INVESTIGATING SCIENCE TEACHERS’ PERCEPTIONS OF THE NATURE OF SCIENCE IN THE CONTEXT OF CURRICULUM REFORM IN SOUTH AFRICA

by

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DECLARATION:

In accordance with Rule G4.6.3, I hereby declare that the above-mentioned treatise/ dissertation/ thesis is my own work and that it has not previously been submitted for assessment to another University or for another qualification.

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I would like to thank all those who, through their intellectual, administrative and moral support, contributed to the accomplishment of this degree.

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ABSTRACT

An adequate understanding of the nature of science (NOS) has become increasingly important for science teachers in South Africa as comprehensive curricular reforms over the past decade include promoting informed understandings of the ontological and epistemological bases of scientific knowledge and the methods of science. The main objective of this study was to explore the NOS understandings held by a sample of science teachers in the Eastern Cape Province of South Africa. Data were generated via questionnaires (n=136), semi-structured interviews (n=31), and classroom observations (n=8). The teacher interviews, which were informed by the questionnaire data, enabled further interrogation of the teachers’ philosophical positions. Their classroom practices were examined within the framework of these philosophical positions and the requirements of the new curriculum. The effect of implicit and explicit instruction in NOS on these teachers’ beliefs and classroom activities was also considered. A mixed-method approach informed by positivist and interpretivist perspectives was used for the collection and analysis of the data. The data suggests that explicit instruction in NOS resulted in more informed conceptions of science and the scientific enterprise, and that these conceptions were reflected, to a degree, in their classroom behaviours. However, it was noted that the teachers in this study often held philosophically eclectic views of the nature of scientific knowledge and how scientists develop ideas. Similarly, the South African National Curriculum Statement portrays science in contrasting ways, i.e. often within a modern/realist framework, but in other instances within postmodern/relativistic understandings (particularly in terms of indigenous knowledge systems). As such, an approach which aims at providing a firm foundation for understanding NOS ideas within a modern/realist perspective before emphasising the postmodern/relativist aspects of the scientific enterprise is suggested for teacher training and curriculum development.
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1. Introduction

In past decades science education in South African schools has been in a crisis, with statistics on the science results achieved in the matriculation examinations at the national level over the past few years revealing a depressing scenario (Kahn, 1995; Chisholm, 2005; Christie, Butler, & Potterton, 2007). A very small percentage of learners at the FET level (Grades 10 to 12) have opted for science as a subject of choice and of this small percentage of learners, a small minority qualified to study for science-related programmes at the tertiary level (Asmal, 2000; Christie, Butler, & Potterton, 2007)). The former national Minister of Science and Technology, Mosibudi Mangena stated that only five percent of matriculants left school with sufficient marks in science and mathematics to qualify to study science at university (Daily Dispatch, 2005). A critical area of concern, among others, which contributes towards this abysmal picture, can be attributed to the morale and competency of science teachers (Howie, 2005).

The problems in science education are not unique to South Africa. Many other countries (both developed and emerging) have been experiencing similar problems, prompting education authorities to embark up on sweeping national curricular reforms in science education with the explicit vision of achieving scientific literacy for all citizens (Mathews, 1994). Numerous studies (Klopfer, 1969; National Science Teachers Association, 1982; Lederman, 1992; Schwartz & Lederman, 2002; Wang & Schmidt, 2001; Dekkers,
Ogunniyi, Mosimege & Marenga, 2004; Lederman, 2006) have argued for an adequate understanding of the Nature of Science (NOS) among teachers as a prerequisite for achieving scientific literacy.

Currently the South African education system is going through extensive curriculum changes. The objective of the new science curriculum is a radical shift from the traditional inductivist based and exam-oriented curriculum of the past to one of promoting scientific literacy and the development of critical thinkers who are able to make informed decisions about Science-Technology-Society (STS) related issues in a South African cultural context (Department of Education, 2003). An assessment of the teacher-preparedness in terms of the implementation of the ethos of the new curriculum in science has thus become very important.

2. PHILOSOPHICAL FRAMEWORK

The image of science developed in school education is largely influenced by the epistemology of the nature of science held by science teachers and the way in which science is depicted in the media, and particularly in text books (Gallagher, 1991). Gallagher (1991) argues that science teachers who lack formal education in the history, philosophy and sociology of science reinforce ‘text book science’ which presents the subject simply as a body of knowledge to be comprehended. In contrast, Mathews (1994) strongly advocates for the inclusion of the historical and philosophical dimensions of science in teacher education programmes.

The teaching of science by focussing on theories, laws and principles and verifying some of these theoretical products by contrived experiments provides the learners only with a partial view of science (Lederman, 2006). Practice of this nature does not provide a holistic picture of science and illuminates very little on the nature of the scientific knowledge, how
the knowledge is generated and validated by the community of scientists, the context of
discovery or the ethical issues. The message implied is that science progresses by accretion of
undisputable knowledge.

2.1 Scientific Literacy

The prevailing worldview of science as a difficult, albeit important, subject is not
limited to the South African context, but has a global perspective. The failures of a discipline-
based science curriculum with an emphasis on facts, laws and content resulted in extensive
curriculum reforms being proposed in the 1980s in the US, the UK, Canada, Australia, as well
as in many other countries (Mathews, 1994). The primary objective of the various curriculum
initiatives (e.g., American Association for the Advancement of Science, 1989 and 1993;
National Curriculum Council, 1988 and 1991) was to promote scientific literacy as the goal of
school science education. The rationale for the promotion of scientific literacy is to develop a
society in which the citizens are able to make informed decisions about critical issues
concerning science, technology and society. This assumption is reflected in the AAAS
curriculum initiative Project 2061 (American Association for the Advancement of Science,
1990).

The science-literate person is one who is aware that science, mathematics, and
technology are interdependent human enterprises with strengths and limitations; understands
key concepts and principles of science; is familiar with the natural world and recognises both
its diversity and unity; and uses scientific knowledge and scientific ways of thinking for
individual and social purposes (Rutherford & Ahlgren, 1990).

Although there is no clear definition of scientific literacy (Lederman, 2006), the
various curricular reforms usually espouse knowledge and understanding of three common
themes in science education: (1) science content, (2) the nature of scientific enquiry and (3)
the role of science in society (Osborne, 2001; Bauer, 1994). The extent and depth of content to be covered may vary from one curriculum to another, but the substantial change from the traditional curriculum has been the humanisation of the scientific enterprise – that science is not an accumulation of absolute knowledge by a group of scientists in an isolated social milieu. The new science curricula attempt to help to provide a deeper insight into the historical, philosophical and cultural aspects of science which is of critical importance considering the role of science in contemporary society (Department of Education; 2003).

2.2 The nature of science

According to Meichtry (1993), there is considerable agreement among scientists, science educators and curriculum planners that an understanding of the nature of science is an important component of scientific literacy. Meaningful understanding of science not only includes certain aspects of science content (processes in science, facts, laws and theories) but also an idea of the methods and limitations of scientific inquiry (Driver, Leach, Millar, & Scott, 1996). The latter pertains to the epistemology of scientific knowledge, i.e.:

- How is scientific knowledge generated?
- On what grounds do we consider this knowledge to be reliable and acceptable?
- What are the implications of social, political and economic factors on the development of scientific knowledge?
- What assumptions are held by scientists while they are creating scientific knowledge?

These epistemological questions form the basis for an informed understanding of the nature of science (NOS). The epistemological issues concerning scientific knowledge and creation of scientific knowledge have been debated and researched extensively by
philosophers of science, science educators, curriculum developers and researchers over the past few decades (Lederman, 1992; Lederman 2006). Given the complex and dynamic nature of the NOS, it is not surprising that Alters (1997) and Lederman, Abd-El-Khalick, Bell and Schwartz (2002) suggest that there is neither consensus among philosophers, historians and sociologists regarding a specific definition of the NOS nor a complete agreement on all the aspects that might characterise the NOS. Nevertheless, according to Lederman et al. (2002), there is a current ‘shared wisdom’ and acceptance among philosophers, historians and sociologists of science regarding certain aspects of the NOS, i.e., that scientific knowledge is tentative; theory-laden; is a creation of human imagination and influenced by social and cultural values. In addition to these aspects, they have identified the relationships and functions of scientific theories and laws, the distinction between observation and inference and the myth of the ‘Scientific Method’. Aikenhead and Ryan (1992) suggest that as the NOS can be viewed from various perspectives, this may result in teachers and students holding alternative views of the scientific enterprise.

Four major schools of thought, as recognised by western philosophers, serve to illustrate how this pluralistic perspective may arise, viz. Apriorism, Realism, Empiricism/Logical Positivism and Conventionalism. These positions provide useful scaffolding for discussion of the NOS (Efflin, Glennan, & Reisch, 1999).

McComas, Clough and Almazora (1998) note that the NOS is both a fluid and dynamic concept and the extent to which the above western schools of thought are prioritised depends on the cultural and historical contexts. However, cultural contexts can change over time, as illustrated by the changing perceptions of the NOS in the European context over the past three centuries (Lederman & O’Malley, 1990; Lederman, 1992). Its interpretation in other cultures, such as those found in the Eastern or African cultures, presents a further set of
challenges (Jegede, 1989; Ogunyi, Jegede, Ogawa & Yandilla, 1995). Beliefs and values, especially when strongly held, introduce a worldview context that is likely to have an influence on interpretations of the NOS (Cobern, 1993).

2.3 South African curriculum statement

The National curriculum Statement currently being implemented in South Africa entails a radical shift from the past content-driven, exam-orientated curriculum to one that emphasises the achievement of Learning Outcomes guided by Assessment Standards which provides a framework for the level and depth of knowledge, skills and values required in each Learning Area (Department of Education, 2003).

The Learning Area of the Natural Sciences (Grades R – 9) in the National Curriculum Statement (Department of Education, 2003) stipulates the promotion of scientific literacy as its purpose. This purpose is embodied in the three Learning Outcomes which lays the framework for developing an understanding of the scientific process skills, problem-solving skills and the impact and interrelationships between science, technology, society and the environment. Similar aims and objectives, i.e., scientific inquiry, problem-solving skills in a broad range of contexts and an understanding of the NOS in relation to science, technology and society form the foundation of the Physical Sciences in the National Curriculum Statement (NCS) for Grades 10 – 12 (Department of Education, 2003).

The Learning Outcomes of the NCS underscore the importance of the study of the NOS. This is reflected in the policy document of the NCS when it states that “the nature of science forms the basis from which learning outcomes have been developed” (Department of Education, 2003: 12) and is further evident when the policy document discusses the relevance of science in matters regarding science, society and the environment. According to the NCS, learners in the Physical Sciences need to develop an understanding of (amongst others):
• The scientific enterprise and, in particular, how scientific knowledge develops;

• That scientific knowledge is in principle tentative and subject to change as new evidence becomes available;

• That knowledge is contested and accepted, and depends on social, religious and political factors;

• That other systems of knowledge, such as indigenous knowledge systems, should also be considered;

• The importance of scientific and technological advancements and to evaluate their impact on human lives.

(Department of Education, 2003: 11)

Appreciation of the rich cultural heritage of African Indigenous Knowledge Systems (IKS), comparing different existing science worldviews and evaluating the epistemic worth of diverse and competing knowledge claims form the essence of Learning Outcome three in the NCS (Department of Education, 2003).

The principles, thematic sequence, and the design of the curriculum both in the Natural Sciences and in the Physical Sciences, allow for the smooth progression of learners from the General Education and Training band (Department of Education, 2002) to the Further Education and Training (NCS) level (Department of Education, 2003). It therefore becomes apparent that the new curriculum in science predicates an informed understanding of the NOS for effective implementation.

3. STATEMENT OF THE PROBLEM

The ontology of teachers regarding science in a pluralistic cultural context of South Africa has important bearing on their classroom practices in science. Given the myriad of
beliefs, ‘proven wisdom’ and cultural practices in understanding nature and phenomena held in developing countries in general, and in the South African context in particular in terms of this study, science as a credible and trustworthy way of knowing presents unique challenges.

The new curricula in school science education in South Africa are grounded in an understanding of the philosophical issues concerning scientific knowledge and its creation and, therefore, it has become imperative for South African science teachers to have an adequate understanding of the key elements of the NOS. This study seeks to investigate Eastern Cape teachers’ beliefs and understandings in terms of the NOS and to explore how these beliefs may influence their teaching of science within the parameters of the new South African science curricula.

4. RESEARCH QUESTION

The main objective of this research study is to explore Eastern Cape teachers’ understandings of the NOS and to investigate how their beliefs may influence the teaching of science within the framework of the new curriculum. The principal question of the study is:

- What understandings of the NOS are held by a sample of science teachers in the Eastern Cape Province, South Africa and how do these understandings impact on their ability to teach science within the framework of the new South African Curriculum?

In attempting to answer the above question the following subordinate questions are considered:

- Can their understandings of the NOS be categorised into mainstream philosophical positions, e.g., apriorism, realism, empiricism/logical positivism or conventionalism?

- What aspects of the NOS are reflected in the classroom practices of the science teachers?
Does explicit instruction in the NOS through an INSET programme, i.e. the BEd (Science and Mathematics Education programme, Nelson Mandela Metropolitan University) change teachers’ conceptions of the NOS?

5. PURPOSE OF THE STUDY

The current study emanates from a previous investigation (Linneman, Lynch, Kurup, Webb & Bantwini, 2003) in which the researcher was involved in exploring the NOS views of a group of 135 senior phase science and mathematics teachers in the Transkei in the Eastern Cape. An investigation of a similar nature, i.e. to explore senior phase teachers’ perceptions of the NOS, has been carried out in the Limpopo Province by Dekkers and Mnisi (2003). This research builds on these studies in terms of gathering meaningful information about teacher-understandings of the NOS and their preparedness in terms of implementing the new curriculum.

Moss, Abrams and Robb (2001) argue that students’ conceptions of NOS do not change by merely engaging them in inquiry-oriented classroom activities. Khishfe and Abd-El-Khalick (2002) believe that reflective inquiry-oriented activities which explicitly focus on the NOS make substantial improvements in students’ understandings of the NOS. Gess-Newsome (2002), Dekkers et al.(2004), Lederman and Lederman (2004) also support the notion that explicit instruction in the NOS contributes towards teachers developing informed understandings of the NOS, which in turn enables them to translate these ideas effectively into their classroom practices. It is for this reason that this study investigates whether explicit instruction in the NOS through an INSET programme, i.e. the BEd (Science and Mathematics Education programme) offered by the Nelson Mandela Metropolitan University (NMMU), affects teachers’ conceptions of the NOS.
6. SIGNIFICANCE OF THE STUDY

Science teaching and learning in South Africa in the past have been characterised by a portrayal of science as a body of knowledge that needs to be memorised for exam purposes (Kahn, 1995). According to researchers (Hodson, 1998; Solomon, Scott & Duveen, 1996; Palmquist & Finley, 1997), what teachers teach, and how they teach it, presents a particular view of science to the students. Teaching only basic principles and laws of science create the impression that science is a rigid and abstract body of knowledge, and choosing mainly content that may be logically deduced from classroom experiments convey the message that science is limited to hypothetical-deductive experimentation that leads naturally to scientific laws. The purpose of the National Curriculum Statement (2003) is to radically change this image of science in South African schools. This is reflected in the Learning Outcomes and the corresponding Assessment Standards of both the initial Revised National Curriculum Statement (Department of Education 2002) and the current NCS curricula (Department of Education, 2003).

If science knowledge and understanding are expected to be broader than the concepts of physics, chemistry and biology, as stated in NCS; and if the processes of science are to be taken seriously as a reference for teaching styles and strategies (Linneman, et al. 2002), then an adequate understanding in key aspects of the NOS is vital. South African teachers need to be aware of the critical role that the NOS plays in the new curriculum if they are to be role players in creating a scientifically literate society in which citizens are capable of understanding and of making judgements on important policy decisions regarding critical issues, for example the current issue of HIV/AIDS and how it is caused (Webb, Cross, Linneman & Malone, 2005).
It has thus become important that for teachers to interpret and effectively implement the new curriculum for the Natural Sciences and the Physical Sciences, an informed understanding of the NOS is a prerequisite. Researchers such as Palmquist and Finley (1997) and Laplante (1997) suggest that for students to develop an adequate understanding of the NOS, teachers should be fully conversant in the notions of the NOS and must consider it as an educational outcome rather than merely assigning it pedagogic importance.

As such this study aimed at investigating teachers’ views regarding the NOS and whether explicit instruction in the NOS produced any meaningful changes in their conceptions. More importantly, classroom observations were carried out to investigate whether their beliefs of the NOS are translated into comparable classroom practice.

7. PARTICIPANTS

The study investigated three groups of teachers’ views and teaching strategies – (i) a group of teachers who were registered on a Bachelor of Education (BEd) in-service teacher upgrading programme offered by the Nelson Mandela Metropolitan University (NMMU) and who had been explicitly exposed to notions of the NOS and (ii) a second group of teachers who were part of the upgrading programme but who had not been explicitly exposed to notions of the NOS (but had experienced lecturers who had a contemporary rather than traditionalist view of the NOS), and a group of teachers who were not part of the BEd programme at all and had not received any exposure to the NOS from this source.

The teachers were drawn from within the same school district, viz. King William’s Town and surrounding areas in the Eastern Cape Province. The schools were located either in a rural or peri-urban setting. All 136 teachers who participated in the study had a minimum qualification of M+3 (grade 12 plus three years of university or teacher training college). The participants were practicing science teachers with a minimum of three years teaching
experience. The sample consisted of 68% female and 32% male teachers, spread in different proportions across the three groups.

8. RESEARCH DESIGN

The study was designed in two phases. The first phase involved the development and administration of a Likert-scale questionnaire, while the second phase comprised of focus group and individual interviews and classroom observations of participating teachers.

8.1 Phase 1: The NOS questionnaire

The administration and development of a NOS questionnaire, as well as analysis of the participants’ responses to the questionnaire, formed Phase 1 of the study. This twelve-item Likert-type questionnaire was developed by considering the key aspects of the NOS espoused by Lederman, et al. (2002). The questionnaire involved the use of Likert-Rating scales in respect to ‘philosophical statements’. The framework of reference for interpretation and discussion are in terms of four (Western) schools of thought, i.e. apriorism, empiricism/logical positivism, realism and conventionalism. For the purpose of this study, the four schools of thought are defined as follows:

- **Apriorism:** Pure reasoning, without any sensory experience, can be used to explain natural phenomena.
- **Realism:** There exists an objective reality about nature independent of one’s thinking or reasoning.
- **Conventionalism:** There is no unique truth or theory about nature; it is based on which convention one accepts to be true.
- **Empiricism/Logical Positivism:** Experimental or observational evidence determines the validity of a knowledge claim.

(Alters, 1997)
Items in the questionnaire were modified and revised after discussion with five university lecturers who have been involved in science education for a number of years in an attempt to improve their validity. Since the participants in the study are isiXhosa home language speakers, a language expert was consulted to identify and remedy ambiguities or difficult terms in the questionnaire as it was in English, the language of teaching and learning in their schools. Certain expressions in the questionnaire items were further revised after pilot testing on a small group (n=12) of teachers. However, Lederman, et al. (2002) note that establishing the validity of an instrument for eliciting understandings of the NOS is an ongoing process and that they feel it is incorrect to speak of validity as ever being established in a ‘once-and-for-all’ sense of the word. According to them, one should look for evidence in supporting an instruments’ efficacy in measuring what it has been designed to measure.

8.2 Phase 2: Interviews and classroom observations

Once the questionnaires had been analysed a total of 31 teachers, nine teachers each from the non-NMMU and BEd 1 groups and thirteen teachers from the BEd 2 group, were selected for interviews. Convenience sampling was used for the selection of teachers for interviews based on their willingness to be interviewed and geographic accessibility. Two focus group interviews were conducted separately with the first focus group consisting of five teachers from the BEd 1 cohort and an equal number of BEd 2 teachers formed the second focus group. Thereafter individual interviews were held with the remaining 21 teachers. Eight teachers from those who were interviewed, three teachers each from the non-NMMU and BEd 2 groups and two teachers from the BEd 1 group were identified for classroom observations.

8.3 Quantitative analysis

The quantitative data generated from the teachers’ responses to the questionnaire were analysed to seek patterns or contradictions within each group and between groups in relation
to their views on the nature of scientific knowledge and their perceptions of the scientific enterprise. The participants’ responses to each of the 12 statements in the questionnaire were scrutinised and classified according to the four (Western) schools of thought (Alters, 1997). The graphical presentation of the quantitative scores facilitated to develop narratives with regard to teachers’ perceptions of science and the underpinning philosophies. During the focus group interviews it was revealed that male members of the group dominated the discussion and the female members were not forthcoming with their views. Hence it was decided to change the strategy from focus group interviews to individual interviews.

One science lesson for each of the eight selected teachers mentioned earlier was observed to investigate how/if their perspectives on the NOS are translated into appropriate classroom practices. A classroom observation schedule developed for this purpose was used to identify observable teacher behaviours and learner actions that would indicate the mediation of stated NOS aspects and/or classroom conduct in accordance with the principles and guidelines of the new curriculum (NCS). Research findings (Abd-El-Khalick, Bell & Lederman, 1998) suggest that the relationship between teachers’ NOS conceptions and their classroom practices is rather complex and constrained by various other factors. Against this background, findings from this study should contribute to this debate and inform understandings of the effect of views and beliefs about the NOS and science teaching practice in the South African context.

The quantitative data generated were subjected to statistical analyses, both descriptive and inferential (ANOVA), in order to determine whether any statistically significant differences occurred between groups in terms of questionnaire responses and classroom behaviours. Statistical data were also generated in terms of the level of probability, effect size (practical significance), and reliability of the questionnaire items.
8.4 Qualitative analysis

The participants’ interview data were inspected and interrogated in an attempt to identify trends and/or themes in terms of the teachers’ beliefs and to examine their interpretation of the new curriculum in relation to their views of the NOS.

9. THESIS OVERVIEW

The promotion of scientific literacy as an important curricular goal in science education, both internationally and in the South African context, has been outlined in this chapter, as well as the research findings that show that science teachers need to possess adequate understandings in the NOS to achieve this curricular goal. The significance of the investigation into teachers’ perceptions of the NOS in the context of the new South African curriculum in science in South Africa is discussed and a brief outline of the research design is sketched.

Chapter two reviews current literature on key aspects of the NOS with respect to teachers’ understandings and classroom practices while chapter three discusses the research methodology used in the study. In chapter four the data generated are presented and these data are discussed in the light of the literature review in chapter five. Conclusions and recommendations based on the study findings are outlined in Chapter six.
CHAPTER TWO
LITERATURE REVIEW

1. INTRODUCTION

The recently introduced curricular reforms in South African Schools (Department of Education 2002; 2003), and elsewhere in the not so recent past (American Association for the Advancement of Science, 1989, Rutherford & Ahlgren 1990, National Curriculum Council 1988) envision the development of a scientifically literate society by integrating the more salient features of the prevailing philosophical perspectives of science and science education. Hence the image of science that is portrayed in the classroom in achieving this vision has become the focus of extensive research investigation (Mathews, 1994; Lederman, 2006). In the light of the brief description regarding the various aspects of the Nature of Science (NOS) given in the preceding chapter, this literature review focuses on philosophical perspectives, some of the prominent studies conducted by educational researchers on NOS, and issues relating to NOS in the South African Curriculum Statement. The discussion outlines key findings of investigation into teachers’ and learners’ conceptions of NOS, the relationship between teachers’ and learners’ conceptions and the impact of implicit/explicit instruction of NOS in terms of what is expected by the South African science curriculum. This literature review also includes discussion on efficacy of instruments used in research on the NOS as it pertains to education, the methodologies employed, and how they impact on teaching and learning.
2. PHILOSOPHICAL PERSPECTIVES

Developments in science in general and the nature of scientific knowledge in particular have been the subject of much debate and intense scrutiny by philosophers of science over the centuries and by sociologists in the past few decades (Lederman, 2006). Critical analysis pertaining to the methods and claims of science has given rise to multiple philosophical views which reflect the predominant and characteristic trends at different historical stages. The pluralistic perspectives grounded in epistemological and/or ontological views of science can be classified into four broad categories, i.e. Apriorism, Conventionalism, Empiricism/Logical Positivism and Realism according to Western schools of thought (Alters, 1997) and these categories are not necessarily mutually exclusive (Efflin et al., 1999).

2.1 Apriorism

That notion that nature and natural phenomena can be known by pure reasoning alone formed the basis of early developments in science during the time of the Greek philosophers. Using syllogisms and deductive reasoning (Prior Analytics) Aristotle attempted to describe nature. His purpose was to comprehend the fundamental nature of objective reality aided by deductive reasoning and extensive observation of natural phenomena (Byrne, 1997). However, in contrast with Plato’s ideal that reason alone is the foundation of secure knowledge, Aristotle’s study was empirical (Aryeh, 2004) in the sense that he engaged in a systematic study of living organisms by detailed observation to establish causal relations in nature (Posterior Analytics).

