess the validity of the findings. In sum, an exploratory study is the product of the researcher's perspective, and it

is recognized that a different researcher may identify different features of importance within the same data set.

9.4.1 Methodological Pitfalls

As an effort was made to demonstrate the extraction of learners' conceptions of the NOSI 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 learner's conceptions of the NOSI. The methodological approach used in this study was to try and make inferences about the source of a learner's conceptions of the NOS from what the learner 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 could be made about the Physical Science laboratory being a source of identified learner's conception of the NOSI. The use of classroom observations twinned with interviews appears to be a viable way of understanding learner's conceptions of the NOSI.

Secondly, this study identified and addressed two issues related to methodology. First, review of pertinent literature (Lederman & O'Malley, 1990; Lederman, et al., 1998) has shown that relying solely on Likert scale instruments may not adequately assess learners' views of scientific knowledge. In addition to the available literature, this study has shown that learners' "actual" conceptions of the NOSI (or processes and elements therein of science) may not be fully reflected and elucidated based on certain numerical values. The LUSSI close-ended response section did not produce correlations which were statistically significant with other variables yet the LUSSI open-ended response section addressing the same construct did. This may have suggested that when learners respond to Likert-type questions, they may just tick without giving much thought to the demands of the questions. To acquire a richer understanding of learners' views of NOSI, learners were chosen from three groups (i.e. inadequate, moderately adequate and highly adequate groups) for follow-up interviews based on their scores. More specific interview questions that focused on six dimensions explored in the study were used similar to what Tsai (1998a; 1999) did. The use of interviews appears to be a viable way of understanding conceptions of the NOSI. This

author believes that the methodological approach used in this study could with further development, form the basis for the extraction of learners' and teachers' conceptions of the NOSI.

In this study learners' conceptions of NOSI were found to be related to their gender. It would be interesting to explore how controlling relevant factors may have helped to enhance the validity of these findings to see if plausible significant correlations are produced. This is opposed to other studies (e.g., Cavallo, Rozman, Blickenstaff, & Walker, 2003; Tsai, 2000) who utilized Pearson correlation without controlling other potential factors (e.g., gender and age) when examining the relation between learners' views of scientific knowledge and their learning.

9.5 Conclusion

In this concluding chapter, the major findings, conclusions, implications and recommendations of the study were summarized. Limitations of the study were also highlighted. This descriptive, exploratory and correlational study set out to investigate the nature of learners' conceptions of the NOSI, teachers' conceptions of the NOSI and teacher instructional practices when teaching investigations. As the findings of the study show, sampled learners held mixed NOSI views that ranged from inadequate (naive), moderately adequate (transitional) to adequate (informed) in all six NOSI aspects that were explored. Learners' views were 'internally' inconsistent, fragmented and fluid. Very few or no connections seemed to bridge their conceptions. The investigation of teachers' NOSI conceptions found that overall teachers' NOSI views were fluid and lacked coherence. Although all participants expressed some views that were consistent with current acceptable conceptions of NOSI, some held inadequate (naive) views of some NOSI aspects, including the role of laws and theories in guiding scientific research, the theory-laden nature of observations, the existence of a universal, step-wise ''Scientific Method" and the relationship between categories of scientific knowledge. The investigation of teacher instructional practices when teaching investigations showed that generally the level of inquiry in the studied Physical Science classes is low. Teachers' practices varied from

teacher to teacher and from one inquiry dimension to the other. Generally, the five teachers were found to practice low levels of scientific inquiry. The five teachers varied considerably in how they attempted to engage learners in the active search for knowledge.

When the interactions between variables were considered, both quantitative and qualitative data interpretation revealed some insights into the nature of interaction between learners' NOSI conceptions and their teachers' NOSI conceptions and teachers' conceptions of the NOSI and their instructional practices teaching investigations. It emerged that these interactions between and among the investigated variables are either non-existent or weak. The three interactions were found to be weak and there appears to be not enough bases to give credence to the purported linkages. It was found that the interactions were far from being a direct or simple straight forward affair, but a complex entity influenced by other factors in the instructional environment. For the investigated variables, it is posited that the interaction between variables is under the governance of both the context in which the instruction takes place and some factors already embedded in the teacher's or learner's conceptual ecology. As each variable was discussed, implications and recommendations on these issues were highlighted.

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APPENDICES

Appendix A- LUSSI

Learners Understanding Of Science and Scientific Inquiry (LUSSI) Questionnaire

This questionnaire seeks to find out what your views of science and scientific inquiry are. There is no right or wrong answer. Just indicate what you believe in or think.

Please read each statement carefully, and then indicate the degree to which you AGREE or DISAGREE with the statement by ticking ( ) in the appropriate box choosing from the following: (SD= Strongly Disagree; D= Disagree; U= Uncertain or Not sure; A= Agree; SA= Strongly Agree).

1. Observations and Inferences

Item		SD	D	U	A	SA
A	Scientists' observations of the same event may be different because scientist' prior knowledge may affect their observations.					
B	Scientists' observations of the same event will be the same because scientists are objective.					
C	Scientists' observations of the same event will be the same because observations are facts.					
D	Scientists' may make different interpretations based on the same observations.					

Do you think scientists' observations and interpretations are the same or different? Give reasons for your answer.

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2. Change of Scientific Theories

Item		SD	D	U	A	SA
A	Scientific theories are subject to on-going testing and revision					
B	Scientific theories may be completely replaced by new theories in light of new evidence					
C	Scientific theories may be changed because scientists reinterpret existing observation					
D	Scientific theories based on accurate experimentation will not be changed					

With examples, explain why you think scientific theories do not change OR how (in what ways) scientific theories may be changed.