Although Aristotle’s theories about the natural world were widely believed to be true for nearly 2000 years, his ideas about causal reasons for motion and planetary systems were found to be false in the light of the contributions to science and astronomy from Copernicus and Galileo (Chalmers, 1999). The power of deductive reasoning in developing true
knowledge was further established with the introduction of Euclidean geometry around the
time of Aristotle. Euclid logically derived all aspects of geometry from five postulates which
were considered as self evident (a priori) truths. The structure of space as a self evident
physical reality was one of the hallmarks of Euclidean geometry which was only challenged
in the 19th century with the discovery of relativity theory. The view that pure reasoning must
be the sole route to produce reliable scientific knowledge was dominant until the beginning of
empiricism in the 16th century. The empiricists on the other hand claimed that data from direct
experience rather than reasoning is required to study the natural world.

Kant suggests an alternative to solve the dichotomy between rationalism and
empiricism holding the view that neither reasoning nor experience on its own helps one to
understand the physical world. Kant’s contention is that by pure reasoning we are trying to
make our concepts match the nature of the physical world (Kemerling, 2001) where as data by
themselves, without the necessary cognitive aspects in the human mind, are not sufficient to
make sense of the world (Leeson & Boettke, 2006).

Kant claims that the concepts of space and time, necessary preconditions for our
perception of the physical world, exist in human mind as synthetic apriori propositions
(Leeson & Boettke, 2006). The connection between sensory data and the objects of our
perceptions is mediated through ‘transcendental deductive logic’ involving synthetic a priori
propositions and ‘categories’ of rational thought (Friedman, 2002). In other words, one does
not derive concepts from nature as empiricists claim nor does one impose our conceptions on
nature as rationalists suggest, but one interacts with nature via the synthetic a priori concepts
that already exist in human mind.

Kantian tradition considers Euclidean structure of space as a synthetic a priori
universal category of human faculty. Newtonian mechanics is grounded in the conception of
space as absolute and Euclidean. The Euclidean structure of space had to be revised with the onset of relativity theory founded on a non-Euclidean conception of space. This posed a serious threat to the validity of the universal nature of synthetic a priori arguments (Friedman, 2002).

2.2 Empiricism/Positivism/Logical Positivism

The notion that the true knowledge of the physical world is achievable only through deductive reasoning was challenged by Francis Bacon in the early sixteenth century (Chalmers, 1999). According to Bacon natural phenomena can be understood by analysing observational data rather than pursuing a rationalist approach. He proposed the so called scientific method which starts with an open-minded accumulation of data, followed by the development of a hypothesis to explain the data and finally testing the validity of the hypothesis by specific experiments. The successful verification of the hypothesis results in reliable scientific knowledge (Chalmers, 1999). The formulation of general laws and theories by inductive reasoning to account for natural phenomena forms the philosophical foundation of the Baconian method.

2.2.1 Empiricism

The emphasis on the significance of observational data to develop scientific theories forms the basis of the empiricist philosophy espoused by early British empiricists George Berkley, David Hume and John Locke (Chalmers, 1999). Positivism espoused by Auguste Comte in the eighteenth century is an outgrowth of empiricism and both philosophies signify sensory experience as the epistemological basis of scientific knowledge. Although the two terms are often used interchangeably, there is significant distinction between the two strands (Miller, 1993). While empiricism is limited to knowledge that can be obtained by experience alone positivism acknowledges the existence of an objective world the knowledge of which
can be gained by observation. While empiricism tests theories to check if they hold true against empirical evidence, positivism builds theories to explain the causal regularities in the external world.

The linear structure of space as being absolute in Euclidean geometry formed the ontological basis for scientific reality until the invention of relativity theory. In the aftermath of the revision of the conceptions of space and time in early twentieth century, a new philosophical movement called the Vienna Circle was formed by a group of philosophers and scientists including Rudolf Carnap, Herbert Fiegel, Carl Gustav Hempel and Hans Reichenbach as some of the leading members of the group (Murzi, 2007). Their aim was to make philosophy of science more rigorous by attempting to develop criteria for evaluating the truth or falsity of statements. The movement later came to be known as logical positivism because of the primacy of logic and mathematics in the construction of theoretical statements in science.

There was intense debate among members regarding what counts as science and the methods of science with the debate continuing into the post-war era. According to logical positivists a scientific theory is a linguistic expression of human sensory experience to account for the causal regularities in nature (Klee, 1997). In their view empirical data should be reduced to meaningful and verifiable propositions using the language of logic and mathematics. All meaningful statements are classified as analytic a priori, i.e. statements whose truth or falsity conforms to the language of logic and mathematics and synthetic a posteriori, i.e. statements whose truth or falsity is determined by means of experience (Murzi, 2007). All scientific statements in the natural sciences, psychology and the social sciences belong to the class of synthetic a posteriori statements. Only those propositions of science
which can be tested empirically are admissible and the successful verification of statements justifies their status as reliable and objective knowledge.

2.2.2 Logical positivism

The Britannica Online Encyclopaedia (2008) describes logical positivism in its early days as subscribing to a view that knowledge claims would fall into one of three categories – true, false or meaningless. If a statement does not withstand empirical testing based on observational ‘facts’, it is considered to be false. This negated the possibility that scientific knowledge could be revisable. In their view traditional philosophy or matters relating to metaphysics, for example, Kant’s synthetic a priori statements were considered to be cognitively meaningless since these were unverifiable claims (Uebel, 2006). Logical positivists strived to unify sciences, for example natural science and social sciences, which implies that there is a monistic methodological status for all sciences (Klee, 1997).

2.2.3 Critiques of positivism

Positivists’ claim that only empirically generated forms of knowledge can be considered as valid scientific knowledge reflecting an objective reality gave rise to much criticism and debate among philosophers and sociologists (Chalmers, 1999). The influence of the behaviourist philosophy in the school science curriculum until recently reflects an epistemic basis of scientific knowledge as being hard and immutable in the positivist perspective. The positivist paradigm of science as clinical and separate from the wider socio-cultural contexts causes much concern to social theorists.

Logical positivists in the 1920s belonging to the Vienna Circle, rejected Kant’s synthetic a priori judgements based on the contention that the statements are not analytic since they do not conform to mathematical logic nor are they verifiable by experience (Uebel,
Thus for logical positivists all claims of metaphysics were cognitively meaningless. They adopted a radical empiricists’ approach to philosophical issues and for them it was a matter of “...instead of thinking through things to get the answer via metaphysical insight, let sensory experience decide the answer” (Klee, 1997: 29). According to Uebel (2006) the relegation of philosophy as a critical form of inquiry to a second order status to science was a cause of grave concern to philosophers of science.

2.2.4 Causal relationships

One of the primary goals of science is to seek answers to why events occur in nature the way they do and to understand the causal relations involved. To explain phenomena Carl Hempel and Robert Oppenheim developed a model called the Covering Law Model which includes the Deductive-Nomological explanation (D-N model) and the Inductive-Statistical model (Taylor, 1970). The D-N model for scientific explanation consists of a set of premises as initial conditions including the relevant general law relating to the particular event to be explained. The event is then explained as a deductive argument from the stated premises. According to Hempel, the stated premises must be true and must hold empirical adequacy to rule out traditions of thought from pseudo sciences such as astrology (Klee, 1997). Almeder (2007) states that the model can function as an explanatory argument if the event has already occurred or the argument may be of a predictive nature if the event hasn’t occurred yet.

In Klee’s view (1997), although the explanatory power of the D-N model subsumed under a general law demystifies the phenomenon to be explained, philosophers raised several criticisms of the model’s failure to accommodate for the link between causality and explanation. By citing numerous counter examples for the model Brown (2005) contends that the model does not provide necessary and sufficient conditions for an acceptable scientific explanation. Some of the criticisms leveled are that even when all the stipulated initial
conditions are met an ‘explanation’ can turn out to be completely irrelevant to the *explanandum* (a description of the event to be explained) or in certain cases the conditions stated are not sufficient to provide an adequate explanation. Scientific explanation aided by logic and mathematics is not necessarily a neat and tidy process, as the D-N model would seem to suggest, since the explanation often involves an account of the observed phenomena using entities in the non-observable world.

### 2.2.5 Observational and theoretical terms

The positivist model of scientific theories draws a sharp distinction between observational terms and theoretical terms, i.e. terms that refer to the world of non-observables or ‘the things in themselves’ as Aristotle put it (Klee, 1997). This distinction was important for the positivists because of the epistemological and ontological implications that scientific theories carry. For them an understanding of the laws of nature (the ‘objective’ reality of the physical world) is gained only through investigation of phenomena of events or properties of objects that is directly observable to us. Therefore, the distinction as Klee (1997: 33) puts it “…required that every theoretical term in a scientific theory must be provided with an explicit definition composed entirely of observational terms”. This requirement proved to be problematic because without specific criteria for the distinction, observational terms could be mistaken for theoretical terms. For example, the term ‘particle’ as in the sense of a dust particle is an observational term whereas the same term in kinetic theory of gases refers to the theoretical term for a molecule – a cause for a range of misconceptions that children hold in particulate nature of matter. Secondly, when a theoretical term is grounded in particular observational evidence and the theoretical term has universal applicability, there could be different observational evidence which could be indicative of the same theoretical term. For example, electron is a theoretical term which could be indicative of the luminance on a TV
screen as well as the observable evidence for the divergence of the foils of an electroscope. It is not only the lack of clarity in the distinction between the two terms that posed serious challenges to the positivist paradigm but the assumption that in accounting for an observational evidence a theoretical entity stands on its own caused problems.

2.2.6 Relational authenticity

The authenticity of a theoretical claim justified by observational evidence of a phenomenon is relational to various other theoretical entities which have a bearing on the phenomena observed. For example, to determine whether an object is charged or not by observing the divergence of the leaves of an electroscope, the observation of the occurrence or non-occurrence of the divergence of the leaves depends on a number of conditions such as the presence of other ionic charges present in the electroscope which in turn depends on the humidity of air which in turn depends on the atmospheric conditions and so on. The point is that the theory is underdetermined by the evidence meaning there are other non-observable entities which influence the outcome. The view that scientific theories consist of interconnected non-observable entities which influence an observation in one way or another is the holistic view of science espoused by many philosophers (Klee, 1997; Garrison, 1986; Chalmers, 1999 & Friedman, 2002). It implies that an understanding of a range of background beliefs will be required to draw inference from observations. In other words all observations are theory laden (Garrison, 1986) and there is no theory-neutral observation-language (Klee, 1997) as claimed by logical positivists.

2.2.7 Background beliefs

The influence of background beliefs on making observation statements is further illustrated by Chalmers (1999). He claims that in order to formulate an observation statement, the observer should be in possession of the necessary conceptual framework and appropriate
skills for an accurate interpretation of the event. For example to interpret the spectral lines formed by the radiation from a distant star, one needs to have the necessary background knowledge of atomic radiation and a host of other related information. This knowledge is crucial in drawing conclusions from experimental investigations. The repertoire of background knowledge of the practitioner determines the quality and validity of the claims from the experiment. Equally important is that the presupposition of background beliefs does not guarantee that the observation statements are infallible. For example two observers looking at the same rising sun could interpret the event as a moving sun viewed from a stationary earth or a stationary sun viewed from an earth that is moving. For both observers the rising sun is objective reality but how each one perceives it depends upon the frame of reference that one holds. According to Chalmers (1999) facts are not derived directly from observations. He cites various historical examples in science to elucidate the objective and yet fallible nature of observations. The critical distinction between observation and inference is a problematic concept for both science teachers and learners.

2.2.8 Induction and verification

Besides the issues of ‘objectivity’ of observations empiricists faced several criticisms regarding induction and verificationism. Garrison (1986: 13) asserts that the confirmation of a hypothesis by the inductive process is logically invalid since it amounts to what is commonly known as the “fallacy of assuming the consequent”. Similar view is expressed by Almeder (2007: 175) when he states that “…an inductive justification of induction based on the observation that past futures were like the past pasts is minimally circular for appealing to the inductive justification offered while overlooking the question of how we know that the future futures will be like the past futures”. This problem of induction was initially raised by Hume for whom the successful verification of a hypothesis based on observations did not guarantee
that future events of similar nature could lead to the same result. He did not say that we should not employ inductive reasoning, but that the success of induction cannot lay claims to the truth worthiness of a statement since the claim could be falsified with one recalcitrant experience. The empiricists countered the critics by claiming that a large number of observations of similar phenomena over a wide variety of conditions will assure the legitimacy of the claim (Webb, 2004). But the problem still remained because the conceptions of a “large number of observations” or a “wide variety of conditions” do not preclude the possibility that at some time in future the hypothesis could be shown to be false.

2.2.9 Falsificationism

An account of science based on the inductivist approach according to Karl Popper is essentially faulty because the confirmation of a scientific theory beyond doubt requires an infinite number of observations (Garrison, 1986; Chalmers, 1999). Popper proposed an alternative to the method of verification by induction to solve the problem. The critical element of Popper’s proposal is that one can never prove a scientific theory correct, but it is quite possible to prove a theory false. According to Popper (Chalmers, 1999) there is neither a psychological nor a logical induction. Only the falsity of the theory can be inferred from empirical evidence, and this inference is a purely deductive one.

Popperian falsificationism begins with the identification of a problem in a field of scientific inquiry followed by the formulation of a theory to account for the problem (Chalmers, 1999). Testable predictions are then logically deduced from the conjectured theory. The next step is to design critical experiments with the explicit purpose of showing that the prediction is not true. If the test is successful then the theory from which the prediction is drawn is discarded. If the prediction is not falsified by observation or experiment, then the theory is not confirmed but accepted as the best available explanation.
until it is falsified. Eventually if the theory is falsified, new problems arise which will be subjected to the process of falsification and a superior theory to account for the anomalies gets established. Popper maintains that science progresses in this manner by a series of conjectures and refutations.

Unlike in the inductivist view where scientific knowledge is considered as immutable and an ever-increasing accumulation of facts, the falsificationist view of science characterises scientific knowledge as being tentative and subject to revision which is a more realistic image of science from an historical perspective. However, the method of science as proposed by falsification has certain problems. Scientific theories are complex structures with interdependent concepts that constitute the coherence of the theory as mentioned earlier according to Quine’s holistic picture of theories. So when an observational prediction of a theory is falsified, it is impossible to identify whether the theory as a whole or only some part of it or any one of the auxiliary conditions that support theory that has failed (Klee, 1997). In addition when an observational prediction fails, there is no way of judging whether the failure was due to a weakness in the theory or due to a fallible observation or experiment (Chalmers, 1999). McComas (1998) ponders whether scientists actually pursue a programme of trying to falsify their own theories and whether an account of science based on conjectures and refutations is a true reflection of how developments in science take place from a historical perspective.

2.2.10 Kuhn’s model of science

Thomas Kuhn (1970) portrays an image of science distinct from the positivist or falsificationist account. According to Kuhn both accounts of science emphasise a rational “analysis of mature theories” (Klee, 1997: 129) and the approaches are “too piecemeal” (Chalmers, 1999: 104) lacking a holistic perspective of knowledge development in science.
Kuhn views science from a historical perspective depicting the socio-political influences on research programmes, how scientific enterprise is conducted by a community of practitioners and how anomalies are addressed when they arise.

In Kuhn’s view during normal science, development in scientific research is governed by an accepted paradigm, a shared world view among practitioners, regarding the fundamental principles in a specific domain of science (Kuhn, 1970). The basic sets of beliefs provide the guidelines as to the kind of research activities that could be carried out in that domain with practitioners immersing themselves in “puzzle-solving” and in-depth investigations enriching the field of study. Anomalies that may occur are either ignored or explained away since practitioners do not test or question the fundamental principles guiding the paradigm. However, when accumulation of anomalies poses a serious challenge to the fundamental belief systems, the adherents of the paradigm object to any revision in the existing beliefs which lead to what Kuhn calls as scientific revolution necessitating the establishment of a new paradigm. Thus Kuhn provides an historic account of science characterised by periods of normal science and scientific revolutions resulting in the formation of paradigms.

In Kuhn’s view each paradigm is distinct from the one it replaces in its core features such that it is not possible to compare one paradigm to another. Kuhn claims that paradigms are incommensurable (Chalmers, 1999). Bird (2007) notes three types of incommensurability in the paradigms – methodological, observational and semantic. As each paradigm is unique in terms of its fundamental principles, a common standard of measure cannot be applied to evaluate them implying that each paradigm has to be judged on its own merits. Observational evidence cannot be used as criteria for evaluation since observations underpin theoretical assumptions of the paradigm under study. As far as semantic incommensurability is
concerned, according to Kuhn the meaning of theoretical terms used are contextualised as well as interrelated (holistic) with other terms for a given paradigm and the meaning of the terms change when there is a paradigm change. Klee (1997) suggests that in Kuhn’s model there is no paradigm-independent development in science indicating all knowledge as paradigm bound. This implies that an account of science can only be given in relation to the unique standards and procedures of a particular theoretical framework and therefore it is not possible to consider science as progressing from one paradigm to another. In the absence of any universal standards of measure to account for science, it seems that the epistemic worth or the truth or falsity of a scientific theory can only be judged relative to a given paradigm.

Positivists’ claim that science progresses in a smooth and linear fashion accumulating facts had to be revised with the introduction of Kuhnian perspective of science (Bird, 2007). Secondly the perception that the conduct of science is an esoteric and objective activity carried out by practitioners unaffected by social realities was challenged. Kuhn’s account of how science is conducted within a paradigm and the process of transition to a new paradigm brought to the fore the social and cultural aspects of science which did not form a predominant feature of the philosophy of science previously (Chalmers, 1999).

2.3 Relativism (Conventionalism)

It follows from the incommensurability principle that the possibility of making a choice between competing theories on a rational basis is untenable. In addition, the truth or falsity of theories cannot be tested against an external physical world either since Kuhn does not acknowledge any ontological reality for theories outside the confines of a paradigm (Klee, 1997) as in Kuhn’s view entities in science are conventional symbols and they do not represent any real things in life (Ziman, 1987). Thus the epistemic worth of a theoretical claim can only be determined against the context of the features that constitute the paradigm.
Robert Nola (1988) points out that the relativistic view implied in Kuhn’s historical account of science generated extensive discourse among philosophers on the realism-relativism issue causing proponents of the latter, according to Chalmers (1999), to engage in detailed study into sociological aspects of science.

Reflecting on the literature on realism-relativism debate, Nola (1988) teases out different forms of relativism based on arguments forwarded for holding a relativistic view of science. Ontological relativists hold the view that causal laws of nature or the patterns discerned in nature are human constructions. What exists in nature is relative to theoretical frameworks or cultural belief systems and that there is no theory-independent reality for objects or entities. In other words for an ontological relativist electrons ‘are really there’ only by virtue of an electron theory as opposed to an ontological realist for whom the existence of electrons is a reality independent of any theory. This form of relativism suggests that scientific knowledge is invented rather than discovered which is congruent with the views of sociologists of science who maintain that all knowledge is socially constructed. The dichotomy of whether one can impose humanly constructed rules and laws on nature or nature behaves according to its own rules continues to be an issue for philosophical discourse.

Relativists contend that as conceptual frameworks change, the methods of knowledge production and evaluation vary as well (Nola, 1988) and therefore, there are no fixed universal methods of science or reasoning for the appraisal of theoretical claims. This view has contributed towards the espousal of an extreme version of relativism from philosophers such as Feyerabend and others who claim that methods in science are context-dependent and that there is a range of methods and practices, none of which can be claimed superior to another (Chalmers, 1999). However, Guba (1992) challenges the accusation that relativists ascribe to a notion of “anything goes” in methods of science and that scientific inquiry is
irrational. According to him the denial of a fixed universal methodology to account for all of
science does not imply that relativists subscribe to an “anarchist” view of science, on the
contrary they believe that the various methodologies have been “productive in some way”. In
a similar vein citing various examples from the history of development in science, in
particular Galileo’s contributions, Chalmers (1999) illustrates a progressive image of science
with respect to its aims, methods and standards of evaluation.

Given Kuhn’s model of science, a major criticism levelled against the relativistic view
of science is that, in spite of the perceived progress in science, an account for the progress
cannot be given on rational grounds from one paradigm to another. However, Michael
Friedman (2002) proposes a new perspective underpinning a rational account for scientific
development. Friedman considers the role of mathematical physics as a foundational pre-
supposition to serve a co-ordinative function in co-ordinating the empirical laws and tests in
science. He calls the foundational mathematical principles as relativised constitutive a priori
principles, comparable to Kuhn’s ‘paradigms’. According to him the constitutive a priori
principles are not ‘universals’ as in the Kantian tradition of “synthetic a priori” because
during scientific revolutions, these principles undergo radical revision and hence are said to
be “relativised” a priori principles. From a historical perspective the formulation of the
revised mathematical framework is influenced by the philosophical discourse prevailing at the
time. For example, the transition from classical mechanics to relativity theory was guided by
the philosophical debate between Helmholtz and Pointcare regarding the foundations of
Euclidean geometry. According to Friedman (2002) the philosophical contextualisation of the
revised constitutive a priori principles provides the inter-framework rationality during
transition between paradigms. McArthur (2007) notes that Friedman’s neo-Kantian
philosophy highlights the role of relativised a priori principles in the evolutionary process of
science and serves to counter the views espoused by naturalists such as Laudan and other like-minded philosophers.

According to Bird (2007) criticisms levelled against an antimonistic view of science expressed by relativists prompted the emergence of a new philosophy of science, scientific realism, which promotes a belief in the possibility of objective knowledge and justification.

2.4 Realism

In an attempt to account for natural phenomena scientists develop theories and laws which provide plausible explanations as to how nature works (Chalmers, 1999). The theoretical frameworks involve the use of observable and non-observable entities, their properties and causal relationships between the entities at a deep structural level of things or phenomena (Chalmers, 1999). Contrary to the view of science held by positivists, scientific realists argue that the predictive and explanatory powers of theories indicate that they are true or at least approximately true accounts of phenomena and therefore the unobservable entities are real. The proponents of the older version of scientific realism held the view that the structure of the world is a mind-independent reality and that science seeks to discern the underlying causal regularities of the physical world. Scientific realists extended the classical version to include conceptions of the physical world as a stratified reality constituting entities which interact to cause distinct kinds of processes and events (Ellis, 2005). The arguments supporting the epistemic worth of scientific explanations and the conjunct claims about the reality of theoretical entities offer a different picture for the nature of science in the realistic paradigm.

The conception of scientific explanation for realists is quite different from a 'standard view of science' as House puts it (House, 1991) which holds that observed regularities lead to the construction of general laws which enable one to offer an account of the physical world.
According to realists the Humean conception of causal regularities and the constant conjunction of events derived from empirical observations provide only a simplistic view of science and does not account for what really happens beyond the sensory experiences for events to occur. Nor do they agree with an explanation subsumed under covering laws because they contend that the general laws are idealised versions of a real world and hence do not express the underlying conditions under which the laws are applicable. Citing Bhaskar’s views on scientific realism, House notes that scientific explanation consists of three domains namely the empirical constituting the sensory experiences, the actual events that occur and the real entities involved in causing the events. Regarding the nature of scientific explanation House (1991: 4) states that:

“...events themselves are not the ultimate focus of scientific analysis. Rather events are to be explained by examining the causal structures that produce the events, and events are produced by complex interactions of a multitude of underlying causalities. Reality consists not only of what we can see but also of the underlying causal entities that are not always directly discernible. Reality, then, is stratified. Events are explained by underlying structures, which may be explained eventually by other structures at still deeper levels. Hence, the process of scientific discovery is continuous”.

House (1991: 4)

Therefore, for scientific realists theories refer to the complex activities of real entities at work. They do not draw a distinction between theoretical terms and observational terms, for them what is observed is the manifestation of the interaction of underlying entities beyond the observable world. Ian Hacking (cited in Klee, 1997) points to the fact that various subatomic particles can be manipulated and controlled in experimental settings validates the claim for the existence of non-observable entities. Chalmers (1999) suggests that the predictive success of theories involving theoretical entities such as electrons and gravitational fields support a realistic view of science and the trustworthiness of these explanations can be tested by
interacting with the world. Citing various examples from molecular biology, Klee (1997) illustrates that there are instances where a particular theory is supported even when diverse experimental procedures guided by different background theories are adopted. In other words different experimental outcomes converge on the same theory. The implication is that if the theoretical terms posited in the different experimental procedures did not refer to the same entities, this convergence wouldn’t have been possible. The convergence argument adds credence to the claims by realists for the epistemic worth of scientific theories.

2.4.1 Pragmatic realism

There seems to be no consensus among philosophers regarding scientific realism and this is evident in the vast literature on the realism – anti-realism debate (Klee, 1997; Chalmers, 1999; Hendry, 2001; De Regt, 2006; Raley, 2007; Chakravartty, 2008). Both Almeder (2007) and Hendry (2001) note that philosophers who adhere to a pragmatic view of science does not see the pursuit of truth as a goal of science, instead they see the aim of science is to generate theories to account for sensory experience. In other words pragmatists are not concerned about the ontological implications of the external world. For them theories are successful instruments for prediction and control. According to De Regt (2006) Karl Popper rejects the notion of real entities on the ground that these conceptions cannot be falsified and therefore not acceptable. Antirealists challenge the claim that a theory is approximately true because of its predictive success. According to them this is invalid since many successful theories in the past depicted as true descriptions of reality were shown to be false and hence there is no guarantee that the current theories will not be shown false in the future (Chalmers, 1999).
One of the challenges for scientific realism is the notion of underdetermination of theories (Klee, 1997). Underdetermination holds that, given two mutually inconsistent but empirically adequate theories, one cannot make a choice between them regarding which theory is true based on observational evidence alone. It implies that either one of them is true or both of them are true or both are false. This poses a serious challenge to realists since nature cannot be considered as the sole arbiter of truth for scientific theories. An example for this would be Fresnel’s theory of light from classical physics. Fresnel’s wave theory of light was shown to be false on account of the assumption of ether and the subsequent invention of photoelectric effect. However, in Maxwell’s electromagnetic field theory which superseded Fresnel’s theory, most of the mathematical equations pertaining to the properties of reflection and refraction of light from Fresnel’s theory were retained. A solution to this problem is offered by the contemporary theory of realism called structural realism (Slowik, 2006). Structural realists argue that there appears to be a great deal of preservation of mathematical structures when theories change over time. According to Slowik (2006) epistemic structural realism avoids definite commitments to the ontological realities of entities and provides for an account for the empirical progress in science. Michael Friedman’s relativised a priori constitutive principles stated earlier seem to support a similar view regarding continuity in scientific development. Structural realism provides a view of science in which scientific theories are seen to be making steady progress to account for the physical world and that there is some form of continuity when theories undergo revision and change.

3. THE NATURE OF SCIENCE AND SCIENCE EDUCATION

Project 2061, a science education reform project of the American Association for the Advancement of Science (1993), characterises the scientific enterprise as a process that, while
demanding evidence, blends logic and imagination in an attempt to explain or predict our natural world (Moss et al., 2001). The National Science Education Standards also “advocates that students develop an understanding of the nature of science through participation in the scientific enterprise” (Moss et al., 2001: 772). However, a 1981 study by Harms and Yager reports that “activities which … sustain the teaching of scientific enquiry” are largely absent in most American schools, and that the goals relating to scientific literacy for “societal decision making” are largely ignored (Vandervoort, 1983: 38). It seems that science educators in general are either unaware of the rise of science in the last hundred years, the conduct of science, its influence on values and priorities and its relation to social responsibility, or do not consider these aspects worthy of teaching in their classes.

3.1 Science teachers, curricula and learning materials

Science teachers play a key role in forming the image of science for the general public and so their knowledge about the nature of science is important (Gallagher, 1991). Hodson (1985) argues that, although to be a skilled scientist does not require an understanding of arguments in the philosophy of science, it is essential for science teachers. Schwartz and Lederman (2002) feel that in order to teach the nature of science effectively a teacher must not only have a firm understanding of the nature of science, but also knowledge of effective pedagogical practices relative to the nature of science. Matthews (in Moss, 2001), however, warns against too high expectations and proposes modest goals when teaching the nature of science, saying that it is unrealistic to expect teachers or students to become competent philosophers of science.

3.1.1 Transfer of teacher knowledge

Research has demonstrated the complexity of the transfer of nature of science knowledge into classroom practice. In general transfer is influenced by a variety of contextual
and personal factors including classroom management, constraints of the curriculum or institution, time, concerns for student motivation and ability, and teaching experience (Abd-El-Khalick et al., 1998; Bell, Lederman & Abd-El-Khalick, 2000; Hodson, 1993; Lederman, Abd-El-Khalick, Bell & Schwartz, 2002). Other factors affecting transferability relate to teachers’ understanding of the NOS and subject-specific pedagogical knowledge (Schwartz & Lederman, 2002). However, in-depth explorations of teachers’ development of nature of science knowledge, instructional intentions, and approaches to nature of science instruction have not been the focus of much research (Schwartz & Lederman, 2002).

What is known is that teachers tend to promote a view of science as simply the collection of data, leading to the formulation of a hypothesis, testing it, and then forming a general principle, as if all observations will be the same (Lederman, 2006). This approach assumes that we all observe the same things in the same way and suggests that many teachers “subscribe to the inductivist view of science, a view long-abandoned by philosophers” Hodson (1986: 216). This is despite a number of calls for “a reconsideration of the epistemological basis of the science curriculum in the light of contemporary views in the philosophy … of science” and the fact that it has been shown that teachers understanding of the nature of science can be enhanced by appropriate in-service education (Hodson, 1986: 216)

3.1.2 Curricula

Many curriculum reforms in science education have failed to effectively incorporate the nature of science as central to an explanation of how scientific knowledge is developed (Donnelly, 2001). Jenkins analyses the curricular impact of the nature of science, and when he “highlights its pluralism and conflicted agenda” he brings into focus the importance of recognising the contested nature of the NOS when developing a curriculum (Donnelly, 2001:
190). Donnelly states that the way in which issues around the NOS were addressed in the National Curriculum for England and Wales were “a case study in how not to proceed when dealing with contested intellectual matters which somehow need to be adapted and codified in the school curriculum”. He says that this is because issues such as the NOS are often “addressed in a piecemeal fashion by a series of ad hoc committees” and that “intense academic debate surrounding these issues went un-acknowledged in the statutory text” (Donnelly, 2001: 191).

3.1.3 Learning materials

Most secondary science textbooks contain a large body of scientific knowledge that is accepted by the scientific community and the story the authors tell is one of what we know, and not how we came to know it (Gallagher, 1991). The main approach has been to present scientific knowledge as revealed truth rather than the manner in which scientists formulated this knowledge, and this encourages the teacher to simply try to cover the content. This is understandable as text book writers are often teachers who probably have had no formal education in the history, philosophy, or sociology of science, and they have little knowledge of the applications of science (Gallagher, 1991).

3.2 The nature of science concepts and science education

The issues around the key characteristics that accurately portray the nature of science as well as the philosophical positions underpinning the NOS (such as empiricism versus realism, realism versus relativism etc.) have been intensely debated and continue to be debated among philosophers, historians and science education researchers (Alters, 1997; Efflin et al., 1999; Mathews, 1994; Abd-El-Khalick et al.,1998). Abd-El-Khalick et al.(1998) contend that the philosophical issues being debated are too abstract and not relevant for the school science curriculum. However, the literature suggests that there is sufficient agreement
among philosophers and science educators that there are certain characteristics of NOS that are important and relevant to school science education. These are the tentative and temporary status of scientific knowledge; that new knowledge in science is produced by creative acts of the imagination; that scientific knowledge is inferred from observations of phenomena; that there is no one scientific method; that the methods of science are characterised by the nature of values rather than techniques; that science is a social activity, both influencing and responding to social needs; and that consensus among experts is the basis of scientific knowledge (Aikenhead & Ryan, 1992; Abd-El-Khalick et al.,1998 ; Moss et al., 2001).

Similarly, the authors of the Benchmarks for Project 2061, i.e. the science education reform project of the American Association for the Advancement of Science (1993), state that students should know; that scientists assume that the universe is a vast single system in which the basic rules are the same everywhere, and that the rules can be discovered by careful systematic study; that science’s ongoing processes lead to an increasingly better understanding of how things work in the world but not to absolute truth; that there are different traditions in science about what is investigated and how, but they all have in common certain basic beliefs about the value of evidence, logic and good arguments; that scientists in any one research group tend to see things alike, so even groups of scientists may have trouble in being entirely objective about their methods and findings; that, in the short run, new ideas often encounter vigorous criticism; theories are judged by how well they fit with other theories, the range of observations they explain and how effective they are in predicting new findings; that people from all cultures contribute to science; and that science disciplines differ from one another in what is studied, techniques used and outcomes sought, but they share a common purpose and philosophy, and are all part of the same scientific enterprise.
3.3 Image of science in curricular reforms

In the light of the complexities involved in the development and validation of scientific knowledge an account of the description of science in the curriculum documents lends itself to different, albeit valid, interpretations. Good and Shymansky (2001) provide a detailed analysis of the reform documents in the US: Benchmarks for Scientific Literacy (1993) and National Science Education Standards (1996). The authors cite various controversial issues regarding the image of science portrayed in the reform documents. These include among others, that science is tentative and yet not likely to change drastically in future, that scientists differ on ideas and evidence but decision making is consensual, that there are no fixed steps that scientists follow but scientific investigations are usually characterised by collection of data, development of hypotheses and explanations to account for the data, that scientists are influenced by socio-cultural factors but explanations based on cultural and personal beliefs are not scientific. The authors contend that contrasting views of NOS reflected in the curriculum documents can only serve to confuse science educators and learners, a sentiment shared by Clough (2007: 2) who says that “Students who claim that science is tentative without acknowledging the durability of well-supported scientific knowledge can hardly be said to understand the nature of science”.

According to Good and Shymansky (2001) focusing only on certain aspects of NOS reflected in the documents will provide a postmodern/relativist view of science, while emphasis on certain other aspects put forward a modern/realist image of science. Citing Mathews (1994) and various other philosophers, as well as espousing the core assumption in both Benchmarks and Standards, the authors claim that science is ‘universal’ reflecting a modern/realist view and the ‘multicultural’ view of science as supported by postmodern/relativists is inappropriate for students just beginning to learn science.
Considering the implications of multiple perspectives of NOS on the teaching and learning of science, the authors suggest:

Philosophy of science tends to emphasise the stable, rational, progressive, universal, consensus nature of science while history of science tends to point out the unique, personal, variable, complex, local side of science and, of course, both sides and viewpoints are correct. However, when compared to other ways of knowing or believing, modern science is by far the most progressive, stable and rational way of knowing yet devised by humans and it is this side (modern/realist) rather than the other (postmodern/relativist) that better characterises the enterprise of science.

(Good & Shymansky, 2001: 62)

As mentioned earlier the South African National Curriculum Statement (NCS) aims to promote scientific literacy in schools and a number of NOS conceptions, e.g., the tentative and socio-cultural aspects of science, the inferential nature of science, multiple ways of understanding the physical world, etc. These are similar to the views expressed in both Benchmarks and Standards. In the light of the above discussion it appears important for South African science teachers to have a balanced and developed view of NOS to achieve the objectives of the revised curriculum.

3.4 Understanding what is meant by the term ‘scientific theory’

Scientific theories are well-established, highly substantiated, internally consistent systems of explanations and they serve to explain large sets of seemingly unrelated observations in more than one field of investigation (Lederman et al., 2002). Theories have a major role in generating research problems and guiding future investigations, and they are often based on a set of assumptions and posit the existence of non-observable entities. Thus, according to Lederman et al. (2002) theories cannot be directly tested. Only indirect evidence can used to support theories and establish their validity. They are “inferred explanations of observable phenomena” (Lederman et al. 2002: 500). Hodson (1986) states that in school
science theories are often represented as simple statements and argues that a more appropriate and philosophically sounder view is that they are “complex structures that stand or fall on their ability to describe, explain and predict observable phenomena, without being dependent on any single observation” (Hodson, 1986: 217).

Theories are inferred explanations for observable phenomena (Lederman, et al. 2002) and it is this understanding that should provide an underpinning for contemporary science curricula. In attempting to meet this challenge Linneman, Lynch, Kurup, Webb & Bantwini (2003) suggest that teachers should be encouraged to discuss philosophical issues in the classroom with the aim of promoting teacher-generated curriculum changes that advance discussions. The argument is that if science knowledge and understanding are expected to be broader than the concepts of physics, chemistry and biology, and if the processes of science are to serve as a reference for teaching styles and strategies, then issues around the NOS have to be addressed (Linneman, et al., 2003).

3.5  Education research on teacher knowledge and NOS

The results of research on whether science instruction has been successful with respect to improving students' conceptions have been disappointing and one conclusion was that students' poor understandings must be the result of a lack of curricular attention to the NOS (Lederman, 2006). Effort has therefore been placed on the development of curricula, but the results were mixed - some curricula worked for some teachers and not for others. Other researchers believe that the teacher is a critical factor and so the focus fell on teachers' understandings (Lederman, 2006). The assumption was that a teacher could not be expected to teach what he or she did not understand. Unfortunately, the focus on the teacher initially did not consider what the teacher did in the classroom as opposed to what the teacher knew about the NOS. It was assumed that there was a direct relationship between teachers' and
students’ understandings of the NOS and between a teacher's understandings and his/her instructional behaviour (Lederman, 2006). These assumptions guided research on the NOS throughout the 1970s and early 1980s. Both assumptions were found to be wrong (Lederman, 1986) and the current view is that teachers' knowledge is necessary, but not sufficient for improving students' conceptions of the NOS.

3.5.1 Focus on teacher behaviour

Initially, research that focused on teachers' behaviours assumed that if students were engaged in scientific activities they would come to understand the NOS implicitly. This third assumption did not prove to be true either as the research in the 1990s and early 2000s clearly indicates that students and teachers best learn the NOS if it is presented in a reflective, explicit manner (Lederman, 2006). That is, the NOS needs to be taught in the same manner as other more traditional cognitive outcomes. Explicit in this case means engaging students in discussions that ask them to reflect on what they did during investigations and what implications these activities have for the resulting knowledge and conclusions.

3.5.2 How the research was done

Standardised paper and pencil instruments have generally been used to assess teachers’ views on the NOS (Lederman et al., 2002). Aikenhead, Ryan and Desautels (1989) point out that the assumptions that underlie these instruments are problematic and may cast doubt on their validity. Instruments are usually based on the assumption that the respondents perceive and interpret the instruments items in the same way as the instrument developer and that respondents agree or disagree with statements for the same reasons as the researcher (Aikenhead et al., 1989; Lederman & O’Malley, 1990). Also, Lederman et al. (1998) state that standardised NOS instruments usually reflect their developer’s views of the NOS and their biases, and the choices that are given to respondents are designed with a certain
philosophical stance in mind. As such, it becomes possible that the views attributed to respondents are an artifact of the instrument rather than a representation of the respondent’s own conceptions of the NOS.

3.5.3 Dynamic aspects of the NOS

These problems are exacerbated by the fact that the NOS remains a difficult and problematic construct to deal with for a number of reasons. Firstly, there is no essential shared meaning for the ‘NOS’ (Alters, 1997) and, as noted earlier, there are a number of major schools of thought, e.g. apriorism, realism, empiricism/logical positivism and conventionalism. Secondly, the concept of the NOS is fluid and dynamic and the extent to which schools of thought are prioritised depends on the cultural context. Thirdly, the cultural context can change over time, as shown by changing perceptions of the NOS in the European context (Lederman & O’Malley 1990, Lederman 1992, Lederman, 2006), and its interpretation in other cultures such as those found in Africa represents a further set of challenges (Jegede, 1989; Ogunniyi, Jegede, Ogawa & Yandilla, 1995). Also, beliefs and values, especially when strongly held introduce a worldview context that is likely to have its own influence on the interpretation of what constitutes the NOS (Cobern, 2000).

3.5.4 Findings

After approximately 50 years of research on the NOS, the following generalizations can be made: K-12 students do not typically possess ‘adequate’ conceptions of NOS; K-12 teachers do not typically possess ‘adequate’ conceptions of NOS; conceptions of NOS are best learned through explicit, reflective instruction as opposed to implicitly through experiences gained by simply ‘doing’ science; teachers' conceptions of NOS are not automatically and necessarily translated into classroom practice; and that teachers do not
regard NOS as an instructional outcome of equal status with that of ‘traditional’ subject matter outcomes (Abell & Lederman, 2006).

4. THE SOUTH AFRICAN NATIONAL CURRICULUM STATEMENT

With the advent of democracy in South Africa in 1994 the newly elected government embarked on sweeping curriculum changes in education to redress the inequalities and injustices of the past in an attempt to bring about social transformation and economic development for all its citizens (Moll, 2002). In March 1997, the national Minister of Education announced the introduction of Curriculum 2005 (C2005) which was radically different from the curriculum of the past both in its philosophy and vision.

4.1 Outcomes-Based Education (OBE)

The guiding principles of C 2005 were outcomes-based education with the emphasis on the needs of the learner to become a productive citizen in the global arena rather than being a passive learner in a teacher-centred, content-based and exam-driven curriculum which focussed on developing the learner’s ability to recall rote-learned facts and principles. This purpose is clearly evident in the C2005 policy document.

The move towards an outcomes-based approach is due to the growing concern around the effectiveness of traditional methods of teaching and training which were content-based. An outcomes-based approach to teaching and learning, however, differs quite drastically and presents a paradigm shift

(Department of Education, 1997)

Besides addressing the inequities and crisis perpetuated by the apartheid education in South Africa, the rationale for choosing OBE as a model was in response to international trends in curriculum reforms in countries such as Australia, New Zealand, the UK and in some states of the USA (Botha, 2002).
OBE is a learner-centred approach which focuses on what the learner can demonstrate (do) at the end of the learning process as illustrated in the NCS “…OBE encourages a learner-centred and activity-based approach to education.” (Department of Education, 2003: 2). The achievement of clearly defined, pre-determined outcomes constitutes the integration of knowledge, skills and values relevant to the needs of a developmental society. The classroom pedagogy in the implementation of the new curriculum based on the OBE approach therefore requires a transformation of the teacher from the traditional role as an instructor (imparting knowledge) to that of a facilitator who can guide the learners in developing their skills and competences to become critical thinkers and problem-solvers for real-life situations (Botha 2002: Parker, 2003). The sequential introduction of C2005 started with Grade One in 1998 and the implementation was to be completed in all Grades of the school curriculum by 2005. However, the implementation of C2005 met with challenges and had to be revised.

4.2 Revision of C2005

In an extensive study involving nearly 500 secondary science and mathematics teachers in the Mpumalanga province, conducted over a one year period to assess their perceptions of C2005, revealed that they held a range of misconceptions and negative conceptions about the new curriculum (Aldous, 2004). Research carried out by the Department of Education indicated that the policy, framework and the implementation aspects of C2005 were experiencing severe difficulties, prompting the national Minister of Education to appoint a committee to review C2005 in February 2000 (Chisholm, 2003). The Review Committee reported that although there was overwhelming support for OBE and C2005, the implementation was beset by a number of issues. Chisholm stated:

These (issues) included a skewed curriculum structure and design, lack of alignment between curriculum and assessment policy, inadequate orientation, training and development of teachers, learning support materials that were variable in quality,
often unavailable and not sufficiently used in classroom, policy overload and limited transfer of learning into classrooms, shortages of personnel and resources to implement and support C2005, and inadequate recognition of curriculum as the core business of education departments.

(Chisholm, 2003: 277)

The Review Committee proposed that C2005 be revised by retaining certain design features and dropping those features of the curriculum such as 66 specific outcomes, assessment criteria, phase and programme organisers, range statements, performance indicators and so on which contributed towards the complexity and misinterpretation of the curriculum. Subsequently a simplified and streamlined version of C2005 was developed – the Revised National Curriculum Statement (RNCS) for Grades R – 9 for implementation in 2004 and for Grades 10 – 12 in 2006. South African schooling system takes place in two phases – phase one is the General Education and Training (GET) band which refers to Grades R – 9 and phase two is called the Further Education and Training (FET) band, which covers Grades 10 – 12. The revised curriculum for the GET phase was called the RNCS (but now is the NCS, as is the curriculum statement for the FET band).

4.3 Revised National Curriculum Statement for Grades R – 9 (RNCS)

As was the case for C2005, the RNCS (Department of Education, 2002) was based on the social transformation agenda enshrined in the constitution of South Africa. The curriculum was governed by OBE principles and seven critical outcomes and five developmental outcomes to be achieved by learners through eight Learning Areas, was stipulated (the Natural Sciences being one of them). The critical outcomes emphasise the importance of learners to become critical and creative thinkers, problem solvers, collaborative workers in a team, aware of their responsibility towards the environment and the health of others by being able to use science and technology effectively. The developmental outcomes,
among others, envisage a learner becoming a productive and responsible citizen in both local and global communities.

4.3.1 Promotion of scientific literacy and the RNCS

The promotion of scientific literacy has been stated as one of the main goals of curriculum reforms in science education in the western countries in the recent past (American Association for the Advancement of Science, 1993: National Research Council, 1996). Although there is considerable debate among science education researchers on the notion of scientific literacy, there is general agreement that this should be an important goal of science education for the needs of the twenty first century (Laugksch, 2000; Fensham, 2003; Hodson, 2003; Yore & Tregust, 2006). In keeping with the global trends in curriculum reforms, the South African National Curriculum Statement makes its purpose evident when it states:

The Natural Sciences Learning Area deals with the promotion of scientific literacy. It does this by: the development and use of science process skills in a variety of settings; the development and application of scientific knowledge and understanding; and the appreciation of the relationships and responsibilities between science, society and the environment

(Department of Education, 2002: 4)

This purpose is clearly articulated via three Learning Outcomes (LOs) of the natural sciences curriculum with LO1 focusing on scientific inquiry, LO2 with the emphasis on the development and application of scientific knowledge and LO3 dealing with the social and cultural impacts of science and technology. The achievement of the outcomes are to be measured using prescribed Assessment Standards for each Learning Outcome. Scientific literacy involves an understanding of the scientific processes, the nature of scientific knowledge and its social implications. This invariably means that an adequate understanding of the nature of science (NOS) is a prerequisite for the development of scientific literacy as
the “...Nature of Science (NOS) is an essential component in achieving scientific literacy” (Khishfe & Lederman, 2006: 395).

4.3.2 Nature of Science views and the RNCS

The NOS views that are expressed in the RNCS policy document are analysed under three groupings: Scientific inquiry and development of scientific knowledge; nature of scientific knowledge and the social and cultural aspects of science and technology (STS).

Scientific inquiry and the development of scientific knowledge:

It must be stated at the outset that scientific inquiry is placed under the grouping related to NOS views with respect to the epistemological implications of science processes such as the theory-laden nature of observations or the interpretation and evaluation of knowledge claims. Lederman, et al. state that “…although there is overlap and interaction between science processes and NOS, it is nevertheless important to distinguish the two” and caution against such a conflation (Lederman, et al., 2002: 499).

Lederman, Lederman and Bell (2004) and England, Huber, Nesbit, Rogers and Webb (2004) highlight the importance of developing science process skills as a cognitive outcome in learners by explicit instruction in teaching scientific inquiry. The South African Curriculum Statement explains the meaning of the term ‘process skills’ as “....the learners’ cognitive activity of creating meaning and structure from new information and experiences” (Department of Education, 2002). Whereas ‘scientific inquiry’ in the previous science curriculum in South Africa was restricted to ‘closed problem solving’ characterising verification of established scientific facts by worksheet-based science experiments, the new curriculum emphasises the development of process skills in learners by engaging them in investigative activities to understand the physical world around them as illustrated in the
policy document “...from the learning point of view, process skills are an important and necessary means by which the learner engages with the world and gains intellectual control of it through the formation of concepts” (Department of Education, 2002: 13).

The policy document identifies the set of process skills to be developed across all three Learning Outcomes as: observing and comparing, measuring, recording information, sorting and classifying, interpreting information, predicting, hypothesising, raising questions about a situation, planning science investigations, conducting investigations and communicating science information. A detailed description for each of the skills is also provided in the policy document (Department of Education, 2002: 13-14). Acknowledgement of the epistemological nature of processes skills is evident as the Assessment Standards for evaluation of data with respect to Learning Outcome 1 in grade nine requires that a learner “…considers possible bias in sources of information that are used” (Department of Education, 2002: 51).

Learning Outcome 2 provides the information on the substantive science content knowledge that is required for each Grade. Although not stated explicitly, the new curriculum underpins the constructivist model of teaching and learning whereby learners are expected to construct science knowledge by interpreting and evaluating information and be able to apply appropriate knowledge to solve problems in unfamiliar situations. In addition learners are required to develop higher order cognitive skills such as analysis, synthesis and evaluation of scientific knowledge as they progress. Another substantial shift from the past content-driven curriculum is evident in the statement: “...This Revised National Curriculum Statement does not want learners to memorise material which has no meaning or connections for them; however this Learning Outcome recognises that the ability to retrieve connected ideas is still a valuable intellectual skill” (Department of Education, 2002: 9).
Nature of scientific knowledge:

According to Lederman (2006) the development of an informed understanding of NOS includes among others, an understanding that scientific knowledge is tentative and it is empirically based. The contemporary view of the nature of scientific knowledge as being dynamic and prone to revision is illustrated in the RNCS policy document as follows:

Knowledge production in science is an ongoing process that usually happens gradually, but occasionally knowledge leaps forward as a new theory replaces the dominant view. As with all other knowledge, scientific knowledge changes over time as people acquire new information and change their ways of viewing the world.