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3. Scientific Laws vs. Theories

Item		SD	D	U	A	SA
A	Scientific theories exist in the natural world and are uncovered through scientific investigations					
B	Unlike theories, scientific laws are not subject to change					
C	Scientific laws are theories that have been proven					
D	Scientific theories explain scientific laws					

With examples, explain the nature of and difference between scientific theories and scientific laws

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4. Social and Cultural Influence on Science

Item		SD	D	U	A	SA
A	Scientific research is not influenced by society and culture because scientists are trained to conduct "pure", unbiased studies.					
B	Cultural values and expectations determine what science is conducted and accepted.					
C	Cultural values and expectations determine how science is conducted and accepted.					
D	All cultures conduct scientific research the same way because science is universal and independent of society and culture.					

With examples, explain how society and culture affect OR do not affect scientific research.

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5. Imagination and creativity in Scientific Investigations

Item		SD	D	U	A	SA
A	Scientists use their imagination and creativity when they collect data					
B	Scientists use their imagination and creativity when they analyze and interpret data					
C	Scientists do not use their imagination and creativity because these conflict with their logical reasoning					
D	Scientists do not use their imagination and creativity because these can interfere with objectivity					

With examples, explain how and when scientists use imagination and creativity OR do not use imagination and creativity.

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6. Methodology of Scientific Investigations

Item		SD	D	U	A	SA
A	Scientists use a variety of methods to conduct scientific investigations					
B	Scientists follow the same step-by-step scientific method					
C	When scientists use the scientific method correctly, their results are true and accurate.					
D	Experiments are not the only means used in the development of scientific knowledge.					

With examples, explain whether scientists follow a single, universal scientific method OR use different types of methods

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.....
.....

The End

Thank You

Appendix A1- LUSSI open-ended scoring rubric

APPENDIX A: Rubric for scoring LUSSI open responses developed from Liang *et al*. (2009)

Question	Not classifiable	Naïve view (1)	Transitional view (2)	Informed view (3)
1. With examples, explain why you think scientists' observations and interpretations are the same OR different.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based on the rubric descriptions.	Scientists' observations AND/OR interpretations are the same because scientists are objective. OR The response includes misconceptions concerning the nature of science or self-contradicting statements.	Scientists' observations OR interpretations may be different because of their prior knowledge, personal perspective, or beliefs. OR The observations AND/OR interpretations may be different, but failed to provide reasons for justification.	Scientists' observations AND interpretations may be different because of their prior knowledge or perspectives in current science.
2. With examples, explain why you think scientific theories do not change OR how (in what way) scientific theories change.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based on the rubric descriptions.	Scientific theories do not change over time if they are based on accurate experiments or facts. OR The response includes misconceptions concerning the nature of science or self-contradicting statements.	Scientific theories may be changed when experimental techniques improve, or new evidence is produced.	Scientific theories may also be changed when existing evidence is reinterpreted.
3. With examples, explain the nature of and difference between theories and scientific laws.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based	Scientific laws are more certain than theories, or theories become laws when they are proven. OR The response includes misconceptions concerning the nature of science or self-	Scientists FIND theories or laws in nature. OR The student provides valid example(s) of scientific laws and theories without further elaboration.	Scientific theories are well substantiated explanations of natural phenomena or scientific laws. AND Both scientific laws and theories are subject to change.

	on the rubric descriptions.	contradicting statements.		
4. With examples, explain how society and culture affect OR do not affect scientific research.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based on the rubric descriptions.	Science is a search for universal truth and fact which is not affected by culture and society. OR The response includes misconceptions concerning the nature of science or self-contradicting statements	Scientists are informed by their culture and society. Culture determines what OR how science is conducted, or accepted. OR The student simply states that science is influenced by cultural and society without further elaboration	Scientists are informed by their culture and society. Culture determines what AND how science is conducted, or accepted.
5. With examples, explain why scientists do not use imagination and creativity OR how and when they use imagination and creativity.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based on the rubric descriptions.	Scientists do not use imagination or creativity because imagination and/or creativity are in conflict with objectivity. OR The response includes Misconceptions concerning the nature of science or self-contradicting statements.	Scientists use their imagination or creativity in SOME phases of their work, notably in designing experiments or problem solving.	Scientists use their imagination or creativity throughout their scientific investigations.
6. With examples, explain whether scientists follow a single, universal scientific method OR use different types of methods.	There is no response; they state that they do not know; the response does not address the prompt; OR the response cannot be classified based on the rubric descriptions.	There is a single, universal, or step-by-step scientific method that should be used. OR The response includes Misconceptions concerning the nature of science or self-contradicting statements.	Scientists may use different methods, but their results must be confirmed by the scientific method or experiments. OR Student states that scientists use different methods without providing any justification or examples	There is no single, universal step-by-step scientific method that all scientists follow. Scientists use a variety of valid methods (e.g., observation, mathematical deduction, speculation, library investigation, and experimentation).

Appendix A2- Letter from Liang

Letter from Liang

LASALLE UNIVERSITY

SCHOOL OF ARTS AND SCIENCES
Education Department

February 10, 2010

Dear Washington Dudu:

I am writing to give you permission to use and/or adapt the Student Understanding of Science and Scientific Inquiry (SUSSI) instrument with proper citation in your research project. Please feel free to call me at (215) 951-1174 or email me at liang@lasalle.edu for additional information if needed. I look forward to learning more about your research results.