(Department of Education, 2002: 4)

Green and Naidoo (2006) suggest that a fallibilist view of knowledge is congruent with a post-modern and constructivist perspective which characterises knowledge production as a human activity influenced by social and cultural values of the time. This is a paradigm shift from the traditional curriculum where scientific knowledge was viewed as absolute and unquestionable, and which prompted learners to memorise scientific facts and laws rather than a critical engagement of interpretation and evaluation of knowledge claims.

The revised curriculum acknowledges the empirical nature of scientific knowledge when it states that the “The prevailing world view of science is based on empiricism...” (Department of Education, 2002: 11) and the subsequent explanation highlights the strengths and limitations of the empirical basis of science:

Empiricism fuelled the growth of modern science over the past 400 years and has been remarkably effective in generating accurate and reliable knowledge about the natural world. As an approach to understanding nature, it is used in research and science education in all countries of the world. It is challenged by those who argue that pure empirical science does not concern itself with questions of meaning and
value, and is therefore too limited a way of understanding the world.

(Department of Education, 2002: 11)

While acknowledging the success of the empirical basis of science, the new curriculum policy document states that there are different ways of understanding the physical world. The following paragraphs highlight the significance of Indigenous Knowledge Systems (IKS) as a way of understanding the natural world:

Traditional technologies may reflect people’s wisdom and experience: Indigenous or traditional technologies and practices in South Africa were not just ways of working; they were ways of knowing and thinking. Traditional technologies and practices often reflect the wisdom of people who have lived a long time in one place and have a great deal of knowledge about the environment. Wisdom means that they can predict the long-term results of decisions, and that they can recognise ideas which offer only short-term benefits.

There are other world-views. For example in South Africa many people hold a strong world-view which says that people are not separate from the earth and living things; they believe that all things have come from God or a creative spirit and therefore have spiritual meaning; events happen for spiritual as well as physical reasons.

(Department of Education, 2002: 10-11)

The curriculum policy document stipulates that both IKS and modern science should form part of the school science curriculum, particularly in the light of the fact that different world-views are present in the science classroom and that several times a week learners cross from the culture of home, over the border into the culture of science, and then back again. The existence of different world-views of understanding and explaining natural phenomena poses serious challenges to the way science is portrayed in the classroom. According to Grange (2004) the two perspectives of science – science as ‘multicultural’, or science as ‘universal’ – have been the subject of intense debate among proponents of either of the two views with the
multiculturalists implying a relativistic view of science and the latter portraying a realist view of science.

The ‘universal’ view of science conveys the impression that western science is superior and other knowledge systems from which to understand and make sense of the world as pseudo science. Grange suggests that “These knowledge systems do not have to be viewed as competing perspectives but as complementary frameworks: one perspective of science must not dominate or displace other perspectives” (Grange, 2004: 218). In an enlightening debate between Gilbert Onwu and Mogege Mosimege about the challenges and issues regarding the incorporation of IKS into the science curriculum as required by the South African Curriculum Statement, they highlight that indigenous forms of knowledge and modern science should not be viewed as dichotomous forms of knowledge, but rather the social and cultural context of IKS and the complimentary aspects of both forms of knowledge should be elicited in the science classroom (Onwu & Mosimege, 2004). The Assessment Standards for Learning Outcome 3 for grade nine make it clear that learners should be assisted in reconciling differing world-views when it states:

Achievement is evident when the learner, for example, identifies sources and nature of authority in two differing explanations for an event, coming from two differing world-views; compares ways that knowledge is held in an oral tradition and in a written, public tradition; traces the way a theory about nature has changed over centuries.

(Department of Education, 2002: 59)

Social and cultural aspects of science (STS):

Hodson (2003) highlights the impact of science and technology in shaping the values and culture of people as well as the role it plays in determining the political power and economic status of different nations. Developments in science and technology have paved the
way for a consumerist society resulting in the exploitation of natural resources and irreparable
damage to the environment. Hence it is becoming increasingly important that school science
curricula engage learners in critical discussions on ethical issues related to the use of scientific
and technological knowledge. An important part of the new curriculum is that of science as a
cultural activity that is influenced by prevailing socio-political conditions and values, and at
the same time it impacts on the socio-economic conditions and values of people, locally as
well as globally.

The importance given to STS issues in the new curriculum is evident when one of the
seven Critical Outcomes of the curriculum is that the learners are able to “use science and
technology effectively and critically showing responsibility towards the environment and the
health of others” and two of the five Developmental Outcomes envisage the learners to: (i)
“participate as responsible citizens in the life of local, national and global communities” and
(ii) “be culturally and aesthetically sensitive across a range of contexts” (Department of
Education, 2002: 1). This significance is further illustrated by one of the three purposes of the
Natural Sciences Learning Area, which is:

Science and technology have made a major impact, both positive and negative, on our
world. Careful selection of science content, and use of a variety of ways of teaching
and learning science, should promote understanding of: science as a human activity;
the history of science; the contribution of science to social justice and social
development; responsibility to ourselves, society and the environment; and the
consequences of decisions that involve ethical issues.

(Department of Education, 2002: 5)

As noted earlier, one of the reasons for the incorporation of IKS in the science
curriculum is because of its spiritual base when it states that “…in South Africa many people
hold a strong world-view that all things have come from God or a creative spirit and therefore
have a spiritual meaning; events happen for spiritual as well as physical reasons” (Department
of Education, 2002: 11). This holistic approach displays care and respect for the entire ecosystem and advocates sustainable use of resources.

4.4 Implementation of the Curriculum Statement

There have been very few research reports on the implementation of the ‘new’ science curriculum in South African schools and in particular the extent to which classroom practices in science teaching and learning are aligned with the policies in the National Curriculum Statement. However, there are findings from an extensive ongoing research in Grades 8 and 9 in the Mpumalanga Province (Rogan, 2004; Aldous, 2004; Rogan & Aldous, 2005; Rogan, 2006) and from an investigation into the pedagogic practices of grade six science teachers in the Western Cape Province (Scholtz, Watson & Amosun, 2004) with respect to the implementation of C2005.

The Mpumalanga project was a longitudinal research investigation (Rogan & Aldous, 2005; Rogan, 2006) into the classroom practice of science teachers since 1999 in secondary schools in the Mpumalanga Province of South Africa. This case study included ten randomly selected schools, 240 science and mathematics teachers and over 600 learners. It investigated curriculum innovation in Grades 8 and 9 using questionnaires, analysis of documents such as learners’ books, lesson plans of teachers, interviews and classroom observation. The findings reported various factors which pose challenges to the implementation of the new curriculum, describe classroom practices in science in relation to the intended curriculum and make useful suggestions for implementation strategies in the South African context.

Rogan and Aldous (2005) caution that the introduction of a well-developed curriculum policy per se is not sufficient to bring about desired changes in the education system. Equally important is clearly thought-out implementation strategies taking into account of the contextual factors which could determine the pace and extent of the reform. The case studies
and teacher interviews in the Mpumalanga schools indicated that the capacity to support
innovation depended on teacher factors, physical resources of the schools and the ethos and
principles of school management. They identify teacher factors impacting on the
implementation of the new curriculum in the classroom as being how teachers interpret the
new curriculum, their perceived needs, level of qualification and professional development,
the quality of training received in curriculum innovation and the extent to which they
collaborate with each other at school as community of practitioners in curriculum innovation.

Interviews with teachers by Aldous (2004) on their perceptions of C2005 revealed the
prevalence of a variety of misconceptions and misinterpretations of the new curriculum such
as ‘outcomes’ being another word replacing ‘objectives’ in the old curricula, the new
curriculum lowers the standard of education, the teacher has less control of students in the
classroom and the role of teacher as a facilitator implies diminished responsibility on the part
of the teacher in the teaching and learning environment. Although there has been a shift in the
classroom practice from the traditional “chalk and talk” style to learners sitting in groups and
being engaged in group discussions, there was no evidence of achievement of any specific
outcomes as envisaged in the new curriculum. The tendency observed in the classroom
interaction was the retention of pre-C2005 practices with little modification - to the extent that
some teachers did not see any substantial difference between the two curricula in ideology or
in pedagogy.

Regarding the content area of the science curriculum Mpumalanga teachers appeared
to be coping fairly well since content was the focus of the past curriculum. However, in the
area of science practical work, the practice observed was still teacher demonstrations or
worksheet-based, teacher directed learner activities. In very few schools there was an attempt
at hands-on learner activities using equipment relevant to daily life experiences. However,
these activities were teacher guided and worksheet-based rather than ‘open’ investigations carried out by learners. None of the observed leaner activities involved the development of science process skills in learners, despite this being one of the important specific outcomes in C2005 as well as Learning Outcome 1 in the NCS.

Rogan and Aldous (2005) claim that although some progress was made towards implementation of the new curriculum in science in the observed Mpumalanga schools, the changes are only superficial and that the enacted curriculum does not align with the intended curriculum policies to the extent that none of the specified outcomes are being addressed let alone being achieved. One of the problems identified by the researchers in the Mpumalanga study is that the introduction of C2005 was a giant leap from the traditional curriculum and the training provided for the implementation of the new curriculum was inadequate and did not consider the real needs of teachers. Hattingh, Rogan, Aldous, Howie & Venter (2005) study in Mpumalanga involving more than 700 grade 8 and 9 learners in the Mpumalanga Province also indicated low levels of learner performance in each of the three Learning Outcomes in the Natural Sciences curriculum. The observation of classroom interaction in science in this study did not indicate any evidence of discussion or activity to address STS issues. Similar issues were also observed among the sample of Western Cape teachers in the study conducted by Scholtz, et al. (2004).

Although these studies were conducted on the implementation of C2005, the findings are still pertinent to the implementation of the NCS for two reasons. Firstly, as mentioned before, both C2005 and the NCS are governed by the principles of OBE, a radical shift from focussing on content-retention in learners to that of the development of skills and what learners can do with the new knowledge they acquire. Secondly, the essential elements of the nine specific outcomes stipulated in the Natural Sciences Learning Area in C2005 have been
encapsulated in the three learning outcomes (LO1, LO2 and LO3) in the NCS, a revision effected to reduce the complexity of the original curriculum (Hattingh, et al., 2005).

However, in South Africa the success of a school is largely judged by the public examinations at the end of a phase. So those teachers who produce good results for their learners in the public examinations continue to use the pedagogic practices that they found successful irrespective of the innovation. Findings from the investigations in both Western Cape and Mpumalanga indicated that rather than adopting curriculum innovation, teachers adapted the new curriculum to suit their perceived needs. Lack of physical resources, poor social environment of learners, weak science teaching qualifications and inadequate training received from the Department of Education in curriculum implementation were cited in both studies as negative factors which hinder the implementation of curriculum innovation. Nevertheless, studies in Mpumulanga pointed out that innovation effort had made good progress in the few schools where, the schools were well-resourced and the school ethos and management structures reflected a culture of accountability and monitoring. In addition, the teachers at these schools seemed to be working together as a team espousing a shared vision.

5. RATIONALE FOR THIS STUDY

As noted earlier, one of the primary goals of curriculum innovation in science in South Africa is the promotion of scientific literacy among its citizenry. However, understandings of the nature of science (NOS) have been identified as an important component of the science curriculum in developing a scientifically literate society (Mathews, 1994; Bell, Lederman, & Abd-El-Khalick, 2000; Akerson, Buzelli, & Donnelly, 2008). As such, and in the absence of any explicit reference to NOS in the NCS (Dekkers, 2006), the South African science curriculum policy documents have been interrogated in this study to identify the elements of NOS embedded therein, teachers’ views regarding the NOS are examined, whether explicit
instruction in the NOS produces any meaningful changes in their conceptions is measured, and classroom observations were carried out to investigate whether their beliefs in terms of the NOS are translated into comparable classroom practice.

6. CHAPTER SUMMARY

This chapter provides an overview of the literature review pertinent to the study. The review begins with a sketch of different philosophical perspectives that characterise the history of science and the role played by the different philosophies in developing an image of science that influences science education.

A brief account of the developments in science in the early stages depicting the rise of empiricism with its emphasis on experiential knowledge rather than pure reasoning in understanding the physical world is provided. The conception that there is a set method, the so called ‘scientific method’ to develop reliable knowledge about natural phenomena, which involves ‘open-minded’ collection of data, development of a hypothesis to account for the data and the experimental verification of the hypothesis formed the basis of empiricist ideology. The appeal of the inductive process in generating trustworthy knowledge gave rise to positivism which claims that only those propositions of science which can be tested empirically are admissible as scientific knowledge. The assumptions in the empiricist/positivist philosophy that the observations made in science are objective and value free, that science reveals the ‘absolute truth’ about nature and that science progresses in a linear fashion by the accretion of these ‘truths’ came under severe criticisms. Karl Popper’s falsificationist approach to the development of scientific knowledge addresses some of the epistemological and ontological issues in the positivist conception of science.

The perception that the conduct of science is an esoteric and objective activity in the pursuit of truth about nature unaffected by the social realities was challenged by Thomas
Kuhn who proposed that developments in science are determined by the prevailing socio-political environment. Kuhn’s account of science as a cultural activity demystified the image of science implying that there are different ways of understanding the natural world. A detailed account of the conduct of science as a complex human activity raising further challenges and debate regarding the practices and methods of science as well as the appraisal of theoretical claims made about the ‘non-observable’ world is provided in the review. The ontological status of the theoretical constructs in science in accounting for causal regularities in the natural world continues to be the subject of intense discourse among philosophers of science.

The rationale for the reforms in science education in various countries in the recent past has been an attempt to provide a realistic image of science in congruent with the prevailing philosophical perspectives of science with the aim of developing an informed public understanding of science. The achievement of this aim is incumbent upon an informed understanding of the scientific enterprise and the nature of the knowledge it produces, that is, an informed understanding of the Nature of Science (NOS) on the part of science educators. A brief account based on current literature, of what constitutes NOS; the dynamic and fluid nature of NOS and the appropriate pedagogic skills required by science teachers to develop an informed understanding of NOS in learners is given in the review.

A detailed analysis of the recently revised science curriculum (NCS) in South Africa indicates that South African science teachers need to have a developed understanding of NOS as well as pedagogic practices relevant to the diverse cultural contexts in South African schools to mediate this understanding in the science classroom.
CHAPTER THREE
RESEARCH METHODOLOGY

1. INTRODUCTION

In this chapter the philosophical positions underpinning this study, the theoretical perspectives behind the methodology, the methods of data collection and the analysis of data to achieve the main objective of the study are described. The main objective of this study is to explore Eastern Cape teachers’ understandings of the NOS and to investigate how their beliefs may influence the teaching of science within the framework of the new curriculum.

As noted in chapter 1, the primary question that encapsulates the main objective is:

• What understandings of the NOS are held by a sample of science teachers in the Eastern Cape Province, South Africa and how do these understandings impact on their ability to teach science within the framework of the new South African Curriculum?

The teachers’ NOS conceptions originate from their ontological and epistemological views of science. Therefore, an understanding of their philosophical positions with regard to their NOS views is pertinent to this study. Secondly in the context of the new curriculum which requires an adequate understanding of NOS conceptions by the teachers, it is useful to find whether explicit instruction in NOS by participation in a professional development programme affects their classroom practice in science. In view of these considerations, the following subordinate questions are asked.
• Can their understandings of the NOS be categorised into mainstream philosophical positions, e.g., a priorism, realism, empiricism/logical positivism or conventionalism?

• What aspects of the NOS are reflected in the classroom practices of the science teachers?

• Does explicit instruction in the NOS through an INSET programme, i.e. the BEd (Science and Mathematics Education programme, Nelson Mandela Metropolitan University) change teachers’ conceptions of the NOS?

2. RESEARCH PARADIGMS

Philosophical ideas remain largely latent in research and it is important that these “hidden” ideas which influence inquiry be made explicit (Creswell & Plano Clark, 2007). The set of beliefs and practices, or paradigms, that influences the methodological practices in research are defined by metaphysical considerations, including how knowledge is generated (epistemology), a patterned set of assumptions concerning reality (ontology), values (axiology) and the particular ways of knowing that reality (methodology) (Hanson, Creswell, Plano Clark, & Creswell, 2005; Guba, 1990). Many researchers suggest that these metaphysical beliefs represent a system of ideas which inform our reality and, ultimately, one’s mental framework influences the paradigm in which one works (Mertens, 2003). In other words, the paradigm that a particular theorist accepts and employs frames not only the research methodology, but also dictates the research techniques adopted (Morgan, 2007; Mouton, 1993). Although epistemology and methodology are closely related, the former relates to the philosophical underpinnings about knowledge development about the physical world while the latter refers to the epistemic values and assumptions associated with the
methods of gathering data in research (Henning, Van Rensburg & Smit, 2005; Cohen & Manion, 1995).

Despite the commonality of purpose that binds the work of theorists together (Burrell & Morgan, 1979), researchers generate and approach their data from a variety of theoretical perspectives (LeCompte, Millory & Preissle, 1993). Figure 3.1 illustrates Burrell and Morgan’s (1979) depiction of sociological paradigms which they situate in four distinct quadrants.

<table>
<thead>
<tr>
<th>Change</th>
<th>Subjective</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. CRITICAL THEORY</td>
<td>II. STRUCTURALISTIC</td>
<td></td>
</tr>
<tr>
<td>III. INTERPRETIVISM</td>
<td>IV. POSITIVISM</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 3.1:* Research paradigms (Burrell & Morgan, 1979)

Burrell and Morgan’s (1979) matrix is based on four established debates in sociology and the following paragraph summarises how these debates inform the components of the matrix.

The first debate deals with the notion of reality. It questions whether one's reality is developed by means of societal construction or whether reality is a product of the mind (as one perceives it to be). The second debate focuses on how one begins to understand a new idea, concept or practice and questions whether it is necessary for one to experience
something in order to understand it. The next argument deals with the concept of free will. It focuses on whether individuals are guided by free will or whether their decisions are determined by their environment. Finally, the debate surfaces on how understanding is best achieved. Is it through a systematic way of thinking, or through practice-based knowledge and understanding through direct experiences? The way in which one analyses these four debates is addressed along the axes of the matrix. The fundamental issue investigates social theories that emphasise regulation and stability (Order) to theories that emphasises radical change (Change). These theories are then juxtaposed to individualistic (Subjective) or structural (Objective) theories (Burrell & Morgan, 1979).

As this study is situated in the lower quadrants of order, as well as along the continuum of individualistic and structural theories, interpretivism and positivism will be discussed as separate and distinct paradigms. However, with respect to this study, these paradigms were not used exclusively. Instead, a mixed-method approach, which includes the qualitative dimension of interpretivism and the quantitative dimension of positivism, may best describe the set of combined beliefs and practices used.

2.1. Positivism

The 19th century French philosopher, Auguste Comte, is credited with developing the term positivism to describe the philosophical position in which the focus is to verify or falsify a prior hypothesis (Howe, 2009; Moring, 2001) and uses scientific ‘evidence’ to explain phenomena or situations (Cohen, Manion & Morrison, 2000). According to McFarlane (2000), when used in the social sciences, the positivistic paradigm seeks to emulate the objectiveness in the natural sciences and that it aims to find certainty through observable patterns. This paradigm often makes use of quantitative methods to prescribe, predict and
control situations, and generally identifies variables as the causal factors for specific types of behaviour.

Positivism is associated with the idea that laws govern social reality (like physical reality), and that these laws influence the behaviour of people who, in turn, set up social systems that reflect these principles (Goodman, 1992). Positivism, therefore, adopts an ontology which describes the world as an entity external to individual cognition and comprises hard, tangible and relatively immutable structures. This thinking has led to the general doctrine which states that all genuine knowledge is based on sensory experience and that progress in the accumulation of knowledge can only be made by means of observation and experiment (Cohen et al., 2000).

2.2. Interpretivism

The interpretivist framework and interpretivist-based research focuses on meanings and attempts to understand the context and totality of each situation by employing a variety of qualitative methods (Mouton, 2001). Similar to theories of constructivism, naturalistic and micro-ethnography, a key feature in the interpretivist tradition pays particular attention to the social construction of knowledge (Easterby-Smit; Thorpe & Lowe, 1994; Lather, 1991). It views the objective of research as an attempt to understand and interpret social situations by becoming part of situations, by listening to the participants, and by sharing their perceptions and their experiences (McFarlane, 2000).

The epistemology of this tradition focuses on the relative nature of knowledge and understands that knowledge is created, interpreted and understood from a social as well as an individual perspective. As such, this paradigm seeks to explain the participant’s behaviour from their individual viewpoint, as opposed to viewing them as passive actors who are completely determined by the situation in which they are located. The participants in an
interpretive approach are seen as active agents who are autonomous and able to create their social reality (Denzin & Lincoln, 2003).

In order to gain a better understanding of individual behaviour, interpretivist researchers attempt to observe ongoing processes and researchers within this tradition generally select a small sample to provide an in-depth description and insight of the participants’ social reality (Appleton & King, 2002). While interpretivists attempt to understand individual behaviour and social realities, interpretivist researchers accept Hume and Popper’s seminal arguments which suggest that one’s prior knowledge and biases shape what one decides to study, a researcher’s hypotheses or expected outcomes, as well as how one chooses to conduct the investigation (Chalmers, 1976). As such, the interpretivist researcher acknowledges that an individual is subject to their prejudices, opinions and perspectives and openly recognises that human interests and values drive science.

2.3. Pragmatism and the mixed method approach

Pragmatism is generally regarded as the philosophical underpinnings for mixed method research. The paradigm is based on the notion that the research question or set of questions should guide the researcher in choosing the most suitable methodological approaches to addressing the enquiry (Creswell & Plano Clark, 2007; Johnson & Onwuegbuzie, 2004; Tashakkori & Teddlie, 2003). Tashakkori and Teddlie (2003) suggest that the researchers within the pragmatist tradition abide by what they term ‘the dictatorship of the research question’, meaning that they place more importance on the research question than the method or paradigm that underlies the investigation. Additionally, they believe a practical combination of methods may offer greater insight, or may put forth the best chance of answering specific research questions (Johnson & Onwuegbuzie, 2004).
2.3.1 Mixed method approach

Research methodologies and approaches are grounded in the philosophical assumptions underpinning existing research (McFarlane, 2000). Therefore, the objective and subjective theories have been conventionally distinguished, as in Burrell & Morgan’s (1979) matrix, as purely quantitative approaches that are based on a philosophy of positivism to purely qualitative approaches that are based on a philosophy of interpretivism (Johnson & Onwuegbuzie, 2004). However, a growing number of mixed method researchers suggest that research should not be restricted to exclusive paradigms and limited methodological practices (Creswell & Plano Clark, 2007; Teddlie & Tashakkori, 2006; Creswell, 1994; Greene, Caracelli, & Graham, 1989). Rather they state that one should choose a combination of methods that provides sufficient evidence for answering the research question given “...the inquiry objectives, research context, and the available resources (Jang, McDougall, Pollon, Herbert, & Russell, 2008: 222).”

The mixed method approach incorporates a distinct set of ideas and practices that separate the approach from the traditional qualitative-quantitative dualities. Leading mixed methodologists such as John Creswell, Jennifer Greene, Burke Johnson, David Morgan, Anthony Onwuegbuzie, Abbas Tashakkori, Charles Teddlie and others offer defining characteristics of the mixed method approach. Descombe (2008: 272) adequately summarises these characteristics of the approach, which involves the use of:

- Quantitative and qualitative methods within the same research project;
- A research design that clearly specifies the sequencing and priority that is given to the quantitative and qualitative elements of data collection and analysis;
- An explicit account of the manner in which the quantitative and qualitative aspects of the research relate to each other, with heightened emphasis on the
Mixed method researchers posit that the majority of research questions generally cross paradigmatic boundaries and cannot be adequately addressed using exclusively the positivist or interpretivist philosophies. In fields such as sociological and educational research, where evaluation and achievement scores are as important as its contributing factors, mixed methods research is increasingly used as a legitimate alternative to conventional mono-methods (Jang, et al., 2008; Creswell & Plano Clark, 2007; Teddlie & Tashakkori, 2006; Reichardt & Rallis, 1994; Howe, 1988).

2.3.2. Rationale for using a mixed method approach

There are many ways in which social researchers use mixed methods research. Primarily, the incorporation of both qualitative and quantitative approaches or methods are employed throughout the process of collecting and analysing the data, integrating the findings and drawing inferences within a single study (Tashakkori & Creswell, 2007). However, the prevailing rationales for methodological pluralism include improving the accuracy of ‘mutually illuminating’ data (Bryman, 2007) and producing a more holistic picture of the phenomenon under investigation (Descombe, 2008; Creswell & Plano Clark, 2007). Greene et al., (1989) and later Bryman (2006) identified a number of purposes for conducting mixed methods research designs. Yet, the most prominent reasons for a mixed method design points to issues of illustration of data, explanation of findings, offsetting weaknesses and providing stronger inferences, as well as strengthen triangulation.