Sincerely,

Ling L. Liang, Ph.D.
Associate Professor of Science Education

Appendix B-Probes

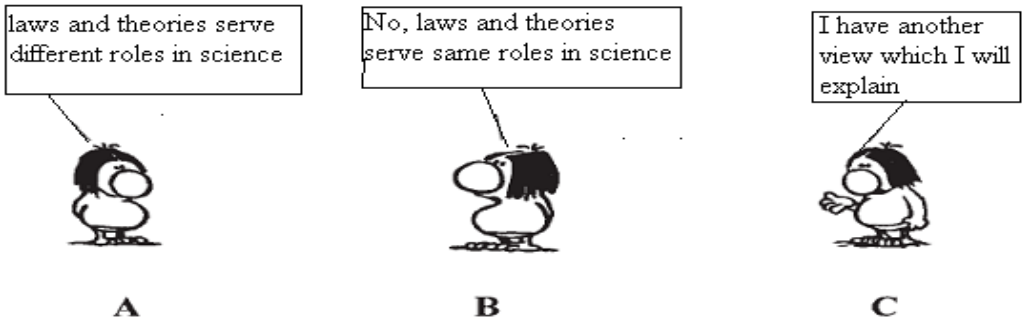
PROBES

The probes below seek to find out what your views of science and scientific inquiry are. There is no right or wrong answer. Just indicate what you believe in or think.

Please read each probe carefully, and then indicate the degree to which you **AGREE** or **DISAGREE** with the statement by circling in the appropriate box choosing from (A, B or C).

Probe 1

You now think about the roles of laws and theories in science



With whom do you most closely agree? (Circle one): | A | B | C |

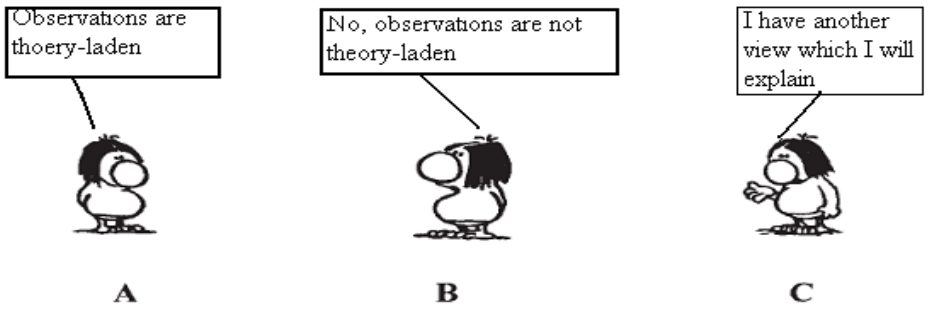
Explain your choice.

_____

_____

Probe 2

You now think about observations you make in science



With whom do you most closely agree? (Circle one): | A | B | C |

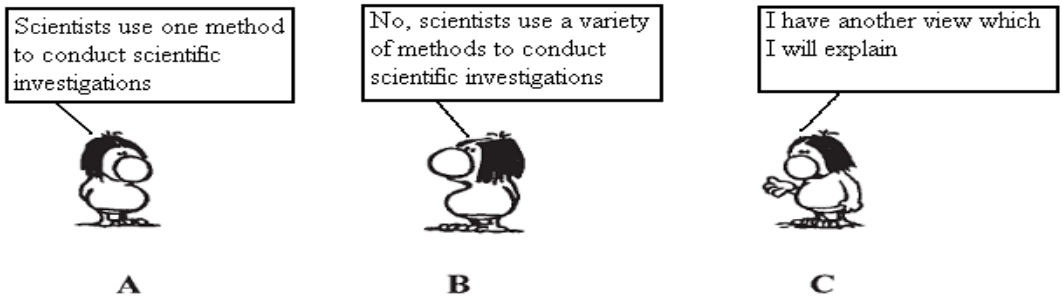
Explain your choice.

_____

_____

Probe

Now you think about methods scientists use to conduct investigations



With whom do you most closely agree? (Circle one): | A | B | C |

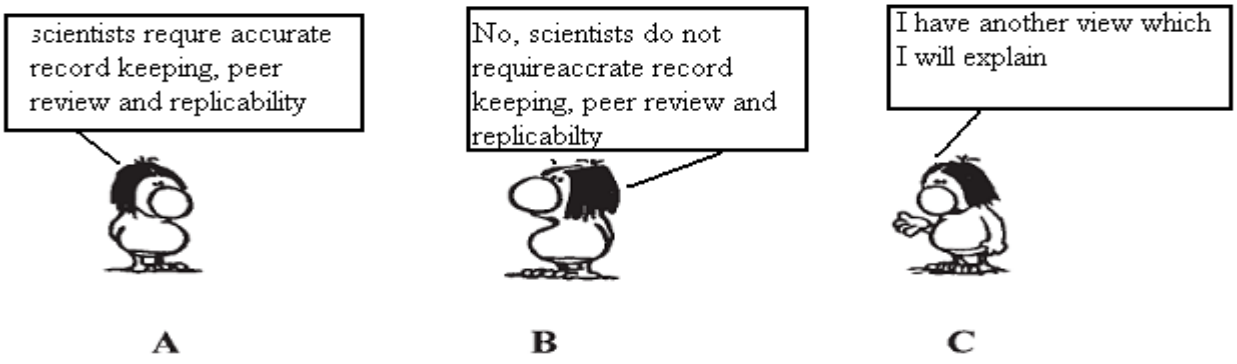
Explain your choice.

_____

_____

Probe 4

Now you think about ways in which scientists validate new knowledge



With whom do you most closely agree? (Circle one): | A | B | C |

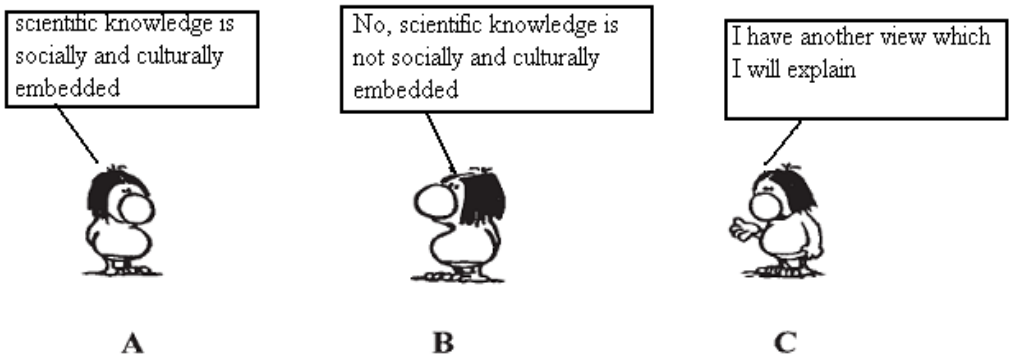
Explain your choice.