Triangulation is used to verify or support a single perspective of a particular social phenomenon (Jang, et al., 2008) and allows for greater validity through corroboration (Doyle,
et al., 2009). In addition to increased validity, the use of qualitative and quantitative methods provides a clearer illustration of the data and, as some researchers suggest, may neutralise the weaknesses in singular approaches while building on their strengths (Creswell, 2003). This is deemed useful when providing qualitative explanations to quantitative findings (or vice versa). For example, in this study, teacher interviews and classroom observations were conducted to elucidate the quantitative results from the questionnaire data.

2.3.3. Challenges to the mixed method approach

Paradigms influence ‘how we know’, our interpretation of reality and our values and methodology in research. Traditional methodologists posit that the combination of two distinctive perspectives, such as an interpretivist and positivist paradigms, offer philosophically incompatible assumptions about human nature and the world (Lincoln & Guba, 1989; Howe, 1985). For example, a predominant challenge of utilising a mixed method design centres on how the researcher is able to adopt an objective position of distance and neutrality (positivist) from the process and the participants, while promoting a subjective level of closeness and reciprocity when attempting to understand or make sense of the participant’s social realities (interpretivist) (Patton, 1990). Challenges such as these lead paradigmatic purists to posit that integrity of positions should be maintained and knowledge claims cannot be mixed (Smith, 1983; Smith & Heshusius, 1986). Additionally, researchers are cautioned to use different research methods in such a way that the resulting combination has complementary strengths and not overlapping weaknesses (Johnstone & Turner, 2003; Brewer & Hunter, 2006; Webb, Campbell, Schwartz, Sechrest, & Grove, 1981).

2.4. Paradigmatic approaches to this study

This research study is situated within the pragmatic paradigm, which holds the position that the research question, or set of questions, should guide the researcher in
choosing the most suitable methodological approaches to addressing the enquiry (Creswell & Plano Clark, 2007; Johnson & Onwuegbuzie, 2004; Tashakkori & Teddlie, 2003). Within the context of the study, knowledge is generated using empirical evidence and attempts to gain a deeper understanding of the social realities on which the evidence is based. The generation and analysis of the quantitative data places this aspect of the research within a positivistic framework, yet qualitative instruments, analysis and attempts at understanding ‘social reality’ also places this study within the interpretive paradigm. The use of both qualitative and quantitative methods assists in providing a clearer understanding of the data (Creswell, 1994). This approach is in line with Hall & Howard’s (2008: 252) viewpoint, which posits that “neither approach inherently overrides the other as [value is placed on] the contributing epistemologies, theories, and methodologies equally all the time despite necessary fluctuations in the use of their quantitative or qualitative methods throughout the research process.”

3. **RESEARCH DESIGN**

According to Mouton (2001), the aim of science is to generate truthful (valid and reliable) descriptions, models and theories of the world, yet it is not possible to produce scientific results that are infallible and true for all times and contexts (Chalmers, 1976). In spite of the relativeness of these descriptions, there is some agreement within current methodological researchers that multiple methods are useful to achieve greater understanding of events under investigation (Denzin & Lincoln, 1998). Research methods drawn from a range of paradigms, primarily of the mixed methods approach, make more in-depth understandings of events possible and can produce different sources and kinds of information (Fraser, 1996).
Hall & Howard (2008), along with other mixed methodologists, maintain that the careful consideration of typological designs are essential for making research design decisions and working in a comprehensive structure. The first of three design considerations deals with determining the ‘weight’ (Creswell & Plano Clark, 2007; Creswell, 2003) and the priority of each approach used in the study (Morgan, 1998). For example, it must be decided whether the qualitative or quantitative aspects are of equal status or if more emphasis is placed over one than the other.

The next consideration involves identifying the stages in which the qualitative or quantitative approaches are mixed. Caracelli & Greene (1997) offer two approaches to design: component design and integrated design. In the component design, the qualitative and quantitative methods remain discrete through data collection and analysis while the mixing takes place at the level of interpretation and inference. Conversely, the integrated design allows for incorporating and mixing methods throughout the research process. Teddlie and Tashakkori’s mixed-strands matrix (2006) expanded on Caracelli & Greene’s (1997) ideas to include other forms of design, such as concurrent, sequential, conversion, and fully integrated designs. While the concurrent and fully integrated designs are consistent with Caracelli & Green’s (1997) notion of the component and integrated designs (respectively), the sequential and conversion designs offer additional practical approaches. In the sequential design, qualitative and quantitative strands are used chronologically. For example, a quantitative analysis of surveys and questionnaires may be used to formulate questions, develop instruments or form hypotheses to be tested qualitatively through interviews or focus groups. In conversion, data is analysed accordingly and results are transformed for further analysis using the other methodological approach. The last consideration focuses on “the timing decision” (Creswell & Plano Clark, 2007) and “the sequence decision” (Morse, 1991) which addresses the stages and the order in which the qualitative and quantitative methods are used.
3.1 Design approaches in this study

This study seeks to investigate teachers’ conceptions of the nature of science and how these conceptions influence their classroom practice with respect to the revised science curriculum and both qualitative and quantitative approaches have been used. Citing Greene et al., Johnson and Onwuegbuzie (2004) propose that the rationale for using mixed methods approach in view of the objective of the study must be made explicit in the beginning. The purpose of the mixed methods approach in this study is to seek clarity and deeper understanding of teachers’ NOS views by finding convergence and corroboration of results from three data sources, namely, teachers’ responses to the NOS questionnaire, interviews with the teachers and classroom observations.

The initial stage of the research in 2005 made use of a twelve-item Likert-scale questionnaire to gather quantitative data regarding teachers’ views on NOS. Johnson and Onwuegbuzie (2004) suggest that quantitative data collection approach is useful when studying large numbers of people. A large number of teachers (n = 136) were involved in the questionnaire aspect of this study in order to provide sufficient data for meaningful statistical analyses. These data provided the framework for a more in-depth qualitative study with respect to the teachers’ NOS conceptions via interviews and classroom observations.

It was stated in the previous chapter that the concept of NOS is fluid and dynamic (Lederman, 1992) and that different worldview perspectives influence teachers’ conceptions of science (Jegede, 1989). Considering these aspects of NOS it was found necessary to engage in a detailed qualitative study of teachers’ views of NOS as well as to gain insight into the causal factors related to their views. The qualitative data were collected by interviewing a relatively large number of teachers (n = 31) subsequent to the administration of the questionnaire and by analysing the videotape recordings of science lessons of eight teachers.
In view of these considerations the research design was sequential and gave more ‘weight’ (Creswell & Plano Clark, 2007) to the qualitative data to achieve the main objective of this study.

The following table summarises how the study utilised both qualitative and quantitative approaches during the data collection, analysis and interpretation. The typology of triangulation and the mixed method design support Leech and Onwuegbuzie’s (2005) fully mixed, sequential and unequal status design.

Table 3.1:

*Summary of mixed method approaches used in this study*

<table>
<thead>
<tr>
<th></th>
<th>Data Collection and Analysis</th>
<th>Interpretation and Inferences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Qualitative</td>
<td>Quantitative</td>
</tr>
<tr>
<td>NOS Questionnaire</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Teacher Interviews</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Classroom Observations</td>
<td>✓</td>
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</tbody>
</table>

The study was conducted in two phases with phase one focussing on the collection of quantitative data using the NOS instrument followed by the qualitative investigation in phase two, i.e. interviews and classroom observations. The data gathered in phase one were analysed quantitatively using statistical methods and presented graphically to seek an overview of the teachers’ perceptions on the different aspects of NOS. These perspectives were expressed explicitly as well as implicitly in the questionnaire statements. The quantitative results were then converted to narratives to seek patterns and contradictions in the NOS views held by the teachers and to glean teachers’ philosophical positions with respect to their conceptions of the nature of scientific knowledge and scientific enterprise.
In the second phase of the study the qualitative data from teacher interviews were analysed to discern the reasons for the NOS views held by the teachers and to corroborate the findings from the questionnaire data. The data from classroom observations gathered using the classroom observation schedule were analysed to determine whether the classroom practice was aligned to the teachers’ NOS views and to establish whether their classroom behaviours were guided by the principles of the revised science curriculum (NCS). The treatment of the quantitative and qualitative data in this study closely resembles the seven-stage data analysis model in mixed methods research approach suggested by Onwuegbuzie and Teddlie (2003) and is summarised in the table below.

Table 3.2:

Summary of the stages in data analysis (Onwuegbuzie & Teddlie, 2003)

<table>
<thead>
<tr>
<th>Data analysis</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data reduction</td>
<td>Statistical methods for quantitave data and thematic analysis of qualitative data</td>
</tr>
<tr>
<td>Data display</td>
<td>Graphs and tables</td>
</tr>
<tr>
<td>Data transformation</td>
<td>Quantitative data converted to narratives</td>
</tr>
<tr>
<td>Data correlation</td>
<td>Qualitative data correlated with quantitative data</td>
</tr>
<tr>
<td>Data consolidation</td>
<td>Quantitative and qualitative data combined</td>
</tr>
<tr>
<td>Data comparison</td>
<td>Quantitative and qualitative data compared</td>
</tr>
<tr>
<td>Data integration</td>
<td>Quantitative and qualitative data integrated</td>
</tr>
</tbody>
</table>

The analysis of the qualitative data provided a “thick description” (Geertz cited in Henning et al., 2005) to provide an account of the reasons why the teachers subscribed to particular views of NOS and to gain insight into their classroom behaviours in relation to their image of science. The mixed methods approach adopted in this study contributed towards
developing a clear picture of the teachers’ perceptions of NOS as well as how these perceptions may or may not influence their teaching practice.

4. SAMPLE AND SETTING

A total of 136 teachers participated in this study constituting three distinct groups. A cohort of 44 teachers (designated as Non-NMMU teachers) formed the control group. These teachers were not registered with NMMU for any professional upgrade programmes during the course of this study and had not received instruction in NOS from this source in the past. The second cohort of 51 teachers (designated as BEd 1 teachers) were registered with NMMU for a two-year part-time BEd programme focussing in maths and science education and this group of teachers were in their first year of their BEd course. The third cohort of 41 teachers (designated as BEd 2 teachers) who participated in this study was in the second year of the BEd programme specialising in maths and science education. The rationale for selecting these three different groups of teachers was to determine the impact of a professional development programme which included both implicit and explicit instruction in NOS on the teachers’ perceptions of NOS. The three groups of teachers taught science either in the GET phase (Grades 4 – 9) or in the FET phase (Grades 10 – 12) with some teachers engaged in science lessons in both the GET and FET phases.

The teachers were selected from schools located in peri-urban or rural settings around King William’s town. The home language of the majority of teachers in this study is isiXhosa. The language of teaching and learning is English in all of the schools and all of the learners’ speak isiXhosa as their home language.

King William’s town is one of the Off-Campus centres of NMMU where INSET courses for practising teachers are offered. The teachers on the BEd programme attended lectures at this off-campus centre in the afternoons and over week-ends.
4.1. Non-NMMU teachers

The teachers in all of the three groups were purposively selected from schools in the rural and township (peri-urban) settings located within a radius of approximately 30 km from King William’s town. The other criteria used in the selection of teachers were accessibility to the schools by road, particularly in the rural regions, and that the teachers should not be registered with any higher education institution for a professional development programme specialising in maths and science education. The non-NMMU teachers held a minimum qualification of M+3 (Grade 12 pass plus three years of university or teacher training college) and two out of the forty four teachers held postgraduate qualifications. There were 23 males as opposed to 21 female teachers in this group and the teaching experience in science ranged from 3 years to 25 years.

4.2 BEd 1 teachers

In the first year of the BEd programme, besides focusing on maths and science modules at the Senior Phase level (Grades 7 – 9), these teachers were exposed to an English language module with the emphasis on developing their language skills in the teaching and learning of maths and science concepts in English. The course materials in science were designed to develop teachers’ understandings in science concepts as well as the development of pedagogic content knowledge within the framework of the revised curriculum. Although the teachers were not given NOS instruction directly, several aspects of NOS were embedded in the science lectures. The qualifications of the BEd 1 teachers were similar to that of the Non-NMMU teachers (M+3) with three teachers holding postgraduate diploma in education. With regard to gender distribution there were more female teachers (35 females as opposed to 16 males) in this group.
4.3  **BEd 2 teachers**

Compared to the BEd 1 group the BEd 2 teachers received explicit instruction in NOS in the second year of the BEd programme. The course materials in NOS exposed teachers to the history and philosophy of science highlighting the epistemological issues of knowledge development in science, the social character of science and its tentative nature. Although the approach used in the teaching of NOS conceptions was not integrated with science content, references were made to contextual examples from the science modules in the first year BEd curriculum to illustrate NOS aspects. The gender distribution in the BEd 2 group was 23 females compared to 18 male teachers.

4.4  **Setting**

As mentioned earlier the schools selected in this study were almost equally divided between rural and peri-urban setting. The schools within a 5 km radius of King William’s town were classified as peri-urban while schools further away were classified as rural. The schools in each setting are from previously disadvantaged communities and were generally matched in terms of infrastructure and science resources.

5.  **DATA COLLECTION: QUANTITATIVE DATA**

In order to gauge the teachers’ perceptions about NOS a twelve-item, Likert-scale questionnaire was developed and administered to a total of 142 teachers. The researcher visited the Non-NMMU teachers at their schools and, after seeking permission from the principals of the respective schools, the purpose of the research and the significance of the participants’ contributions towards the study were explained to the science teachers. The teachers were also informed that their responses to the questionnaire would be treated as confidential. In certain schools more than one science teacher participated in the investigation.
The completed questionnaires were collected from the schools within a period of one week and this procedure ensured a 100% return of the questionnaires. Of the total of 142 teachers, 136 questionnaires in which responses to all 12 statements were recorded were included in the study while six partially completed questionnaires were discarded.

The nature of this study was explained to the BEd 1 and BEd 2 teachers when they attended lectures at the NMMU centre in King William’s town. Although it was pointed out to them that participation in the study was voluntary the teachers from both groups fully participated in the investigation. The questionnaires were completed during the lecture sessions.

6. DATA COLLECTION: QUALITATIVE DATA

Teachers’ responses to each statement in the questionnaire were classified into two broad categories, i.e., responses which reflected a positivist view of science and those which represented a contemporary view of science. This broad classification indicated that the teachers in each group (Non-NMMU, BEd 1 and BEd 2) hold mixed views with regard to science and the methods of science. Convenience sampling for interviews and classroom observations was employed but equal numbers of schools from both rural and per-urban settings were chosen.

6.1 Teacher interviews

A total of 31 teachers were selected for interviews with nine teachers each from the Non-NMMU and BEd 1 groups and thirteen teachers from the BEd 2 group. Convenience sampling was employed in the selection of teachers from each of the three groups for interviews. Some interviews were held at the NMMU centre in King William’s town and the rest at the respective schools of the teachers after school hours or during breaks in their
teaching programme. The researcher conducted all the interviews. The semi-structured interviews were based on the sequence of the statements in the questionnaire with the interviewer taking cue from the responses given during the interviews to get a deeper understanding of the views held by the respondents.

Initially two focus group interviews were conducted at the NMMU centre in King William’s town with the BEd 1 and BEd 2 teachers separately and each focus group consisted of five teachers. Both these interviews were videotaped. During the focus group interviews it was observed that the male members of the group tended to dominate the discussion and in certain instances the female members expressed a wish to change their answers after listening to the male members in the group. For these reasons it was decided to hold individual interviews with the remaining selected teachers (n=21). All individual interviews were recorded on audio tapes. Both focus group and individual interviews were transcribed verbatim.

6.2 Classroom observation

Eight teachers volunteered from those who participated in the interviews for observation of their classroom practice in science lessons, i.e. the selection of teachers was primarily based on the willingness of a teacher to participate in this activity. Three teachers each from the Non-NMMU group and the BEd 2 group and two teachers from the BEd 1 group participated. One science lesson for each of the teachers was videotaped. With the exception of one science lesson which was completed in one school period (35 minutes) the remaining seven lessons were double sessions (70 minutes each). The classroom actions of each teacher was analysed using a classroom observation schedule developed especially for this purpose.
7. DATA COLLECTION INSTRUMENTS

Two instruments were used in this study, an NOS questionnaire to gather the quantitative data and a classroom observation schedule to capture the qualitative aspects of classroom teaching and learning in science.

7.1. NOS questionnaire

This study emanated from a previous investigation by Linneman et al. (2003) to explore the NOS views of teachers in the Transkei region (a former homeland in South Africa) of the Eastern Cape Province. In this study (Linneman et al., 2003) the NOS questionnaire used was based on the instrument developed for the Children’s Learning in Science Project (CLiSP) and adapted to elicit teachers’ understanding of science in the South African context. The questionnaire developed for this study was an adapted version of the instrument used in the investigation of teachers in the Transkei. The twelve item Likert-scale questionnaire used in the current study also focused on investigating teachers’ perceptions of scientific truth, the nature of scientific theories, differences between theories and laws, and the development of scientific knowledge, but included additional items on multicultural images of science and the relationship between science and technology.

7.2. Classroom observation schedule

The observation schedule used in this study is a modified version of a validated classroom observation schedule used in a number of other studies (Webb & England, 2007). The classroom observation schedule listed criteria that would indicate the performance of key NOS aspects reflected in the questionnaire as well as classroom behaviours of both learners and teachers with respect to the guidelines and principles of the revised curriculum (NCS). The classroom observation schedule measured the degree to which the teachers incorporated
the NOS aspects mentioned above on a progressive scale of levels 1 to 4 with level 4 indicating explicit actions to include the NOS components. Seven NOS components and a component related to science and technology (i.e. a total of eight) which formed the basis of the instrument are:

1. The “Scientific Method”
2. Tentative nature of scientific theories
3. The role of imagination and creativity in the development of scientific knowledge.
4. Subjectivity/objectivity in observation and inference
5. Distinction between theories and laws
6. The social character of science
7. The role of IKS in science
8. The relationship between science and technology

The observable components that would mainly indicate classroom behaviour with respect to the new curriculum, such as the seating arrangement of learners, the nature of classroom discourse and the engagement of learners in scientific investigations, were also included in the classroom observation schedule.

8. DATA ANALYSIS

The quantitative data from this study provided descriptive statistics of all participating teachers. Analysis of variance (ANOVA) techniques were used to investigate the statistical significance between group and gender scores as well as the results of the Scheffe’ tests to differentiate between the groups. The participants’ responses to each of the 12 statements in the questionnaire were analysed to determine general trends/contradictions in teachers’
conceptions of NOS. The graphical analysis of the quantitative scores facilitated to develop narratives with regard to teachers’ perceptions of science and the underpinning philosophies. The data thus generated were consolidated for each group to draw comparisons between the groups as well as to identify congruence or contradictions with respect to the various NOS components within each group.

The transcripts from the interview data were analysed on conceptual schemes related to the teachers’ views of NOS and comparisons were made with the general views espoused in the responses to the questionnaire. The findings based on the qualitative analysis of the interview data illuminated the reasons for particular views of NOS held by the teachers.

The analysis of the classroom practice using the classroom observation schedule provided the means to determine whether the teachers’ classroom actions are influenced by their views of science and in accordance with the ethos of the new curriculum. The data from the three sources, i.e., questionnaire, interviews and classroom practice were finally integrated to gain an overview of the teachers, perceptions of NOS and their classroom practice in relation to the views held.

9. ETHICAL CONSIDERATIONS

Scientists have a moral commitment to search for truth and knowledge, yet this quest should not be at the expense of the rights of individuals in society (Mouton, 2001). In keeping with the accepted professional ethics of research, the aims of the study, as well as the research design and methodologies, were communicated and discussed with the principals and teachers prior to any data collection taking place. The participants’ right to anonymity, including their right to refuse participation in the study were conveyed. All of the participants used in this study were informed volunteers and were aware that their responses would be used for this
thesis. The right to seek full disclosure about the research topic and the results of the study were also guaranteed.

10. VALIDITY AND RELIABILITY

Both the NOS questionnaire and the classroom observation schedule were modified versions of previously validated instruments. In addition the NOS questionnaire was revised after discussion with five university lecturers who have been involved in science education in the Eastern Cape for a number of years to improve the validity of the instruments. After pilot testing the questionnaire on a small group of teachers (n = 12) certain terms and wording in the questionnaire items were revised. The reliability of the questionnaire data was calculated using Cronbach \( \alpha \).

11. METHODOLOGICAL LIMITATIONS

The participants in this study represented schools from rural and peri-urban settings in the Eastern Cape and the teachers from schools in the urban areas of the province were not included. In view of this the findings from this study may not be a general reflection of teachers’ perceptions of NOS across South Africa.

In Thomas Kuhn’s seminal Structure of Scientific Revolutions (1962), he emphasised that observation is ‘theory-laden’ and shaped by the humanly constructed ‘paradigms’ that scientists invariably bring to observation. As such, there may be a possibility of misinterpretation of teachers’ responses during the interviews. However, to minimise this limitation on validity, interview responses were probed as deeply as possible and discussed with the teachers for clarification.

There is always the possibility that the lessons presented by the participating teachers were not ‘authentic’ in the sense that they may have presented a rehearsed lesson to impress
the researcher. However, as the focus was on their NOS views as represented by their pedagogical practices, it is unlikely that they could have modified their behaviour to what they perceived as being expected by the observer.

12. **CHAPTER SUMMARY**

As the research design of this study is influenced by both interpretivist and positivist perspectives, the study is grounded in the theoretical framework of pragmatism. In light of this, a mixed-method approach was used for the collection of data. As this study seeks to investigate teachers’ perceptions of NOS and how these perceptions influence their classroom practice in the light of the new curriculum, quantitative and qualitative methods were conducted sequentially with more ‘weight’ being given to the qualitative data as suggested by Creswell and Plano Clark (2007). The data analysis and triangulation of data were informed by the model proposed by Johnson and Onwuegbuzie (2004). The validity of the instruments and measures of reliability of the results have been noted and justified. In addition, the ethical considerations in terms of the participants’ right to privacy as well as the methodological limitations of the study, are discussed.
CHAPTER FOUR

RESULTS

1. INTRODUCTION

In this chapter responses to the questionnaire items by the three groups of participants (n=136) are presented and the mean scores of these items per group, as well as the statistical significance of these data, are noted. Each mean score is placed on a five-point scale ranging from a traditional or positivistic understanding (1) to an informed or ‘contemporary’ understanding (5) of the nature of science (NOS). The mean score data are treated statistically using analysis of variance techniques.

The interview and classroom observation data are interrogated and reported in terms of the ideas embedded in the questionnaire items related to the development of scientific knowledge (e.g., the ‘Scientific Method’), the nature of scientific theories and laws, the role of imagination and creativity in the development of scientific knowledge, the distinction between observation and inference, the social character of science, the status of indigenous knowledge and issues of science, technology and society.

2. QUESTIONNAIRE

The group names that have been used in this research depict teachers who were in their second year of study (BEd 2) of the in-service teacher upgrading in science education programme offered by the Nelson Mandela Metropolitan University (NMMU); teachers in their first year of study (BEd 1) on this programme; and teachers who were not part of the BEd teacher upgrading programme.
At the time of data collection the BEd 2 group had received explicit instruction in the nature of science and had been exposed to the teaching practices of their lecturers who modelled an informed or contemporary view of the nature of science. The BEd 1 group had not experienced explicit instruction in terms of NOS as part of the BEd programme, but had been exposed to the ‘informed’ teaching practices of the BEd programme lecturers. The ‘non-NMMU’ group comprised of teachers judged to be from a similar background teaching in roughly similar schools to those in which the BEd teachers taught, but who have not been introduced to the notions, content or practices of the NMMU BEd science education programme.

As noted above, the mean scores for the three groups have been tabulated; the results of analysis of variance (ANOVA) techniques to investigate the statistical significance between group and gender scores are presented; as are the results of the Scheffe’ tests to differentiate between the groups. The participants’ responses to each of the 12 items on the questionnaire are presented in graphical form and explanatory comments are also made.