_____

_____

Probe 5

Now you think about the nature of scientific knowledge



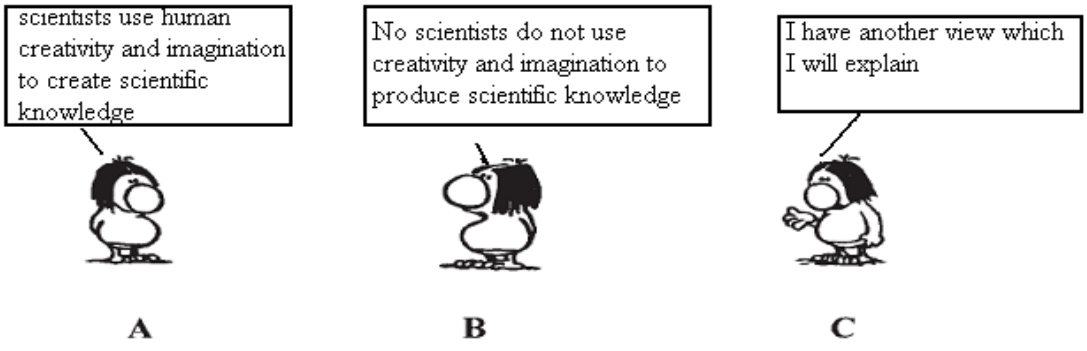
With whom do you most closely agree? (Circle one): **A** **B** **C**

Explain your choice.

P

Probe 6

Now you think about how scientific knowledge is created



With whom do you most closely agree? (Circle one): **A** **B** **C**

Explain your choice.

Appendix C-Learner Perception of Classroom Inquiry

Learner Perception of Classroom Inquiry

This questionnaire wants to find out what you think about what you experience during science lessons. Indicate how often you think each of the activities listed happens during your science lessons by ticking (√) in the appropriate box.

Item		Almost never	Seldom	Some-times	Often	Almost always
A	Learners ask questions/framing research questions: in the science classroom					
A1	I formulate questions which can be answered by investigations					
A2	My research questions are used to determine the direction and focus of the lab					
A3	Framing my own research questions are important					
A4	Time is devoted to refining my questions so that they can be answered by investigations					
B	Designing investigations: in the science classroom					
B1	I am given step-by-step instructions before they conduct investigations					
B2	I design their own procedures for investigations					
B3	We engage in the critical assessment of the procedures that we employ when we conduct investigations					
B4	We justify the appropriateness of the procedures that are employed when we conduct investigations					
C	Conducting investigations: in the science classroom					
C1	I conduct my own procedures of an investigation					
C2	The investigation is conducted by the teacher in front of the class					
C3	I actively participate in investigations as they are conducted					
C4	I have a role as investigations are conducted					
D	Collecting data: in the science classroom					
D1	I determine which data to collect					
D2	I take detailed notes during each investigation along with other data I collect					
D3	I understand why the data I am collecting is important					
D4	I decide when data should be collected in an investigation					
E	Drawing conclusions: in the science classroom					
E1	I develop my own conclusions for investigations					
E2	I consider a variety of ways of interpreting evidence when making conclusions					
E3	I connect conclusions to scientific knowledge					
E4	I justify my conclusions					

Appendix D-Teacher Perception of Classroom Inquiry

Teacher Perception of Classroom Inquiry

This questionnaire wants to find out what you think about what you experience during science lessons. Indicate how often you think each of the activities listed happens during your science lessons by ticking (√) in the appropriate box.

Item		Almost never	Seldom	Some-times	Often	Almost always
A	Learners ask questions/framing research questions: in the science classroom					
A1	Learners formulate questions which can be answered by investigations					
A2	Learners' questions are used to determine the direction and focus of the lab					
A3	Learners' framing their own research questions are important					
A4	Time is devoted to refining learner questions so that they can be answered by investigations					
B	Designing investigations: in the science classroom					
B1	Learners are given step-by-step instructions before they conduct investigations					
B2	Learners design their own procedures for investigations					
B3	Learners engage in the critical assessment of the procedures that we employ when we conduct investigations					
B4	Learners justify the appropriateness of the procedures that are employed when we conduct investigations					
C	Conducting investigations: in the science classroom					
C1	Learners conduct my own procedures of an investigation					
C2	The investigation is conducted for learners by the teacher in front of the class					
C3	Learners actively participate in investigations as they are conducted					
C4	Learners have a role as investigations are conducted					
D	Collecting data: in the science classroom					
D1	I determine which data to collect					
D2	Learners take detailed notes during each investigation along with other data I collect					
D3	Learners understand why the data they are collecting is important					
D4	Learners decide when data should be collected in an investigation					
E	Drawing conclusions: in the science classroom					
E1	Learners develop their own conclusions for investigations					
E2	Learners consider a variety of ways of interpreting evidence when making conclusions					
E3	Learners connect conclusions to scientific knowledge					
E4	Learners justify my conclusions					

Appendix E-Permission from Wits University Human Research Ethics Committee (Non-medical)

Ethics Clearance letter



Wits School of Education

27 St Andrews Road, Parktown, Johannesburg, 2193 • Private Bag 3, Wits 2050, South Africa
Tel: +27 11 717-3007 • Fax: +27 11 717-3009 • E-mail: enquiries@education.wits.ac.za • Website: www.wits.ac.za

Student number: 324944
Protocol: 2010ECE040

19 April 2010

Mr. Washington Dudu
Marang Center
WSoE

Dear Mr. Dudu

Application for Ethics Clearance:

I have a pleasure in advising you that the Ethics Committee in Education of the Faculty of Humanities, acting on behalf of the Senate has agreed to approve your application for ethics clearance submitted for your proposal entitled:

Grade 11 teachers' and learners' understandings of scientific inquiry in relation to instructional practices

The Protocol Number above should be submitted to the Graduate Studies in Education Committee upon submission of your final research report.

Yours sincerely

Matsie Mabela
Wits School of Education

Appendix F- Permission from Gauteng Department of Education (GDE)

Permission from Gauteng Department of Education

Date:	**17 February 2010**
Name of Researcher:	**Dudu Washington Takawira**
Address of Researcher:	*Room A3*
	Private Bag 3
	Wits 2050
Telephone Number:	**0117173414/0731049553**
Fax Number:	**0820994405**
Research Topic:	**South African Grade 11 Teachers' and Learners' Understandings of Scientific Inquiry in Relation to Instructional Practices**
Number and type of schools:	*5 Secondary Schools*
District/s/HO	**Johannesburg East, South, West, North and Ekurhuleni East**

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved to conduct the research. A separate copy of this letter must be presented to both the School (both Principal and SGB) and the District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted.

Permission has been granted to proceed with the above study subject to the conditions listed below being met, and may be withdrawn should any of these conditions be flouted:

1. ***The District/Head Office Senior Manager/s concerned must be presented with a copy of this letter that would indicate that the said researcher/s has/have been granted permission from the Gauteng Department of Education to conduct the research study.***
2. ***The District/Head Office Senior Manager/s must be approached separately, and in writing, for permission to involve District/Head Office Officials in the project.***
3. ***A copy of this letter must be forwarded to the school principal and the chairperson of the School Governing Body (SGB) that would indicate that the researcher/s have been granted permission from the Gauteng Department of Education to conduct the research study.***
4. ***A letter / document that outlines the purpose of the research and the anticipated outcomes of such research must be made available to the principals, SGBs and District/Head Office Senior Managers of the schools and districts/offices concerned, respectively.***
5. ***The Researcher will make every effort obtain the goodwill and co-operation of all the GDE officials, principals, and chairpersons of the SGBs, teachers and learners***

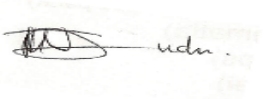
involved. Persons who offer their co-operation will not receive additional remuneration from the Department while those that opt not to participate will not be penalised in any way.

6. ***Research may only be conducted after school hours so that the normal school programme is not interrupted. The Principal (if at a school) and/or Director (if at a district/head office) must be consulted about an appropriate time when the researcher/s may carry out their research at the sites that they manage.***
7. ***Research may only commence from the second week of February and must be concluded before the beginning of the last quarter of the academic year.***
8. ***Items 6 and 7 will not apply to any research effort being undertaken on behalf of the GDE. Such research will have been commissioned and be paid for by the Gauteng Department of Education.***
9. ***It is the researcher's responsibility to obtain written parental consent of all learners that are expected to participate in the study.***
10. ***The researcher is responsible for supplying and utilising his/her own research resources, such as stationery, photocopies, transport, faxes and telephones and should not depend on the goodwill of the institutions and/or the offices visited for supplying such resources.***
11. ***The names of the GDE officials, schools, principals, parents, teachers and learners that participate in the study may not appear in the research report without the written consent of each of these individuals and/or organisations.***
12. ***On completion of the study the researcher must supply the Director: Knowledge Management & Research with one Hard Cover bound and one Ring bound copy of the final, approved research report. The researcher would also provide the said manager with an electronic copy of the research abstract/summary and/or annotation.***
13. ***The researcher may be expected to provide short presentations on the purpose, findings and recommendations of his/her research to both GDE officials and the schools concerned.***
14. ***Should the researcher have been involved with research at a school and/or a district/head office level, the Director concerned must also be supplied with a brief summary of the purpose, findings and recommendations of the research study.***

The Gauteng Department of Education wishes you well in this important undertaking and looks forward to examining the findings of your research study.

Kind regards

Pp Nomvula Ubisi
Martha Mashego
ACTING DIRECTOR: KNOWLEDGE MANAGEMENT & RESEARCH

The contents of this letter has been read and understood by the researcher.	
Signature of Researcher:	
Date:	17/02/2010

Appendix G- Primary Documents tables-Codes and Quotations (LUSSI and Probes)

Primary Documents tables from Atlas.ti for LUSSI and probes' responses

CODES-PRIMARY-DOCUMENTS-TABLE (CELL=Q-FREQ)
Report created by Super - 2011/10/30 08:19:12 PM
"HU: [C:\Documents and Settings\a0020689\Desktop\PhD Thesis-Analyzing LUS...\LUSSI an Probes Analysis.hpr6]"

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PD-Filter: Primary Doc Family "Teachers-Probes" [6]
Quotation-Filter: All [30]

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PICISIT-CSK2-Imagina	1	0	0	0	0	0 1
PICISIT-CSK5-Imagina	3	0	0	0	0	0 3
PMOSIT-MSCI1-Not cod	0	1	0	0	0	0 1
PMOSIT-MSCI1-Scienti	0	1	0	0	0	0 1
PMOSIT-MSCI3-Differe	0	2	0	0	0	0 2
PMOSIT-MSCI5-Variety	0	1	0	0	0	0 1
POST-ObS1-Not codeab	0	0	1	0	0	0 1
POST-ObS5-Theory-lad	0	0	4	0	0	0 4
PRLTST-LT2-Same role	0	0	0	1	0	0 1
PRLTST-LT3-Laws more	0	0	0	1	0	0 1
PRLTST-LT7-Theories	0	0	0	3	0	0 3
PSCIOST-NSK1-Not cod	0	0	0	0	1	0 1
PSCIOST-NSK2-Science	0	0	0	0	1	0 1
PSCIOST-NSK3-Science	0	0	0	0	1	0 1
PSCIOST-NSK4-Culture	0	0	0	0	1	0 1
PSCIOST-NSK5-Society	0	0	0	0	1	0 1
PWVSKT-WSVNK3-Record	0	0	0	0	0	3 3
PWVSKT-WSVNK4-Review	0	0	0	0	0	1 1
PWVSKT-WSVNK5-Commun	0	0	0	0	0	1 1
Totals	5	5	5	5	5	5 30