2.1 Mean scores of questionnaire items

The mean scores for each item and each group are presented in table 4.1. The BEd (SP) 2 group attained the highest mean score for each item of the questionnaire. This was also the case for the total mean score (n=136). In seven out of the 12 cases (items 1, 2, 4, 5, 10, 11 and 12) the BEd (SP) 1 group scored a higher mean score than the non-NMMU group did, but in five cases it did not (items 3, 6, 7, 8 and 9). The total mean score attained by the non-NMMU group was slightly higher than the BED 1 group, viz. 2.77 and 2.71 respectively. The standard deviation scores did not appear to vary markedly between the groups in terms of individual items or total score. The overall Cronbach \( \alpha \) score was 0.361 which suggests a low level of reliability in terms of the test items.
Table 4.1:

Mean scores for the responses to the questionnaire items per each category of respondents

<table>
<thead>
<tr>
<th>Item</th>
<th>BEd 1 Mean</th>
<th>SD (σ)</th>
<th>BEd 2 Mean</th>
<th>SD (σ)</th>
<th>Non-NMMU Mean</th>
<th>SD (σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.88</td>
<td>1.05</td>
<td>3.34</td>
<td>1.15</td>
<td>2.70</td>
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<td>1.78</td>
<td>0.54</td>
<td>1.88</td>
<td>0.64</td>
<td>1.64</td>
<td>0.49</td>
</tr>
<tr>
<td>3</td>
<td>2.20</td>
<td>1.06</td>
<td>2.76</td>
<td>1.28</td>
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<td>1.23</td>
</tr>
<tr>
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<td>1.13</td>
<td>3.68</td>
<td>1.17</td>
<td>2.98</td>
<td>1.27</td>
</tr>
<tr>
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<td>3.34</td>
<td>0.69</td>
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</tr>
<tr>
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<td>4.29</td>
<td>0.90</td>
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</tr>
<tr>
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<td>3.63</td>
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<td>1.06</td>
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<td>1.07</td>
</tr>
<tr>
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<td>3.02</td>
<td>1.05</td>
<td>3.61</td>
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<td>3.57</td>
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<td>0.82</td>
<td>3.22</td>
<td>0.88</td>
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<td>0.88</td>
</tr>
<tr>
<td>12</td>
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<td>0.87</td>
<td>1.51</td>
<td>0.93</td>
<td>1.39</td>
<td>0.87</td>
</tr>
<tr>
<td>Total</td>
<td>2.72</td>
<td>0.37</td>
<td>3.30</td>
<td>0.31</td>
<td>2.97</td>
<td>0.37</td>
</tr>
</tbody>
</table>

2.2 Statistical significance

Analysis of variance (ANOVA) techniques were applied to the data in terms of group and gender (see Appendix C). In terms of overall (total) mean scores statistically significant differences were noted in terms of group (p=0.0152) and gender (p=0.0046). Scheffe’ test results revealed that these differences occurred between the BEd 2 and BEd 1 groups (p=0.003) and the BEd 2 and non NMMU groups (p=0.043).

The differences in mean scores between the three groups were not statistically significant at the 95% level of confidence (p≤0.05) for items 2, 3, 6, 8, 9, 11 and 12. Statistically significant differences at the p≤0.05 level were recorded for items 1 (p=0.353); 4 (p=0.0181); 7 (p=0.0188) and 10 (p=0.0152). A statistically significant difference at the 90%
level of confidence (p≤0.1) was also recorded for item 5. Scheffe’ tests revealed that these differences were statistically significant between the BEd (SP) 1 and the non NMMU groups for item 1 (p=0.037) and 4 (p=0.0181); between the BEd (SP) 2 and BEd (SP) 1 groups for item 10 (p=0.050); and between both the BEd (SP) 2 and BEd (SP) 1 groups (p=0.004) and the BEd (SP) 2 and non NMMU groups (p=0.050) for item 7. These data are represented in full in Appendix D.

The only statistically significant difference at the 95% level of confidence (p≤0.05) level in terms of gender, apart from the total mean gender difference (p=0.0046) was recorded for item 6 (p=0.023). Statistically significant differences between genders at the 90% level of confidence (p≤0.1) were recorded for items 7 and 8.

2.3 Responses to individual questionnaire items

The responses to each item on the questionnaire are presented individually in graphical format and explanatory comments are made. The responses ‘strongly agree’ and ‘agree’ were conflated to provide an ‘agree’ response, as were the strongly disagree and disagree responses. This was done to make the graphical representations clearer and less cumbersome.

2.3.1 Scientific theories reveal absolute truth

Sixty-three percent of the BEd 2 group disagreed with the statement that scientific theories reveal absolute truth, with 34% agreeing. These responses are considerably more ‘contemporary’ or ‘informed’ than the responses by the BEd 1 and non NMMU groups where only 43% and 34% respectively disagreed. Similarly, 8% and 11% of the BEd 1 and non NMMU teachers respectively ventured no opinion on this item as opposed to only 2% of the
BEd 2 group. As noted in section 2.2., the difference between the BEd 2 group and the non-NMMU group was statistically different at the 95% level of confidence.

![Figure 4.1: Group percentage responses (n=136) to questionnaire item 1 – Scientific theories reveal absolute truth](image)

All three groups believed that there is a set method for the development of scientific knowledge and that scientists follow a sequential step-by-step process in generating knowledge with over 95% teachers from all three groups agreeing with this statement. Strong support for this statement from the Non-NMMU teachers is suggested as all 44 (100%) teachers concur with the statement with 16 (36%) teachers expressing a ‘strongly agree’ view. However, 5% of BEd 2 teachers disagreed with this statement expressing an informed view about the development of scientific knowledge. It is interesting to note that this was only one of two statements (the other being Statement 11) where teachers expressed a specific view.

2.3.2 The development of scientific knowledge is an orderly, rational and step by step process

All three groups believed that there is a set method for the development of scientific knowledge and that scientists follow a sequential step-by-step process in generating knowledge with over 95% teachers from all three groups agreeing with this statement. Strong support for this statement from the Non-NMMU teachers is suggested as all 44 (100%) teachers concur with the statement with 16 (36%) teachers expressing a ‘strongly agree’ view. However, 5% of BEd 2 teachers disagreed with this statement expressing an informed view about the development of scientific knowledge. It is interesting to note that this was only one of two statements (the other being Statement 11) where teachers expressed a specific view.
2.3.3 Scientists use imagination and creativity only during the planning and design stages of investigations

Nearly 75% of BEd 1 and non-NMMU teachers seem to be of the view that scientists use imagination and creativity only during the initial stages of an investigation compared to 56% of BEd 2 teachers. Although the statistical analysis shows that there is no significant difference between the groups, the percentage of responses suggests that while not statistically significant; the BEd 2 teachers do hold a more contemporary (informed) view than their peers. Compared to 44% of BEd 2 teachers who are of the opinion that scientists need to be imaginative and creative throughout the process of knowledge development, only 16% of BEd 1 and 23% of non-NMMU teachers express an informed view with regard to this aspect of NOS. Compared to the other two groups, a relatively larger percentage (8%) of BEd 1 teachers did not express a view on this matter.
2.3.4 The theories developed by scientists are influenced by the social, political and cultural contexts

As noted in section 2.2, there is a statistically significant difference between the views expressed by the BEd 2 and non-NMMU teachers with the latter holding an informed view when 78% of this group indicates that social, political and cultural factors influence scientists in the development of scientific knowledge. A similar view is held by 59% of BEd 1 teachers and only 41% of the non-NMMU teachers. It is worthwhile to note that of the 45% of non-NMMU teachers who disagree with this statement, a majority of them (34%) strongly disagree with this view indicating that scientists are unbiased in their work.
Figure 4.4: Group percentage responses (n=136) to questionnaire item 4 – Social and cultural aspects of science.

2.3.5 *After repeated and successful verification, a scientific theory becomes a law*

It appears that most teachers subscribe to a hierarchical view of scientific theories and laws, i.e. theories mature as laws over time. Surprisingly 93% of BEd 2 teachers and 86% of BEd 1 teachers, as opposed to 80% of the non-NMMU group, hold the view that successful verification of a theory leads towards the establishment of a law in science. There was only a small number of respondents (the maximum being 5% in the non-NMMU group) who did not express a view on this statement.
2.3.6 Scientists discover theories and laws

Eighty percent each of the BEd 1 and BEd 2 teachers hold the notion that scientists discover theories and laws compared to 75% of non-NMMU teachers. While relatively a small percentage of teachers only, i.e. 18% of BEd 1, 17% of BEd 2 and 16% of non-NMMU teachers disagree with this statement. Whether this belief is due to a lack of a deeper understanding of the concepts of discovery and invention or because the teachers do not hold an informed view of scientific process may be made clear during interviews with the participants. Compared with the BEd groups, a greater number of non-NMMU teachers (9%) did not express any opinion on this item.
Figure 4.6: Group percentage responses (n=136) to questionnaire item 6 – Scientists discover theories and laws.

2.3.7 Scientific theories may change with time

Ninety percent of BEd 2 teachers believe in the tentative nature of scientific theories compared to 63% of BEd 1 teachers and 77% of non-NMMU teachers. Of the 90% BEd 2 teachers who hold an informed view, nearly 50% of the teachers strongly believe that scientific theories are revisionary. The prevalence of this view is in congruence with the statistical finding noted in Section 2.2. It is surprising to note that more non-NMMU teachers hold a contemporary view regarding the nature of scientific theories than do the BEd 1 teachers.
2.3.8 Different scientists draw the same conclusion from the same data

A majority of BEd 2 teachers (73%) hold an informed view that scientists differ in their interpretations of the same data which is congruent with their views expressed on the social and cultural influences on scientists. 47% of BEd 1 teachers and 52% of non-NMMU teachers also subscribe to similar views where as 18% each of these two groups of teachers and 5% of BEd 2 teachers do not express any opinion on the inferential nature of observations.
2.3.9 The ‘Scientific Method’ is the only way to study nature

The teachers seem to be evenly divided in their views regarding “scientific method” with nearly 43% of all three groups concurring with the notion of “scientific method” being the only way to understand nature and an average of 41% hold the view that there are different ways of understanding natural phenomena. However, there is a noticeable difference in the views held by the BEd 2 teachers with 44% of teachers subscribing to a contemporary view when they disagree with this statement as compared to only 39% who agree with this statement. It must be noted that a relatively large number of teachers in the BEd 2 and Non-NMMU teachers, 15 % and 16 % respectively and 6 % of BEd 1 did not have any specific view on this aspect of NOS.
2.3.10 Indigenous knowledge is not scientific knowledge

Generally a large number of BEd 2 and Non-NMMU teachers, 71% and 70% respectively, disagree with the notion that indigenous knowledge cannot be regarded as scientific knowledge. This view seems to be at odds with their response to statement # 9 when nearly 41% of both groups consider ‘scientific method’ to be the only way to study the physical world. The BEd 1 teachers are evenly divided in their opinion with 43% teachers agreeing and 43% disagreeing with this view. Compared to the other two groups, a large portion (14%) of BEd 1 teachers did not express any specific view on this matter. It is important to note that there was a statistically significant difference between BEd 1 and BEd 2 teachers on this questionnaire item when BEd 2 teachers are of the opinion that indigenous knowledge should be regarded as scientific knowledge.
2.3.11 Science is different from technology

Almost 90% of all participants do not view science and technology as being distinct. It is significant to note that this was one of two items (the other being knowledge development in science as a step-by-step process) for which there was no respondent who did not express a specific view. This implies that a majority of the teachers hold the notion that science and technology are essentially the same.
2.3.12 Observations may be objective, but the conclusions drawn could be subjective

Sixty seven percent of BEd 1 teachers and 66% of BEd 2 teachers agree that there is a distinction between observation and inference drawn from the observation by scientists while only 59% of non-NMMU teachers subscribe to this view. It must be noted that this was the only item with the largest number of teachers who did not express an opinion (20% of BEd 1, 15% of BEd 2 and 27% of Non-NMMU teachers) indicating that not all participants may have had clarity on the objective and subjective nature of observations and inferences.
3. INTERVIEWS

From the total sample of 136 teachers 31 teachers (approximately 20%) were selected for interviews. The criterion of selection was convenience sampling. Nine teachers each from the non-NMMU and the BEd 1 groups and thirteen teachers from the BEd 2 group were selected. The purpose of the interview was to determine whether the teachers had difficulty in understanding any of the questionnaire items and to explore the reasons for the choices that they had made for each of the statement in the questionnaire. The interview also provided the opportunity for teachers to change their response (for interview purposes only) to a statement if the meaning was ambiguous to them. The interviews were semi-structured with the interviewer taking cue from the responses given during the interviews to get a deeper understanding of the reasoning of the respondents.

Some interviews were held at the Off-Campus centre of NMMU in King William’s Town and the rest at the respective school of the teacher being interviewed either during

Figure 4.12: Group percentage responses (n=136) to questionnaire item 12 – Observations are objective and conclusions are subjective.
school break or immediately after school hours. Initially two focus group interviews were conducted at the Off-Campus centre for the BEd 1 and BEd 2 groups separately with each group consisting of five teachers. The focus group interviews were videotaped. It was observed during the focus group interviews that the male members in the group tended to dominate the discussion and that many female members of the group wanted to change their responses to their questionnaire items after listening to the views of the male members during the interviews. For these reasons it was decided to hold individual interviews for the rest of the selected teachers. All individual interviews were recorded on audio tapes. Both focus group and individual interviews were transcribed verbatim.

3.1 Interviews with the non-NMMU teachers

During the interviews each teacher in this group acknowledged that the meaning for statement one was clear and did not wish to change from his/her original response. The non-NMMU teachers were equally divided regarding their conception of scientific theories suggesting consistency with the responses to item 1 in the questionnaire. The four teachers who disagreed with the notion that scientific theories reveal the truth about natural phenomena could not provide any argument or specific example in support of their response except for T106 who stated that “…you can’t say with certainty that theories and science are always true. So I disagree”. The remaining four teachers who agreed with the statement seemed to hold the view that theories in science are true because the theories are verified by experiments. This sentiment is reflected in the statement of T110:

“I agree with the statement in the sense that true scientific theories will undergo experiments, you make research and then come up with the truth which you were checking by doing the experiments, which means there is no uncertainty about the truth. It reveals the absolute truth – so I agree with that.”
All teachers interviewed believe that development of scientific knowledge is a sequential, step-by-step process. Teachers were divided in their opinions regarding the role of imagination and creativity in science with some holding the view that development of knowledge is based on observable data and experiment and very few teachers, in contrast to 85% in the questionnaire, subscribe to the view that scientists use imagination and creativity in their work. One of the two teachers from the latter group, T122, elaborated by stating that “…that only part is what I am not comfortable with because I think – you know – throughout the whole process they need to use scientific imagination and creativity….”

Six non-NMMU teachers believe that social and cultural factors will not influence the knowledge developed by a scientist largely for the reason that scientists are in pursuit of eternal truths about nature and are not influenced by human needs or frailties. The general view is implied in the statement of T110 “I disagree with that one in the sense that social and political – in my perception – are not part of science per-se. They are falling under humanities in a way, how people are living.” However, a more informed view about knowledge development in science is reflected in the argument by T96:

“For instance, where there is a need for, for something iscientsists (“i”-means “the” in isiXhosa) will sit down and see what can be done, for example now we have an AIDS epidemic. Now the scientists will have to put their heads together and see how do we fight with the epidemic. Therefore it is influenced by social and cultural factors.”

All the nine teachers interviewed believe that scientific theories mature into laws with T96 stating that “A law I believe is derived from a theory” consistent with the responses to the questionnaire item to which a large proportion of teachers (80%) subscribed to the notion that theories eventually become laws. Most teachers were not clear about the distinction in the
meaning between the words “discover” and “invention”. After the meanings were made clear to the teachers by the interviewer using non-scientific examples, they maintained their initial response that scientists discover realities about nature.

Six of the nine teachers interviewed believe that scientific theories change with time because of “new discoveries” (T96) but could not substantiate with any specific example. T110 cited the example of developments in the Periodic Table to justify his reasons:

“I strongly agree because I once heard that a periodic table once had certain number of elements, now it has changed to more than that number. So, as time goes on there are developments that take place, that improve scientific theories. From the mere fact that there is improvement it means that it has changed from what it was before.”

However, for T101 “change” meant accretion in knowledge which is reflected in his statement “Yes, I do agree with that because as time goes on you discover new things- you accumulate more knowledge”. When the interviewer asked the teacher whether knowledge changes as time goes on he said “No, it cannot be different from what it was yesterday. They add.”

Most teachers believe that inferences drawn from an observed phenomenon are influenced by the theoretical framework of the scientist which is evident when T102 states that “...we are two different entities – we can see the same thing but interpret it in two different ways.”

With the exception of two teachers the remaining seven teachers believe that indigenous knowledge should be considered as scientific knowledge citing examples of the success in predicting the seasons correctly for farming purposes as well as in traditional
medicine when T96 claims that “… there are scientists who are consulting herbalists for some of the medicines…” Most teachers do not see any distinction between technology and science implying that technology is “applied science”.

3.2 Interviews with BEd 1 teachers

The BEd 1 teachers who were interviewed believe that scientific theories do not reveal the truth about nature, but this belief is underpinned by different reasons. Unlike the non-NMMU group, the BEd 1 teachers elaborated on the reasons usually based on the NMMU science course they attend as part of their BEd programme for the views expressed. Majority of the teachers subscribe to the view that unless a theory is “proven” by experiments several times, it cannot be regarded as an acceptable theory. The importance of experimental “proof” is clearly articulated in the argument given by T1 when she elaborates on the particle theory of matter:

“If you take perfume, the learners do not understand that particles are moving.
So I have to make an example, practical, so that learners can understand that particles are moving…like spraying the perfume in a corner of the class and the learners can smell in the other corner. So I need a practical example.”

Often teachers mistake the concept of “proof” for evidentiary support. On the other hand T20 expresses an informed view regarding his disagreement with statement implying that the theoretical frameworks held by a scientist may influence the nature of knowledge developed when he states:

“I disagree with the statement – because the statement says ‘scientific theories reveal the absolute truth’ – meaning no alternative about the truth. When scientists do investigation – depending on individual views because there
cannot be an absolute truth, because your truth may change again – but during that time it was taken as the truth.”

Regarding the development of knowledge in science there is general agreement among the BEd 1 teachers that scientists follow a sequential step-by-step process. However, they don’t seem to agree that “scientific method” is the only route to understand nature reflected in the argument posed by T18:

“There is no specific method because we Xhosas in the olden days knew nothing about science at that time. But we knew the seasons, when to plant when science was not there at that time. That is why I disagree with that statement.”

The views expressed during the interviews are consistent with their responses to items 2 and 9 in the questionnaire.

Teachers were divided in their views regarding the role of imagination and creativity in the development of scientific knowledge. One teacher (T16) believes that scientists use both imagination and creativity “throughout the scientific process”, while T5 agrees that scientists must be creative but they have to be objective and should rely on “the hard facts before them”. According to T5 imagination does not play any role in the work of scientists.

Most teachers (T16, T21, T3 and T 20) strongly believe that the prevailing socio-political contexts and the scientists’ own cultural beliefs impact on the development of scientific knowledge with T20 arguing that “…whenever an investigation is made it is made because there is an existing knowledge which is already on people’s minds – so scientists have own knowledge in their minds…” T5 on the other hand believes that “… science has
very little to do with social or political context.” In the focus group T4 changed her view to concur with the view expressed by T5.

Except for T18 who believes that “theory and law are the same” the remaining BEd 1 teachers interviewed hold the notion that a scientific theory becomes a law after it has been successfully verified by experiments a few times. This general view is reflected when T4 states:

“A theory is something which is not proved by experiment. Once it is proved many times, it becomes a law.”

When the interviewer asked whether a scientific law should be given a higher status than a theory, all five teachers in the focus group responded affirmatively.

Teachers were unanimous in their view that scientists discover (T3) “… what is out there in nature” and T4 referring to the particle nature of matter says “… particles are there, you don’t put it there”. Most of the responses to this item indicate that teachers equate theoretical models with nature rather than being models developed by humans to understand nature and natural phenomena.

BEd 1 teachers were divided in their responses to item 7 in the questionnaire which refers to the nature of scientific theories. Since this item follows immediately after the statement about whether scientists discover or invent theories, two teachers used the same reasoning, i.e., theories reveal the truths about nature as they are, to argue that theories do not change. This reasoning is reflected in the statement of T5 when he says:

“Well in number six I said scientists discover theories, they are there and I disagree that they may change with time because they have not changed since they were there…since they were discovered. So it will not change.”
T18 believes theories can change and her reason is based on the science education she had received in her school days compared to the one she is receiving in the BEd programme. Referring to the BEd science course she said:

“When I came here the only thing that knew about matter was that matter is something that occupies space. I didn’t know that air occupies space because when there is nothing in a room there is no matter in the room. Now I know that there is air in a room. Air is also matter.”

On the other hand, T20 expresses an informed understanding of the nature of theories when he states:

“I agree...as I have said before that if there is an investigation and the scientists agree on a certain issue... after some years they may change from that idea to another. It depends on what they have found out.”

All BEd 1 teachers interviewed agreed that inferences drawn from an observation are influenced by the theoretical assumptions held by the observer compared to only 47% of teachers agreeing with this aspect of NOS in the questionnaire. This view is reflected in the statement of T21 to questionnaire item 8 when she states “No, you can’t reach the same conclusion ... even if we can watch it at the same time, even if we can discuss it. We can never reach the same conclusion because of prior knowledge” and in the response to item 12 in the questionnaire by T3 when she said:

“I agree because when you come to observe something, you come with your perception, your prior knowledge and then you look at the thing with those eyes and then you come out with what you saw.”
Except for one teacher (T20), the remaining teachers agreed that indigenous knowledge should be accepted as valid knowledge. When asked by the interviewer whether they trust the medicine from herbalists, the teachers were quite apprehensive and stated that they do not have faith in traditional medicine citing the reason that it is not “scientifically tested”. According to T18, while she acknowledges the contribution of traditional knowledge in the area of farming, she wouldn’t trust traditional medicine because “… it is a delicate matter. I wouldn’t play with it (meaning her life). You can’t buy your life, but you can buy a plant.”

The teachers were divided in their views regarding the relationship between science and technology. While the majority of teachers held the view that science and technology cannot be separated from each other two teachers (T5 and T4) believed that there is a distinction between the two. According to T4:

“I think that science should be separated from technology. In my mind I think technology has got to do with for example it has got to do with computers, play stations and things like that. It has nothing to do with science because science has to do experiments, tests, lot of testing in laboratories…”

3.3 Interviews with BEd 2 teachers

Most of the thirteen BEd 2 teachers who were interviewed disagreed with the notion that scientific theories reveal the absolute truth. During the interviews two teachers (T 58 and T67) changed their views from “Agree” to “Disagree”. In contrast to the non-NMMU or the BEd 1 group no teacher from the BEd 2 group talked about experimental “proof” as the reason for his/her response. According to the BEd 2 teachers theories may change as more evidence comes to light and/or advances in technology takes place implied in the statement from T56 “… investigation is never final, because as time goes technology develops, there is
also new ideas and new theories.” The impact of the Nature of Science module completed by the BEd 2 students was evident when T57 made the following argument:

“Okay I don’t change my answer. I can say that there is no truth about scientific theories because they can be changed as time goes by. Like there can be scientists that come up with some views that can falsify a certain theory – so it cannot be an absolute truth – it can change.”

Interviews indicate that generally BEd 2 teachers held the view that the development of scientific knowledge is a rational and step-by-step process except for T85 who espoused an informed view when he stated that “… I don’t think so. ... I don’t agree with this ‘orderly manner’ I think information can come with the third step and the first may follow…”. unlike the other two groups BEd 2 teachers maintained that scientists need to be imaginative and creative throughout the process of knowledge development emphasising that the role of imagination and creativity is not restricted to the initial planning and design stages. This view was reflected when T69 said:

“I think I agree with this one. Looking at their use of creativity and imagination because before you start doing a thing you have a mental picture of what you want to do, then after you have put your thinking in perspective, it is where you start being creative, trying to collect all those things you are going to use. After that now you start planning or designing what you want to put across or what you want to develop. So both imagination and creativity are part of the solution of the problem.”

All BEd 2 teachers interviewed concurred with the view that the development of scientific knowledge is influenced by the prevailing socio-political context by making explicit reference to the Nature of Mathematics module in the BEd 2 course. T70 stated:
“I can strongly agree because when we learn about the development of mathematics we learned about the Greeks and the Egyptians – how they developed functional maths – how pure maths came into existence – those were the things that were done practically not knowing that they were trying to derive a form of maths, but eventually became the maths that we are using today- you see…”

Regarding the distinction between theories and laws, most teachers adhered to the notion that theories mature to become laws after successful experimental verification and consensus among scientists similar to the views held by BEd 1 teachers. This is evident in the statement of T67 when he said “… theories are laws in the making, most scientists should agree with it before it becomes a law.”

Similar to the other two groups the BEd 2 teachers were not clear about the distinction between “discovery” and “invention” and most still maintained that scientific theories are discovered by scientists. All teachers interviewed were in full agreement with the view that scientific theories do change with time as new evidence challenges the existing theories and the developments in technology enhances the understanding of the physical world. The response from T66 reflects this view when she stated:

“As time changes may be even technology changes. May be in some existing theories they may add something to make them work. Because may be as most people are getting more and more educated. Therefore may be the existing theory may be proven wrong and if it is proven wrong then new ones will come because people are getting more educated and moving from one level to another and technology is helping them.”
Teachers believe that prior conceptions held by an observer influence both the observation of a phenomenon and the inferences drawn from it. T77 said “… because of different way of thinking. We are not thinking the same.” T57 cited an example from the Nature of Science module when she stated:

“Okay Sir. I can say we cannot see the same thing the same way – someone can analyse that thing their own way- like there was in the Nature of Science that person who was observing steps – if you see those steps one sees them as moving up another sees them as going down – so people cannot analyse the same thing the same way.”