CODES-PRIMARY-DOCUMENTS-TABLE (CELL=Q-FREQ)
Report created by Super - 2011/10/30 08:17:06 PM
"HU: [C:\Documents and Settings\a0020689\Desktop\PhD Thesis-Analyzing LUS...\LUSSI an Probes Analysis.hpr6]"

Code-Filter: All [126]
PD-Filter: Primary Doc Family "Learners-Probes" [6]
Quotation-Filter: All [1002]

	PRIMARY DOCS						
CODES	6	8	10	12	14	16	Totals
PICISIL-CSK0-No resp	0	6	0	0	0	0	6
PICISIL-CSK1-Not cod	0	27	0	0	0	0	27
PICISIL-CSK2-Imagina	0	43	0	0	0	0	43
PICISIL-CSK3-Imagina	0	39	1	0	0	0	40
PICISIL-CSK4-Imagina	0	8	0	0	0	0	8
PICISIL-CSK5-Imagina	0	44	0	0	0	0	44
PMOSIL-MSCI0-No resp	0	0	4	0	0	0	4
PMOSIL-MSCI1-Not cod	0	0	17	0	0	0	17
PMOSIL-MSCI2-Single,	0	0	22	0	0	0	22
PMOSIL-MSCI3-Differe	0	0	62	0	0	0	62
PMOSIL-MSCI4-Differe	0	0	3	0	0	0	3
PMOSIL-MSCI5-Variety	0	0	58	0	0	0	58
POSL-ObS0-No respons	0	0	0	7	0	0	7
POSL-ObS1-Not codeab	0	0	0	23	0	0	23
POSL-ObS2-Not theory	0	0	0	50	0	0	50
POSL-ObS3-Observatio	0	0	0	48	0	1	49
POSL-ObS4-Theory-lad	0	0	0	18	0	0	18
POSL-ObS5-Theory-lad	0	0	0	21	0	0	21
PRLTSL-LT0-No respon	0	0	0	0	5	0	5
PRLTSL-LT1-Not codea	0	0	0	0	51	0	51
PRLTSL-LT2-Same role	0	0	0	0	16	0	16
PRLTSL-LT3-Laws are	0	0	0	0	43	0	43
PRLTSL-LT4-Different	0	0	0	0	43	0	43
PRLTSL-LT5-Valid exa	0	0	0	0	1	0	1
PRLTSL-LT6-Theories	0	0	0	0	2	0	2
PRLTSL-LT7-Theories	0	0	0	0	6	0	6
PRLTST-LT2-Same role	0	0	0	0	0	0	0
PSCIOSL-NSK0-No resp	0	0	0	0	0	7	7
PSCIOSL-NSK1-Not cod	0	0	0	0	0	28	28
PSCIOSL-NSK2-Science	0	0	0	0	0	64	64
PSCIOSL-NSK3-Science	0	0	0	0	0	43	43
PSCIOSL-NSK4-Culture	0	0	0	0	0	16	16
PSCIOSL-NSK5-Society	0	0	0	0	0	8	8
PWSVNKL-WSVNK0-No re	7	0	0	0	0	0	7
PWSVNKL-WSVNK1-Not c	28	0	0	0	0	0	28
PWSVNKL-WSVNK2-Accur	67	0	0	0	0	0	67
PWSVNKL-WSVNK3-Recor	40	0	0	0	0	0	40
PWSVNKL-WSVNK4-Revie	17	0	0	0	0	0	17
PWSVNKL-WSVNK5-Commu	8	0	0	0	0	0	8
Totals	167	167	167	167	167	167	1002

Appendix H-Primary Documents tables-Codes and Quotations (Interviews)

Primary Documents tables from Atlas.ti for interviews

CODES-PRIMARY-DOCUMENTS-TABLE (CELL=Q-FREQ)
Report created by Super - 2011/10/31 06:45:53 PM
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PD-Filter: Primary Doc Family "Teachers-Interviews" [5]
Quotation-Filter: All [117]

	PRIMARY DOCS					
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SRDI-IV-Communicatio	0	0	0	0	0	0
TCL-NV-What applies	0	0	1	0	0	1
TCT-IV-change with n	0	1	0	1	0	2
TCT-IV-You can only	0	1	0	0	0	1
TCT-NV-Limited room	0	0	1	0	0	1
TDC-They do it in gr	0	0	1	0	0	1
TDC-They do it indiv	1	1	0	1	1	4
TDI-It's also hierac	0	0	0	1	0	1
TDI-Learners design	0	1	0	1	1	3
TDI-Teacher (I) give	0	0	1	0	0	1
TDSL-IV-Laws are exp	0	0	0	1	1	2
TDSL-NV-A law cannot	0	1	0	0	0	1
TDSL-NV-A scientific	1	0	0	0	0	1
TDSL-NV-Theory becom	0	0	1	0	0	1
TDST-IV-theories are	0	1	0	1	0	2
TDST-IV-Theories exp	0	0	0	0	1	1
TDST-NV-A kind of In	0	0	1	0	0	1
TEF-Financial issues	0	0	1	0	0	1
TEF-How to address l	0	1	0	0	0	1
TEF-Lack of time	0	1	2	0	0	3
TEOP-Put learners in	1	0	1	0	1	3
TFRQ-It becomes hier	0	0	0	1	0	1
TFRQ-It depends, som	1	0	0	0	0	1
TFRQ-They frame in g	0	1	0	1	1	3
TFRQ-We get them fro	0	0	1	0	0	1
TICDI-IV-Creativity	0	1	0	0	0	1
TICDI-IV-Imagination	0	1	0	2	1	4
TICDI-NV-There is no	1	0	1	1	0	3
TLAGC-They are strug	0	1	0	0	0	1
TMOSI-IV-There are s	0	1	0	1	1	3
TMOSI-NV-I use the s	1	0	0	0	0	1
TMOSI-NV-More emphas	1	0	0	0	0	1
TMOSI-NV-There is a	1	0	1	0	0	2
TNOP-3 per term but	0	1	0	0	0	1
TNOP-One per term	0	0	1	0	0	1