Teachers were uniform in their views that indigenous knowledge should be considered as acceptable knowledge and that science and technology should not be considered as separate. The views expressed during interviews indicate consistency with the responses to questionnaire items 10 and 11 respectively.

4. CLASSROOM OBSERVATIONS

Eight teachers from those who participated in the interviews were selected to observe their classroom practice in science. Three teachers each from the non-NMMU group and the BEd 2 group and two teachers from the BEd 1 group were chosen. The selection was based primarily on the basis of the willingness of a teacher to participate in this activity. All schools selected for classroom observation are situated in rural communities.

A classroom observation schedule was developed for this study listing criteria that would indicate the performance of key NOS aspects reflected in the Questionnaire. The twelve questionnaire items were reduced to eight key components (Table 4.2) by conflating items which refer to a broad aspect of the nature of science. For example, item 1 which states
“Scientific theories reveal the absolute truth” and item 7 which states “Scientific theories may change with time” relate to the broad aspect of the nature of scientific theories.

Table 4.2:

*Key NOS aspects and questionnaire items*

<table>
<thead>
<tr>
<th>Key NOS aspect</th>
<th>Corresponding questionnaire item(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The “scientific method”</td>
<td>2 and 9</td>
</tr>
<tr>
<td>Nature of scientific theories</td>
<td>1 and 7</td>
</tr>
<tr>
<td>Role of imagination and creativity</td>
<td>3</td>
</tr>
<tr>
<td>Observation and inference</td>
<td>8 and 12</td>
</tr>
<tr>
<td>Scientific theories and laws</td>
<td>5 and 6</td>
</tr>
<tr>
<td>Social character of science</td>
<td>4</td>
</tr>
<tr>
<td>Indigenous knowledge</td>
<td>10</td>
</tr>
<tr>
<td>Science, Technology and Society</td>
<td>11</td>
</tr>
</tbody>
</table>

As mentioned earlier the criteria listed in the classroom observation schedule identify observable teacher behaviours and learner actions that would indicate the mediation of stated NOS aspects and/or a classroom conduct aligned with the principles of the National Curriculum Statement (NCS). For each of the eight NOS aspects, criteria in category 1 relate to the teachers’ observable classroom actions that do not reflect any NOS understanding and thus is deemed as ‘Traditional’. Criteria in category 2 indicate teacher actions that would imply some understanding of NOS and teacher behaviours indicating a more developed understanding of NOS relate to criteria listed under category 3 where as criteria in category 4 refer to explicit classroom practices which reflect an informed understanding of NOS. For example, regarding the empirical nature of scientific knowledge, a teacher in category 1 would focus on scientific principles and laws followed by experiments demonstrated by the teacher to verify the laws whereas a teacher in category 2 would explain the concepts...
involved and discuss the various aspects of the experiment while a teacher in category 3 would engage the learners in scientific investigations to construct scientific knowledge. A category 4 teacher on the other hand would involve the learners in productive discussions to consider all aspects of the investigation with a view towards developing an understanding of how science is done. Therefore, teachers who fall under categories 2 and 3 are classified as ‘Transitional’ since their classroom behaviours resemble either a less informed or a more developed conception of NOS while category 4 teachers are classified as ‘Informed’ since their practices reflect a well developed understanding of NOS.

Learning Outcome one (LO1) and Learning Outcome two (LO2) in both the natural sciences and the physical sciences Learning Areas of the NCS require teachers to engage learners in classroom transactions to assist them in linking conceptual ideas with epistemological issues. In order to meet this requirement, teachers need to have an informed understanding of the NOS conceptions embedded in the questionnaire items as the necessary pedagogic skills and strategies for effective implementation of the curriculum. For example, a teacher who engages learners in scientific inquiry activities and meaningful discussions assist the learners to develop their knowledge, skills and values to achieve LO1 and LO2 as opposed to a teacher who relies on teacher demonstrations in support of stated scientific theories. Engaging learners in classroom activities and discussions related to the impact of scientific and technological developments on society and the physical environment as well as discussions on the role of indigenous knowledge when appropriate in a science lesson would meet the requirements of Learning Outcome three (LO3) which deals with STS issues in the NCS. The criteria listed in the classroom observation schedule include these important aspects and other elements of the Critical Outcomes that the learners are required to develop as envisaged by the NCS.
Each classroom practice was analysed using the classroom observation schedule by observing the recorded classroom action which reflected explicitly or implicitly the criteria listed in the Schedule. For each of the NOS aspect, a teacher was judged to be ‘Traditional’, ‘Transitional’ or ‘Informed’ if he/she displayed behaviours aligned with 50% or more of the criteria listed under each of the respective categories. If a teacher did not display an action related to the NOS aspect which should have formed part of the lesson it is noted as ‘Not Discussed’ (ND) and if the topic under discussion did not involve a specific NOS aspect it is noted as ‘Not Relevant’ (NR).

The analysis of the classroom practice of each teacher was carried out by the researcher and iterated independently by a second researcher. In case of disagreement on any item, the videotape was viewed again to gain clarity in the context of the whole lesson.

4.1 Non-NMMU Teachers

4.1.1 T116

The lesson was on ‘Acids and Bases’ in a Grade 7 class and the teacher introduced the lesson by listing the physical properties of common laboratory acids and bases. She then demonstrated how to identify an acid and a base using pieces of litmus paper. After being prompted by the teacher, the learners repeated in a chorus the test for acids and bases written on the board. The teacher mentioned few household substances which are either acidic or basic. The fact that the teacher did not take advantage of the variety of household substances which are acidic or basic and did not use some of the substances familiar to the learners which could be used as home made indicators in the class, shows that she places greater emphasis and trust on knowledge given in the text book about acids and bases. Neutral substances did not form part of class discussion other than the statement from the teacher that an acid neutralises a base.
The lesson proceeded to the next stage when the teacher demonstrated the characteristic reactions of acids with metals and carbonates. The neutralisation reaction of acids and bases was not demonstrated probably because the school laboratory did not have any stock of liquid indicators and the teacher might have been unaware of home made indicators. However, the teacher engaged the learners in discussions about the test for hydrogen and carbon dioxide gases as evidence for the gases produced during the reactions. She pointed out to the learners that one could not distinguish between an acid and a base by looking at the colour of the solution implying that drawing inferences based on sensory experience is not always correct. The lesson ended with the teacher stating the dangers of handling acids (no mention of the bases) but omitted to relate the danger with the strength of an acid implying that household acidic substances are essentially of a different category. A summary of the categorisation of the lesson is given below.

Table 4.3:

*Categorisation of the lesson on acids and bases*

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Scientific Method”</td>
<td>Transitional</td>
</tr>
<tr>
<td>Nature of theories</td>
<td>Transitional</td>
</tr>
<tr>
<td>Imagination and creativity</td>
<td>Traditional</td>
</tr>
<tr>
<td>Observation and inference</td>
<td>Transitional</td>
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<tr>
<td>Scientific theories and laws</td>
<td>Transitional</td>
</tr>
<tr>
<td>Social character of science</td>
<td>Traditional</td>
</tr>
<tr>
<td>Indigenous knowledge</td>
<td>Traditional</td>
</tr>
<tr>
<td>Science, Technology and Society</td>
<td>Traditional</td>
</tr>
</tbody>
</table>
The lesson was on Boyle’s law to illustrate the relationship between pressure and volume for a fixed mass of gas at constant temperature in a Grade 11 class. The teacher started the lesson by writing an incomplete statement of Boyle’s law (“Volume is inversely proportional to the pressure when temperature is constant”) on the black board and asked the learners to develop a question to investigate the law. A learner suggested “Is volume inversely proportional to pressure when temperature is kept constant?” and the teacher wrote the question on the board. Without any further discussion about the question the teacher gave a brief description of the Boyle’s law apparatus to use in the investigation and stated the independent and dependent variables involved. No explanation was provided regarding the choice nor was there any mention of the variables to be controlled. The focus was on taking some readings of pressure and volume and to enter the readings in a table which the teacher had drawn on the board.

There was no explanation regarding the concepts of pressure exerted by the trapped air in the glass tube. The teacher incorrectly indicated the volume of liquid to the learners as representing the volume of air. He then asked the learners to take the readings in groups by pumping air into the apparatus with the inlet valve tightly closed. He instructed them what graphs to draw using the data collected and asked them to complete the graphs as homework.

The focus of the whole lesson was on verifying the relationship between pressure and volume by recording a set of readings using the apparatus and worksheets given on the black board. There was no discussion related to the theoretical aspects underpinning Boyle’s law.
Table 4.4:

Categorisation of the lesson on Boyle’s Law

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Scientific Method”</td>
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<td>Traditional</td>
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<tr>
<td>Scientific theories and laws</td>
<td>Traditional</td>
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<tr>
<td>Social character of science</td>
<td>Not discussed</td>
</tr>
<tr>
<td>Indigenous knowledge</td>
<td>Not relevant</td>
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<tr>
<td>Science, Technology and Society</td>
<td>Not discussed</td>
</tr>
</tbody>
</table>

4.1.3 T 96

The lesson was on redox reactions presented to a group of Grade 12 learners. The teacher started with the definition of redox reactions, the theory of electron transfer between magnesium and oxygen and the reaction equations. He then wrote the definition and chemical equations on the blackboard and the children copied the notes in their books. There was no discussion in the class about the concepts involved in redox processes. The explanations provided were focused on the number of electrons transferred and how to manipulate the numbers to balance the chemical equation.

After the notes on the board were copied by the learners the teacher demonstrated the reaction of zinc and copper sulfate as an example of redox reactions. He asked the learners to identify the colour zinc metal at the end of the reaction. When learners were unable to provide a reason for the change in colour of zinc, the teacher stated that the brown substance was copper without giving any further explanation. Then he demonstrated the reaction between magnesium and copper sulfate solution. Again there was no explanation for the colour change.
of the solution on the basis of the redox process involved other than the teacher pointing out that this reaction was faster than the previous reaction indicating that magnesium was more reactive than zinc.

Much of the emphasis of the lesson was to develop the skills of learners in balancing chemical equations and to encourage them to learn by rote the principles of redox reactions. The experiments demonstrated did not seem to serve much purpose other than showing learners that what they saw should be called as redox reactions and probably to fulfil the requirement that a science lesson should necessarily involve experiments.

Table 4.5:

**Categorisation of the lesson redox reactions**

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>Category</th>
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<tbody>
<tr>
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<tr>
<td>Science, Technology and Society</td>
<td>Not discussed</td>
</tr>
</tbody>
</table>

4.2 **BEd 1 teachers**

4.2.1 **T16**

The teacher introduced the topic of water cycle to a Grade 7 class by asking the learners to name the sources of water in their environment. She guided them by relevant questions to name the original source of water. The process of evaporation and condensation
was explained by the teacher using a chart on water cycle. The lesson concluded with each group placing an empty petri dish in a bowl of water and the bowl was closed with clear plastic and a small pebble was placed on top of the plastic cover. The learners then placed the bowl in the sunlight outside the classroom to be taken in during lunch break. The investigation was intended to simulate water cycle in nature. However, the teacher did not engage learners in discussions about drawing parallels between the water cycle in nature and the investigation.

Although the teacher encouraged group discussion for mostly close-ended questions, alternative ideas expressed by the learners were not discussed. The focus appeared to be only on ‘right’ or ‘wrong’ answers and the search for the former was encouraged. However, the teacher used examples from children’s daily life experiences to explain the difficult concept of evaporation and condensation. Even though the learners were engaged in an appropriate investigative activity to simulate evaporation and condensation, the different aspects of an investigation, in particular the control of necessary variables did not form part of the discussion. As was in the case of T116, the practice of learners repeating in chorus the statements written on board gave the impression that rote learning of concepts and terms develop understanding in science. The sustainable use of water and the important aspect of clean drinking water particularly in a rural community were not discussed.
Table 4.6:

*Categorisation of the lesson on the water cycle*

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>Category</th>
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<tbody>
<tr>
<td>“Scientific Method”</td>
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<tr>
<td>Indigenous knowledge</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Science, Technology and society</td>
<td>Not discussed</td>
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</tbody>
</table>

4.2.2 T 25

The lesson began with the teacher introducing particle nature of matter to a group of Grade 7 learners. The main topic of the lesson was phases of matter and phase changes. The teacher used the example of a piece of chalk and chalk powder to illustrate the composition of matter from particles. The emphasis on definitions, principles and facts was evident when learners were prompted several times to recite rote learned definitions. Whatever was written on the black board was repeated by learners in a chorus.

However, at times it was also evident in the lesson that understanding in science involves scrutiny of observations and the development of plausible explanations to account for the observed phenomena. To account for matter occupying space, the teacher engaged learners in discussions related to the air in an inflated balloon and the space occupied by water inside a jug. After each demonstration, which also involved learners, the teacher engaged the learners in explaining the concepts involved.
During the lesson much time was also wasted in giving a detailed explanation of matter by going into the details of atoms, elements, compounds, hydrogen, oxygen and formation of water giving the impression that the teacher believes a science lesson should constitute a plethora of scientific terminology and activities not related to achieving the outcomes of the lesson.

The lesson concluded with the demonstration of melting ice cubes and boiling water to illustrate the phase changes in matter. Although not consistent throughout the lesson, the teacher highlighted the importance of evidentiary support to substantiate theoretical claims.

Table 4.7:

*Categorisation of the lesson on particle nature of matter*

<table>
<thead>
<tr>
<th>NOS Aspect</th>
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<tbody>
<tr>
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<td>Not relevant</td>
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<td>Science, Technology and society</td>
<td>Not relevant</td>
</tr>
</tbody>
</table>

4.3 **BEd 2 teachers**

4.3.1 **T 77**

This was a lesson on living and non-living things given to a Grade 5 class. The teacher introduced the lesson by asking learners to choose from list of things on the black board living and non-living things. The list contained things such as rock, chair, plant, car, animals and so
on with which the learners are quite familiar. The learners were actively engaged in group
discussion. As the lesson proceeded each new term introduced was explained by the teacher
in simple language and using appropriate analogies considering learners’ level of
understanding. Often he switched to isiXhosa to explain difficult terms or concepts. This
approach was maintained throughout the lesson.

The teacher guided the learners skillfully in developing an understanding of living
things by identifying and describing key elements that would constitute essential features of
living organisms. Observational data was critically examined to categorise living and non-
living things. The judicial use of analogies implies the role of imagination and creativity in
developing understanding in learners. Although the teacher integrated relevant aspects of
other learning areas such as photosynthesis, opportunities to incorporate elements of IKS
were not fully exploited in the lesson.

Table 4.8:

*Categorisation of the lesson on living and non-living things*

<table>
<thead>
<tr>
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<th>Category</th>
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</thead>
<tbody>
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</tr>
<tr>
<td>Observation and inference</td>
<td>Informed</td>
</tr>
<tr>
<td>Scientific theories and laws</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Social character of science</td>
<td>Transitional</td>
</tr>
<tr>
<td>Indigenous knowledge</td>
<td>Traditional</td>
</tr>
<tr>
<td>Science, Technology and society</td>
<td>Not relevant</td>
</tr>
</tbody>
</table>
The teacher presented a lesson on the formation of tides to a Grade 9 class. He started the lesson by engaging learners in discussing factors that sustain life on earth. The importance of evidence in determining how planet earth distinguishes itself from other planets formed an important part of the lesson. The teacher’s approach was characterised by the use of open-ended questions to learners and guided them in drawing appropriate conclusions. The questions were carefully designed to promote discussion among learners. Integration of different concepts such as gravitation, position of planets, distances and so on was skillfully managed to develop learners’ understanding.

Towards the end of the lesson the causal reasons for the formation of tides were discussed in detail. The relationship between the strength of gravitational force and distance in causing high tides was explained. The impact of different variables, the size of planets, the sun and the distance between the planets were explained using appropriate diagrams on the black board. Learners were encouraged to deduce the effect of the two variables, size of the planets and the distance, in inferring which had a greater impact with respect to the law of gravitation. Although the phases of the moon formed part of the discussion, the opportunities to integrate IKS with respect to the phases of the moon were not exploited.
Table 4.9:

*Categorisation of the lesson on tides*

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Scientific Method”</td>
<td>Informed</td>
</tr>
<tr>
<td>Nature of theories</td>
<td>Informed</td>
</tr>
<tr>
<td>Imagination and creativity</td>
<td>Informed</td>
</tr>
<tr>
<td>Observation and inference</td>
<td>Informed</td>
</tr>
<tr>
<td>Scientific theories and laws</td>
<td>Informed</td>
</tr>
<tr>
<td>Social character of science</td>
<td>Transitional</td>
</tr>
<tr>
<td>Indigenous knowledge</td>
<td>Traditional</td>
</tr>
<tr>
<td>Science, Technology and society</td>
<td>Not relevant</td>
</tr>
</tbody>
</table>

4.3.3 T 75

The lesson was on electric circuits in a Grade 9 class. The teacher put up a chart on the board with the chart showing different diagrams of connecting a light bulb with one cell and one wire and some diagrams with two cells. Learners were asked to make predictions regarding which type of connections would light the bulb based on the diagrams shown. There was animated discussion among the learners and all responses were recorded on the board irrespective being correct incorrect. Learners were encouraged to provide the causal reasons for their predictions.

The teacher then invited three learners at a time to the front of the class and asked them to test each prediction recorded on the board using the materials provided on the front desk. Although the class has more boys than girls, he included at least one girl in the invited group. He asked them to make the connections facing the class so that all learners could observe what they were doing. This was a small classroom with nearly 35 learners. Ideally the room can accommodate a maximum of 20 learners. In an overcrowded classroom the usual
practice is teacher demonstrations. Under these circumstances the teacher employed an excellent strategy to involve learners in the practical activity. The teacher recorded the result of each activity on the board against the result of the predictions made earlier. Then he engaged the class in a discussion regarding why certain connections lit up the bulb and others did not. The discussions lead to recognising the conditions such as the necessity of a complete path and connections between metallic points for a bulb to light up.

In the next stage of the lesson, the teacher put up another chart containing two simple circuit diagrams, one with a cell, a switch and a light bulb and another similar diagram with two cells. He asked the learners to predict whether the bulb will light up with the switch open and then closed as well as make predictions regarding the brightness of the bulb in the different connections. The strategy employed in the first stage of the lesson with learners performing the activity in front of the class was used. The ideas developed during the first stage of the lesson were revisited during the discussion with reference to an open and closed circuit. A gap in the circuit when the switch was open was compared to the glass part of the bulb touching the positive terminal of a cell during the first stage of the lesson. He used the electric switch on wall to link the circuit made in the classroom to learners’ daily life experience. He then engaged the class in discussing the reasons for the bulb to be brighter when two cells were used linking the concept of energy to the brightness of bulbs and the number of cells used.

The lesson ended with the teacher reflecting on the key concepts developed and asked the learners to copy the circuit diagrams in their books. He asked them to write which bulbs would light up and which ones would not light up including the reasons in each case. The only aspect which was missing in the lesson was reference to societal issues such as dangers of tampering with electric circuits at home and the importance of the economical use of
electrical energy. It must be noted, however, that the teacher pointed out the distinction in the use of terms such as cell and battery in everyday life and in scientific context.

Table 4.10:

_Categorisation of the lesson_

<table>
<thead>
<tr>
<th>NOS Aspect</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Scientific Method”</td>
<td>Informed</td>
</tr>
<tr>
<td>Nature of theories</td>
<td>Informed</td>
</tr>
<tr>
<td>Imagination and creativity</td>
<td>Informed</td>
</tr>
<tr>
<td>Observation and inference</td>
<td>Informed</td>
</tr>
<tr>
<td>Scientific theories and laws</td>
<td>Informed</td>
</tr>
<tr>
<td>Social character of science</td>
<td>Informed</td>
</tr>
<tr>
<td>Indigenous knowledge</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Science, Technology and society</td>
<td>Transitional</td>
</tr>
</tbody>
</table>

4.3.4 _Summary of classroom observations_

A summary of the categorisation of the eight lessons observed is presented in Table 4.11. The summary provides an overview of the classroom practices of eight teachers from the three groups, i.e. the non-NMMU, BEd 1 and BEd 2 groups.
Table 4.11:

Summary of the categorisation of lessons

<table>
<thead>
<tr>
<th>No</th>
<th>Description</th>
<th>Non-NMMU Teachers</th>
<th>Bed 1 Teachers</th>
<th>BEd 2 Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T116</td>
<td>T106</td>
<td>T96</td>
</tr>
<tr>
<td>1</td>
<td>“Scientific Method”</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Nature of theories</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Imagination and creativity</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Observation and inference</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Scientific theories and laws</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Social character of science</td>
<td>1</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>7</td>
<td>Indigenous knowledge</td>
<td>1</td>
<td>NR</td>
<td>ND</td>
</tr>
<tr>
<td>8</td>
<td>Science, Technology and Society</td>
<td>1</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

Note: 1 = Traditional; 2 = Transitional; 3 = Transitional; 4 = Informed; ND = Not discussed; NR = Not relevant

5. CHAPTER SUMMARY

In this chapter the presentation of the results begins with the findings from the statistical analysis of the responses to a twelve-item, Likert-scale questionnaire received from a total of 136 teachers who belong to three separate groups, i.e. non-NMMU, BEd 1 and BEd 2 groups. Items for which there was a statistically significant difference between the groups have been highlighted as well as items which did not show any statistically significant difference. Subsequently a graphical analysis of the responses to each questionnaire item was...
presented to investigate patterns and differences in the views of NOS conceptions held by the three groups.

Findings based on the interviews held with thirty teachers selected from the three groups provide a deeper understanding of the reasons that underpin the views of NOS held generally by the teachers involved in this study. In addition, the responses to the interview questions indicate the questions which were found to be ambiguous by some teachers.

The classroom observation data generated from video recordings of the lessons of eight selected teachers provide sufficient evidence to judge whether the classroom practice is aligned with their NOS conceptions as well as the principles of the National Curriculum Statement (NCS). The data gathered from the three sources, i.e. questionnaire, interviews and classroom observations form the basis of discussions in the next chapter.
CHAPTER FIVE
DISCUSSION

1. INTRODUCTION

This chapter critically examines the quantitative data generated from the administration of the questionnaire and the qualitative data gathered via interviews and classroom observations of selected teachers. The quantitative data is interrogated to discern what nature of science (NOS) conceptions are reflected in the teachers’ responses to the items in the questionnaire as well as to seek any patterns or contradictions that emerge with respect to their views on the nature of scientific knowledge and the scientific enterprise as a human activity.

The interview data is analysed to see if the teachers’ views of NOS are consistent with the views indicated in their responses to the questionnaire and to probe for the possible origins of these views. The qualitative data generated with respect to the NOS aspects are based on classroom actions as recorded in the classroom observation schedule. The analysis of the classroom practices of the three groups of teachers (Non-NMMU, BEd 1 and BEd 2) are used to provide an indication of whether the exposure to explicit instructions in NOS that the BEd 2 teachers received impacts on their classroom behaviour. The discussion includes whether the NOS conceptions reflected in the classroom practice provide an adequate understanding of the NOS in order for the participating teachers to implement the South African revised science curriculum (NCS) effectively.
2. QUESTIONNAIRE RESPONSES

The specific NOS aspects that form the basis of discussion of the teachers’ responses to the questionnaire items are the nature of scientific knowledge, ‘scientific method’, social and cultural aspects of science, distinction between observation and inference, role of creativity and imagination and the distinction between scientific theories and laws. With the exception of item 11 (views regarding the status of technology with respect to science) the twelve open-ended Likert-scale statements in the questionnaire can be broadly classified as either referring to the nature of scientific knowledge from an ontological perspective or to the epistemology of knowledge development in science. Statement 11 requires respondents to express their views on the relationship between science and technology.

The trends in current research in science education and in the recent past (Akerson, Buzzelli & Donnelly, 2008; Tsai, 2006; Dekkers, 2006; Bell et al., 2000; Lederman, 1999) suggest that the intention to promote scientific literacy in schools requires teachers to develop informed understandings in the above key aspects of NOS, consider the NOS elements as important instructional objectives and be able to develop appropriate pedagogic practices for NOS within the context of the science curriculum. As such, the teacher’s views to each of the elements are discussed in terms of patterns, contradictions and philosophical perspectives emerging from their responses to the questionnaire items.

One of the objectives of the current study is to determine whether explicit instruction in NOS would contribute towards improved NOS understandings in teachers. Considering the three groups of teachers, i.e. the Non-NMMU, BEd 1 and BEd 2 teachers involved in this study, it is only the BEd 2 group that is known to have received direct instruction in NOS while the BEd 1 teachers were recipients of implicit instruction in NOS. Therefore a
comparison of the NOS views of the BEd 2 teachers with the views of the other two groups will be highlighted.