TOI-IV-Interpretatio	0	1	0	1	0	2
TOI-IV-Observations	1	0	0	0	0	1
TOI-IV-Observations	0	1	0	0	1	2
TOI-NV-Interpretatio	0	0	1	0	1	2
TOI-NV-Observations	0	1	2	2	0	5
TOI-NV-Straightforwa	1	0	0	0	0	1
TPOE-Learners to app	0	1	0	0	0	1
TPOE-NV-For confirma	0	0	1	1	1	3
TPOP-NV-Teacher reit	1	0	0	0	0	1
TPOPW-To augment the	0	0	2	0	0	2
TPOTS-Constructivism	0	1	0	0	1	2
TPOTS-effective teac	0	0	0	1	0	1
TPOTS-start teaching	0	0	1	0	0	1
TROTP-To guide learn	0	0	1	0	0	1
TRPFA-Only one	0	1	0	0	0	1
TRPOTS-I have manage	0	0	0	2	0	2
TRPOTS-Learners part	0	1	0	0	0	1
TRPOTS-to scaffold l	0	0	0	0	1	1
TRR-They record thei	1	1	1	0	1	4
TRR-They record thei	0	0	0	1	0	1
TRRDI-To validate th	0	0	0	0	1	1
TRTLT-They provide r	0	1	0	0	1	2
TRTLT-To provide bac	0	0	1	1	0	2
TRWU-They write and	0	1	0	0	0	1
TSCIOS-IV-Culture de	0	1	1	0	0	2
TSCIOS-NV-In the end	1	0	0	0	1	2
TSCIOS-NV-Letting le	0	0	1	0	0	1
TSCIOS-NV-Science is	0	1	0	0	0	1
TSCIOS-NV-scientists	0	1	0	0	1	2
TSCIOS-TV-Cultural i	1	0	0	0	0	1
TSCIOS-TV-Society de	0	0	0	0	1	1
TSLVT-IV-Theories ex	0	1	0	0	0	1
TSLVT-NV-Learners ca	1	0	0	0	0	1
TSLVT-NV-There is no	0	0	1	0	0	1
TSOG-Available appar	0	0	1	0	0	1
TSOT-I just follow t	0	0	1	0	0	1
TUICSI-IV-Scientists	0	0	0	1	1	2
TWRU-I give them abo	0	0	0	0	1	1
TWRU-They compile on	0	0	2	0	0	2
Totals	15	28	31	22	22	118

Appendix I- Selected Outputs for Inferential Statistics

Selected output tables from SPSS

T-Test

Group Statistics

	Sex	N	Mean	Std. Deviation	Std. Error Mean
Q1	1	59	1.58	.986	.128
	2	108	1.80	1.039	.100
Q2	1	59	1.51	.935	.122
	2	108	1.74	.980	.094
Q3	1	59	.93	.716	.093
	2	108	1.09	.704	.068
Q4	1	59	.98	.841	.109
	2	108	1.31	.934	.090
Q5	1	59	1.59	.985	.128
	2	108	1.45	.858	.083
Q6	1	59	1.42	.969	.126
	2	108	1.63	1.028	.099
Total Score	1	59	8.02	2.707	.352
	2	108	9.03	2.950	.284

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Q1	Equal variances assumed	.503	.479	-1.331	165
	Equal variances not assumed			-1.352	124.799
Q2	Equal variances assumed	.106	.745	-1.488	165
	Equal variances not assumed			-1.508	124.196
Q3	Equal variances assumed	.002	.968	-1.399	165
	Equal variances not assumed			-1.392	117.703
Q4	Equal variances assumed	5.801	.017	-2.272	165
	Equal variances not assumed			-2.343	130.427
Q5	Equal variances assumed	1.608	.206	.953	165
	Equal variances not assumed			.915	106.188
Q6	Equal variances assumed	.909	.342	-1.262	165
	Equal variances not assumed			-1.285	125.629
Total Score	Equal variances assumed	1.734	.190	-2.178	165
	Equal variances not assumed			-2.234	128.370

Correlations

Descriptive Statistics

	Mean	Std. Deviation	N
Sex	1.65	.479	167
School	2.92	1.401	167
Total Score	57.41	6.250	167
Sum 1	11.19	2.053	167
Sum 2	9.72	1.810	167
Sum 3	11.52	2.023	167
Sum 4	12.42	2.084	167
Sum 5	12.56	1.993	167

Correlations

		Sex	School	Total Score	Sum 1	Sum 2
Sex	Pearson Correlation	1	-.176*	.209**	.222**	.051
	Sig. (2-tailed)		.023	.007	.004	.510
	N	167	167	167	167	167
School	Pearson Correlation	-.176*	1	-.201**	-.367**	-.013
	Sig. (2-tailed)	.023		.009	.000	.863
	N	167	167	167	167	167
Total Score	Pearson Correlation	.209**	-.201**	1	.537**	.542**
	Sig. (2-tailed)	.007	.009		.000	.000
	N	167	167	167	167	167
Sum 1	Pearson Correlation	.222**	-.367**	.537**	1	.182*
	Sig. (2-tailed)	.004	.000	.000		.019
	N	167	167	167	167	167
Sum 2	Pearson Correlation	.051	-.013	.542**	.182*	1
	Sig. (2-tailed)	.510	.863	.000	.019	
	N	167	167	167	167	167
Sum 3	Pearson Correlation	.098	-.124	.647**	.061	.188*
	Sig. (2-tailed)	.209	.111	.000	.431	.015
	N	167	167	167	167	167
Sum 4	Pearson Correlation	.095	-.030	.647**	.144	.113
	Sig. (2-tailed)	.223	.700	.000	.063	.146
	N	167	167	167	167	167
Sum 5	Pearson Correlation	.182*	-.081	.757**	.276**	.296**
	Sig. (2-tailed)	.019	.295	.000	.000	.000
	N	167	167	167	167	167

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

T-Test

Group Statistics

	Sex	N	Mean	Std. Deviation	Std. Error Mean
Total Score	1	59	55.64	5.750	.749
	2	108	58.37	6.327	.609
Sum 1	1	59	10.58	2.321	.302
	2	108	11.53	1.816	.175
Sum 2	1	59	9.59	1.652	.215
	2	108	9.79	1.895	.182
Sum 3	1	59	11.25	1.899	.247
	2	108	11.67	2.082	.200
Sum 4	1	59	12.15	2.250	.293
	2	108	12.56	1.983	.191
Sum 5	1	59	12.07	1.902	.248
	2	108	12.82	1.999	.192

Independent samples test

		Levene's Test for Equality of Variances		t-test for Equality of Means	
		F	Sig.	t	df
Total Score	Equal variances assumed	.247	.620	-2.747	165
	Equal variances not assumed			-2.826	129.413
Sum 1	Equal variances assumed	6.531	.012	-2.927	165
	Equal variances not assumed			-2.726	97.388
Sum 2	Equal variances assumed	1.197	.276	-.660	165
	Equal variances not assumed			-.687	133.859
Sum 3	Equal variances assumed	1.065	.304	-1.261	165
	Equal variances not assumed			-1.296	129.039
Sum 4	Equal variances assumed	2.506	.115	-1.224	165
	Equal variances not assumed			-1.179	107.180
Sum 5	Equal variances assumed	.085	.771	-2.377	165
	Equal variances not assumed			-2.412	124.571

Regression

Descriptive Statistics

	Mean	Std. Deviation	N
Total Score	57.41	6.250	167
Sum 1	11.19	2.053	167
Sum 2	9.72	1.810	167
Sum 3	11.52	2.023	167
Sum 4	12.42	2.084	167
Sum 5	12.56	1.993	167

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	Sum 5, Sum 1, Sum 2, Sum 4, Sum 3[a]	.	Enter

a. All requested variables entered.
b. Dependent Variable: Total Score

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	1.000	.000

a. Predictors: (Constant), Sum 5, Sum 1, Sum 2, Sum 4, Sum 3
b. Dependent Variable: Total Score

Appendix J- Inter-rater reliability

Output table for Inter-rater reliability from STATA

```
      name:  <unnamed>
       log:
/Users/Egbon/Documents/Stata/washington
kappa2.log
  log type:  text
 opened on:   9 August 2011, 22:00:10

. use  "washington kappa2.dta", clear

. kap rater1 rater2 rater3 if
dimension== "FQ"

There are 3 raters per subject:

         Outcome |    Kappa          Z
Prob>Z
-----------------+-----------------------
---------
            2.25 |   -0.0909      -0.31
0.6236
            2.25 |    0.4000       1.39
0.0829
            2.25 |    1.0000       3.46
0.0003
            2.25 |   -0.0909      -0.31
0.6236
             2.5 |    0.6571       2.28
0.0114
-----------------+-----------------------
---------
        combined |    0.9385       3.29
0.0005

. kap rater1 rater2 rater3 if
dimension== "DI"

There are 3 raters per subject:

         Outcome |    Kappa          Z
Prob>Z
-----------------+-----------------------
---------
            2.25 |    1.0000       3.46
0.0003
            3.25 |    1.0000       3.46
0.0003
            3.25 |   -0.0909      -0.31
0.6236
            3.25 |    0.1111       0.38
0.3502
             3.5 |    0.4000       1.39
0.0829
-----------------+-----------------------
---------
        combined |    0.9714       3.76
0.0001

. kap rater1 rater2 rater3 if
dimension== "CI"

There are 3 raters per subject:

         Outcome |    Kappa          Z
Prob>Z
-----------------+-----------------------
----
             3.5 |    1.0000       3.46
0.0003
            3.75 |    1.0000       3.46
0.0003
            3.75 |    0.1111       0.38
0.3502
             3.5 |    0.1111       0.38
0.3502
-----------------+-----------------------
        combined |    0.9556       3.33
0.0004

. kap rater1 rater2 rater3 if
dimension== "CD"

There are 3 raters per subject:

         Outcome |    Kappa          Z
Prob>Z
-----------------+-----------------------
---------
            2.25 |   -0.0909      -0.31
0.6236
             2.5 |    0.1111       0.38
0.3502
            2.75 |    0.4000       1.39
0.0829
            2.25 |    1.0000       3.46
0.0003
             2.5 |    1.0000       3.46
0.0003
-----------------+-----------------------
---------
        combined |    0.9714       3.76
0.0001

. kap rater1 rater2 rater3 if
dimension== "DC"

There are 3 raters per subject:

         Outcome |    Kappa          Z
Prob>Z
-----------------+-----------------------
---------
             2.5 |    1.0000       3.46
0.0003
             2.5 |    1.0000       3.46
0.0003
            2.75 |    0.2500       0.87
0.1932
             2.5 |   -0.2000      -0.69
0.7558
-----------------+-----------------------
---------
        combined |    0.9472       3.22
0.0006


log:/Users/Egbon/Documents/Stata/washing
ton
  log type:  text
 closed on:   9 Nov 2011, 22:00:10
```