2.1 Patterns, contradictions and philosophical perspectives

To explore teachers’ conception of science, items in the questionnaire referring to the ontological status of science are grouped together. When investigating their perceptions regarding the process of knowledge development in science, the items are grouped together in separate conceptual schemes which relate to the scientific enterprise as a human endeavour. For example, statements referring to the ‘truth’, nature of theories, ‘discovery’ versus ‘invention’ of theories, and the “tentative” nature of theories relate to the ontological aspect of science. Similarly the statements which refer to the processes in science constitute the category related to the epistemological character of science. Although, for the purpose of discussion, such a categorisation is useful, it must be noted that the categories are not mutually exclusive since the image of science one develops is inherently linked to the methods of science. For example, if science reveals immutable truths about the physical world, then it will be a contradiction if one claims that human imagination and creativity play a significant role in the development of scientific knowledge.

The responses to the questionnaire items described in the previous chapter are analysed based on the above scheme to examine whether the teachers in this study hold an informed view of NOS, or whether they display contradictions in their views regarding the different aspects of NOS. The responses are also examined to discern the teachers’ views on the philosophy of science. The results of this investigation are then compared with the findings of similar research in South Africa and elsewhere.
2.1.1 Nature of scientific knowledge

The responses to statements one, six and seven, i.e. that ‘scientific knowledge reveals certain truth about nature’, ‘scientists discover theories and laws’ and ‘scientific theories may change with time’, respectively are considered to express teachers’ views on the status of the nature of scientific knowledge. The perception that scientists are engaged in uncovering the truth about the natural world reflect a naive realist (traditional) image of science, whereas the view that scientific theories are revisionary and may be subject to refutation in the light of new evidence, suggest a more informed and relativist (contemporary) view of science.

Only about half of the 136 teachers who participated in this study subscribe to a relativist perspective that scientific theories may not reveal the ‘truth’ about nature in responding to statement one. However, the percentage of BEd 2 teachers who hold a contemporary view is significantly higher than the other two groups of teachers (63% as opposed to 34% and 43% of Non-NMMU and BEd 1 teachers, respectively) suggesting a shift in teachers’ views, possibly as a result of explicit instruction in NOS. This inference is similar to those made in a case study by Ogunniyi (2006) of two Western Cape teachers who changed the views of science from a traditional perspective to a more informed view as a result of a discursive course on the philosophy of science.

When only 50% of all teachers view science as revealing the ‘truth’, a majority of the teachers (about 77%) believe that scientific theories change with time. According to Lederman et al. (2002:502) “Scientific claims change as new evidence, made possible through advances in thinking and technology is brought to bear on these claims, and as extant evidence is reinterpreted in the light of new theoretical advances ...”. It is not clear from the questionnaire data that teachers’ conceptions of theory change stem from an informed perspective or a simplistic view as reported by Dekkers and Mnisi (2003: 31). Their
qualitative study in the Limpopo province explored science teachers’ conceptions of NOS and they found that most teachers believe scientific theories to be tentative as a result of the meaning ascribed to theory in a colloquial language sense as “guess” or “possibility”.

The fact that nearly half of the teachers subscribe to a realist position by responding that science uncovers the truth, while 77% of teachers subscribe to a relativist position by indicating that theories are tentative, it is quite possible that at least a quarter of all teachers in this study hold dichotomous views about scientific knowledge, i.e. theories are true statements about nature or natural phenomena, but the theories may change over time. This anomaly is further illustrated as most participants (nearly 80%) believe that scientists discover theories and laws rather than construct scientific knowledge. The belief held by the majority of teachers in this investigation, including the BEd 2 teachers, that there is an external reality - the knowledge of which is waiting to be uncovered by scientists, reflect a realist conception of science (Chalmers, 1999). Considering the fact that a substantially larger proportion of teachers, despite the earlier references to external reality, subscribe to the view that scientists discover theories (as opposed to those who believe that science reveals the truth), it is possible that teachers may not be consciously aware of the implication of the distinction between the terms ‘discovery’ and ‘invention’ as Clough (2007) suggests that whether scientists discover or whether they invent knowledge mostly depend on the concept being addressed. Interview data, considered later in this chapter provide further clarity on this issue.

2.1.2 The ‘Scientific Method’

Lederman et al. (2002: 501) claim that “One of the most widely held misconceptions about science is the existence of the scientific method.” They trace the origins of this belief to Francis Bacon’s assertion in the 17th century that inductive method produced “certain” knowledge in science. Nearly all the participants in this investigation hold the view that the
development of scientific knowledge involves a rational, step-by-step process (Statement 2). This perception is fairly uniform across the three groups of teachers with only five percent of BEd 2 teachers holding an alternative view. Considering that this is only one of two items in the questionnaire that none of the respondents had any doubt about, and to which a quarter of all teachers expressed their views quite strongly, it is reasonable to assume that most teachers believe that scientists follow a set, sequential method to develop knowledge. These findings concur with the results of a study by Callagher (1991) who noted that most of the 27 secondary school science teachers in his sample stressed the importance of the ‘steps of scientific method’ described in textbooks, conveying the impression that science is a body of immutable and objective knowledge.

The strong belief in an established sequential process of science displayed by the teachers implies that science cannot be done without resorting to experiments. This view corresponds to an empiricist view of science (Miller, 1993) which asserts that theories need to be tested to see if they hold true against observational evidence, as opposed to the positivist perspective which assumes the existence of an objective reality the knowledge of which can be obtained by empirical methods. Whatever subtleties of understanding may be held, Hodson (1998) suggests that the frequent use of worksheet-based, recipe like experimental processes in science teaching conveys the message to students that there is a single method of science, something that was reflected in a study of twenty nine gifted Taiwanese students conducted by Liu and Lederman (2002). Akerson and Hanuscín’s (2007) three-year professional development programme involving six elementary science teachers revealed that when teachers get ‘indoctrinated’ in a set way of conducting investigations it is difficult for them to consider alternate methods of scientific inquiry such as observational studies or modelling. It is reasonable to assume that the teachers in this study have been ‘indoctrinated’ to believe in the ‘scientific method’, and that this belief will be highly resistant to change.
The unanimous response to statement two indicating that there is a set method in science reflects a realist perspective of science. However, this perception is not congruent with the view held by almost half of the teachers that scientific theories may not reveal the ultimate truth (Statement 1). This implies that although most teachers adhere to the scientific method, they do not necessarily believe that the method leads to the ‘truth’. Therefore, from the responses to statements one and two it cannot be induced that the majority of teachers in this investigation generally subscribe to a realist image of science and that this inductive inference needs further scrutiny by analysing teachers’ responses to items nine and ten.

More than one third of the teachers do not believe that scientific method is the only way to study nature (Statement 9), which suggests that they consider other ways of knowledge development as valid, i.e. that they hold a relativist perspective of science. However, nearly 16% of Non-NMMU and BEd 2 teachers did not express an opinion on this issue, indicating that either they are not sure of the meaning of the expression ‘scientific method’ or they are undecided about the issue. It would seem that the uncertainty can be largely attributed to the former as nearly two third of all teachers respond that indigenous knowledge must be regarded as scientific knowledge (statement 10), with fewer teachers undecided on this issue. The conviction in their view is reflected by the fact that nearly 25% of the responding teachers strongly disagreed with the statement that “indigenous knowledge cannot be regarded as scientific knowledge”. The relativist position held by the teachers could probably be due to the requirement of the National Curriculum Statement which explicitly highlights the importance of Indigenous Knowledge Systems (IKS) and encourages teachers to infuse IKS into the teaching programme. The shift in teachers’ perspective to what appears to be a more relativist view of science implies that curriculum reforms can play an important role in shaping teachers’ epistemic views about science.
2.1.3 The social and cultural aspects of science

Regarding the socio-cultural impact on science (Statement 4) nearly 60% of all participants hold the view that science is influenced by social, cultural and political contexts. A statistically significant difference between the groups was noted for this item. A steady progression from the Non-NMMU group (41%) to the BEd 2 group (78%) holding an informed perspective on the social and cultural aspects of science suggests the influence of both implicit (BEd 1) and explicit (BEd 2) instruction in NOS course the teachers may have had an impact. Further evidence for this deduction is the fact that approximately 20% of the BEd 2 teachers, as opposed to 10% in the BEd 1 group and 11% in the Non-NMMU group, strongly supported this view. Similar findings were obtained by Akerson, Morrison and McDuffie (2006) in an investigation of the impact of an explicit NOS course on 19 pre-service elementary teachers. According to the authors a substantial improvement regarding the social and cultural influences on science was found in the participants’ views after the completion of the course.

A multicultural perspective of science suggested by Grange (2004: 204) “…that science is culturally produced and that cultures have disparate ways of understanding the natural world and that different ways of knowing should be recognised as science” reflected in the teachers’ response to the statement on the status of IKS is congruent with their response to the statement on the social and cultural aspects of science. In a similar study to explore the NOS conceptions of a cohort of teachers in the Limpopo Province with respect to teachers’ conceptions on science, religion and traditional medicine, Dekkers and Mnisi (2003: 30) state: “While teachers are aware of differences in the processes used to generate and validate these kinds of knowledge, the status of these different kinds of knowledge is not seen as different.” According to the authors a knowledge system is acceptable as long as it is based on validation.
by an authority or expert such as priests using the bible or sangomas communicating with the ancestors or scientists conducting experiments. This view does appear to represent an extreme version of relativism as “anything goes” suggested by some philosophers (Chalmers, 1999). Whether the majority of teachers in the current study subscribe to a similar philosophy based on their responses to statements four and ten is uncertain at this stage, but is examined further when discussing the interview data generated.

The relativist position held by approximately two third of the teachers in this study regarding the social character of science appears to contradict their responses to statements two and six where the majority of teachers expressed an empiricist and a positivist view respectively. Lederman et al. (2002) suggest that there are two types of cultural influences on science. Firstly the influence of external contextual factors such as social, economical, cultural and political imperatives on knowledge development, and secondly factors inherent to the culture of science itself such as the theoretical assumptions held by scientists, and tacit understanding among scientists regarding the process and validation of the knowledge developed. The data seems to suggest that allegiance to a contextual view of science expressed by teachers is due to the influence of the former. Considering that the science taught in South African schools is modelled on western science and the tradition in western science entails intense public scrutiny of knowledge claims, the dialectic between multicultural view of science (Grange, 2004), or the incommensurability of paradigms (Kuhn, 1970), and the science practised in schools, demands that teachers develop an understanding of the appraisal of knowledge development in mainstream science.

2.1.5 Observation and inference

Questionnaire items eight and twelve relate to the subjective nature of scientific knowledge and are designed to probe whether teachers believe scientific knowledge is
objective because all scientists see things the same way and interpret data the same way, or whether they perceive that knowledge generation is influenced by scientists’ prior beliefs and theoretical assumptions. Chalmers (1990: 41) suggests that the reliance on objective observations carries the assumption that science is based on “secure foundations” and thus the knowledge developed is trustworthy reflecting a positivist view of science. On the other hand the notion that scientists from different cultures may draw different conclusions for the same phenomenon based on their background beliefs, research paradigms, training or socio-political contexts, expresses a contemporary view of science (Brown, 2006).

Fifty seven percent of all of the participating teachers displayed a contemporary view of science by disagreeing with the notion that two independent scientists draw the same conclusion from observing a natural phenomenon (Statement 8). The BEd 2 teachers (73%) show a substantially greater belief with regard to this view compared to the non-NMMU teachers (52%), and their conviction is evident as 24% of the BEd 2 teachers opted to choose the ‘Strongly Disagree’ option for this statement. This improvement may possibly be attributed to the explicit instruction that these teachers received during the NOS course where they were engaged in discussions using examples such as the ‘duck-rabbit’ and other illustrations designed to be perceptually dualistic to highlight the influence of prior conceptions in interpreting data.

Item twelve in the questionnaire provides a more explicit distinction between the objectivity of observations and the subjective nature of conclusions drawn. Khishfe and Lederman (2006: 400) point out that “Observations are descriptions of nature that can be directly accessed by the senses, whereas inferences cannot be directly accessed by the senses”. Sixty four percent of the teachers seem to be of the opinion that the same data could be interpreted differently by scientists. However, a relatively large proportion of teachers
(21%) were undecided on this aspect of NOS suggesting that some teachers may not be clear about the meaning of the terms ‘objectivity’ and ‘subjectivity’. Overall a contemporary view of the subjective nature of scientific knowledge displayed by more than half of the teachers with respect to items eight and twelve is congruent with their views on the social character of science in response to the item four. The informed perspective regarding the subjective and inferential aspects of scientific knowledge expressed by more BEd 2 teachers compared to the other two groups points towards the probable impact of explicit instruction in NOS. Similar results were obtained by Akerson et al. (2006) in a study of 19 pre-service elementary teachers. These researchers found that the teachers’ perceptions on several aspects of NOS improved immediately after participation in an explicit course on NOS, but after five months the majority of teachers reverted back to their original naive conceptions.

When citing the findings of the study in the Limpopo province (Dekkers & Mnisi, 2003) earlier, it was suggested that the teachers in this study might hold what might be interpreted as an informed view of the tentative nature of scientific theories because of an inadequate understanding of the term ‘scientific theory’. But it would appear from the responses to the questionnaire items 4, 8 and 12 that the teachers may be considering the revisionary nature of theories in light of the subjectivity involved when scientists interpret observations much in line with the claim by Chalmers (1990: 59) that “What is correct about theory-dependence of observation thesis is not that observation in science lacks objectivity, but that the adequacy and relevance of observation reports within science is subject to revision”.

2.1.6 Creativity and imagination

About sixty seven percent of all teachers in this study hold a naive view regarding the above aspect of NOS as reflected in their response that scientists use imagination and
creativity only at the design stage of investigations. The fact that very few teachers (only 5%) were uncertain in responding to this item, and that nearly a quarter of the teachers opted to respond by choosing the ‘Strongly Agree’ option, indicates that the participants were clear in their conviction regarding this aspect of NOS. The results concur with the findings from similar studies by Abd-El-Khalick (2001) and Dekkers and Mnisi (2003).

A case study of two teachers by Schwartz and Lederman (2002) revealed that the teachers in the investigation showed substantial improvement regarding the creative aspect of NOS after attending a course designed to develop the pedagogical content knowledge with respect to NOS. Similar results were obtained by Cochrane (2003) to investigate the effects of a science methods course on 15 elementary education students enrolled in a pre-service programme. In the case of the BEd 2 group, where 44% expressed an informed view as opposed to an average of 18% teachers in the other two groups provides some evidence on the impact of the NOS course in this study. Similarly, a study involving a group of gifted students in Taiwan by Liu and Lederman (2002) showed that at the end of the intervention half of the students believed that scientists use imagination and creativity throughout the process of knowledge development, but the majority of these students could not support their views in relation to the examples provided in the questionnaire.

The untenable faith in the empirical character of science reflected in the rejection of the creative aspect of science by the majority of Non-NMMU teachers is in agreement with their responses to the questionnaire items two and six, i.e. scientists discover knowledge by adhering to a set procedural approach discussed earlier. McComas (1996: 5) argues that the way science is practised in the classrooms and the engagement of students in step-by-step practical activities “…serve to work against the creative element in science” and project a “dry, clinical and uninteresting” image of science to many students.
Although the response to the questionnaire item with respect to the creative element of science by the majority of non-NMMU teachers is consistent with their responses to the empirical nature of science, they seem to contradict in their responses to other aspects of NOS. For example 67% of all teachers believe that scientists infer different explanations from observed data (items 8 and 12) only about 28% of teachers subscribe to the creative aspects of scientists. In a case study on three elementary teachers to assess the impact of a three-year professional development programme targeting the NOS conceptions of teachers, Akerson and Hanuscin (2007) found that the teachers held conflicting views regarding NOS aspects at the beginning of the course. According to the researchers, before the advent of the course, the teachers believed that science is subjective and at the same time subscribed to the view that scientists discover the “truth” by empirical means. With regard to the teachers in this study the inconsistency indicates that teachers associate the inferential character of science with the cultural and theoretical assumptions of scientists rather than the creative aspects. This adds credence to the earlier deduction that teachers hold a relativist position with regard to the social character of science mainly due to the emphasis given to indigenous knowledge in the revised science curriculum.

2.1.7 Scientific theories and laws

Responses to item five in the questionnaire indicate that a majority of the teachers (86%) believe that after successful experimental verification, a theory matures into a scientific law. With 38% of teachers (the highest for all of the questionnaire items) choosing the ‘Strongly Agree’ option and only a few teachers (3%) not expressing an opinion on this item, it seems that the teachers hold a firm belief in the hierarchical status of theories and laws. According to Schwartz and Lederman (2002) the distinction between theories and laws is a difficult construct for teachers. From the responses to the questionnaire item it would appear
that teachers in this investigation do not perceive theories and laws as different and important entities in science constructed by scientists to serve entirely different purposes, with the former designed to describe, explain and predict natural phenomena, while the latter describes the relationships in the observed phenomena.

McComas (2003: 152) asserts that laws and theories are important “tools and products of modern science and as such lie at the heart of understanding how science functions”. Teachers and students generally tend to believe that laws are superior to theories (Akerson et al. 2006), and that over a period of time theories mature to become laws. According to McComas the everyday use of the term “law” is extended to the language of science resulting in erroneous conceptions. The implication is that theories are “educated guesses” rather than empirically-supported structures to explain natural phenomena involving ingenuity and creativity on the part of scientists. Laws on the other hand are considered to be “eternal truths” rather than statements which describe causal relationships and are used to predict future events to understand how the physical world works.

It is worth noting that this is the only item in the questionnaire for which a ‘reverse trend’ was shown by the teachers across the three groups i.e. the non-NMMU group displayed a more contemporary view than the BEd 1 teachers who displayed a more informed view than the BEd 2 teachers. This finding is similar to the results of a study conducted by Akerson et al. (2008: 761) to investigate the impact of explicit reflective instructional methods on fourteen pre-service teachers. The authors found that after instruction, even teachers who displayed enhanced understandings on various aspects of NOS were found to hold misconceptions such as “laws can be proven, a theory is tentative” or that “laws are better forms of knowledge”. In the light of this, it does not seem very surprising that the BEd 2 teachers in this investigation still held naive conceptions regarding the relationship between
theories and laws compared to the other two groups of teachers despite having gone through explicit instruction in NOS. However, the fact that as a group they held this misconception more strongly than the other two groups, warrants further investigation.

2.1.8 Science and technology

Approximately 91% of all the teachers in this study disagreed with the notion that science should be considered as separate from technology. This is one of only two items (the other item refers to the step-by-step procedural aspect of science) in the questionnaire to which none of the participants opted for a ‘No Opinion’ option. The fact that none of the participants was undecided about this statement indicates the extent to which they consider science and technology as not being different to science. Similar results are reflected in the study conducted by Tairab (2001) to explore the views on the nature of science and technology held by 95 pre-service and in-service secondary science teachers. The author found that about 75% of both categories of teachers viewed technology as applied science. He suggests the common misconception that technology is applied science has cultural origins in the sense that science educators associate developments in technology as a consequence of developments in science. For example, the invention of dynamo and generator is seen as a result of the developments in the field of electricity in pure science. Unless the distinction between science and technology, as well as the interactive relationship between the two, are made clear to the students by educators the misconception held by the teachers could result in students developing the misguided belief that proficiency in science will naturally lead to enhanced technological skills.

Confusion between science and technology is further exacerbated when research and development (R & D) programmes are seen as scientific research initiating technological and economic development (Wakhungu, 2001). Although science and technology enjoy a
symbiotic relationship, developments in pure science do not necessarily result in
technological advance, while developments in technology can take place independently of the
progress in science. However, in view of the global trends in Science-Technology-Society
(STS) issues as highlighted by Hodson (2003), and in the light of the new science curriculum
in South Africa, it has become increasingly important for teachers to develop an adequate
understanding of science and technology. A deeper understanding as to whether the teachers
in this study regard technology as applied science or whether they perceive science and
technology as complementary obviously cannot be gained by analysing their responses to just
one statement in the questionnaire. Data from other sources such as interviews and classroom
observations might assist in developing a fuller picture with respect to teachers’ conceptions
of science and technology, and are discussed later in this chapter.

2.1.9 Overall philosophical perspectives

The analysis of the responses to the questionnaire items does not indicate that the
teachers in this study subscribe to any particular philosophical perspective with regard to the
ontological implications of science or adhere to any specific epistemological view.
Concerning the image of science in certain respects they are realists and in certain other
respects strong relativist tendencies are shown. Similar tendencies are reflected regarding
their views on the methods of science. This finding is not surprising as Koulaidis and Ogborn
(1995) caution that:

The picture we have drawn suggests rather strongly that future research in this area
should avoid investigations assuming that teachers have one or the other completely
consistent view of the nature of science. The evidence suggests that they hold eclectic
or mixed views, adhering to a diversity of elements taken from different philosophical
perspectives.

(Koulaidis & Ogborn, 1995: 280)
A similar picture emerged when Gwimbi and Monk (2003) investigated the philosophical perspectives of 33 science teachers in Zimbabwe. The authors described the eclectic views held by the teachers as process-oriented, deductivist, decontextualist, relativist and instrumentalist.

2.2 Similarities and differences between Non-NMMU, BEd 1 and BEd 2 teachers

With respect to the procedural aspects of science and the function of indigenous knowledge as one of the ways in understanding the natural world, both the Non-NMMU and the BEd 2 teachers exhibited similar trends, although the BEd 2 teachers tended towards a more informed view of the NOS. Very few teachers in both groups displayed an informed perspective regarding the former while a larger proportion of teachers in both categories held more informed view of the role of cultural knowledge in science. The source for the similarity in the views of the two aspects of NOS could be found in the world views held by different cultures in understanding the physical world. Besides the influence of the NCS requirement with respect to IKS mentioned earlier, cultural influence must be considered as an important factor. According to Jegede (1993: 3) in the African traditional world view “There is often more than one way to view the world. It is therefore in order and natural for the African to view nature relative to the indigenous conceptual model”. From this perspective it appears reasonable for the teachers in this study to exhibit a relativist view of science. Jegede (1993) notes that as the African view of science is that it is something special and which enjoys a high status, an uncritical approach to the methods of science constituting of a set procedure as portrayed in the text books becomes plausible for the teachers. The other two NOS aspects where both groups of teachers display less informed but similar views are related to the distinction between theories and laws as well as the relationship between science and technology.
For statements one, three, four and eight twenty percent or more BEd 2 teachers displayed an informed view compared to similar views expressed by the Non-NMMU teachers, as reflected by the statistically significant difference between these two groups. These statements relate to the “truth” nature of scientific knowledge, the social character of science, the subjective and inferential nature of theories as well as the role of imagination and creativity in developing scientific knowledge. Regarding the tentative nature of science (Statement 7) 13% more BEd 2 teachers than the Non-NMMU group express an informed view.

The data from the questionnaire in table 5.1 shows that there are more BEd 2 teachers than BEd 1 teachers who express informed views on the NOS aspects related to the four statements. A negative number indicates fewer informed responses than the Non-NMMU group.

Table 5.1:

The percentage of BEd 1 and BEd 2 teachers who reflect an informed view of NOS compared with Non-NMMU group with similar views

<table>
<thead>
<tr>
<th>Item No</th>
<th>NOS aspect</th>
<th>% BEd 1 teachers &gt; Non-NMMU group</th>
<th>% BEd 2 teachers &gt; Non-NMMU group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>“Truth” nature of theories</td>
<td>9</td>
<td>29</td>
</tr>
<tr>
<td>7</td>
<td>Tentative nature of science</td>
<td>-6*</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>Social aspects of science</td>
<td>18</td>
<td>37</td>
</tr>
<tr>
<td>8</td>
<td>Subjectivity in science</td>
<td>-5*</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>Creativity &amp; imagination in science</td>
<td>-7*</td>
<td>21</td>
</tr>
</tbody>
</table>

*For these items, there are fewer BEd 1 teachers who hold informed views than teachers in the Non-NMMU group.
The improved understandings of the identified NOS concepts among the BEd 2
teachers can possibly be attributed to the explicit instruction in NOS they received.

3. INTERVIEWS

Semi-structured interviews were carried out by engaging the teachers in discussions
with respect to their responses to each of the questionnaire items. The respondents’ views
pertaining to the two broad categories of NOS – the nature of scientific knowledge and the
scientific enterprise – were scrutinised and interrogated to check whether they were consistent
with responses to the questionnaire items and to glean underlying reasons for the views
expressed by the teachers.

3.1 Non-NMMU teachers

For each item related to the nature of scientific knowledge, the interviews with the
nine Non-NMMU teachers showed remarkable consistency with their responses to the
corresponding questionnaire item. As was stated in the results section, although four teachers
expressed an informed view that scientific theories do not reveal absolute truth about nature,
almost all the teachers believed that scientists discover theories and laws implying that
concrete scientific knowledge is awaiting discovery by experts. Even after the interviewer
clarified the distinction between the terms “discovery” and “invention” using non-scientific
examples, the teachers adhered to their stated views. The only exception was T97 (who
believed in the “truth” aspect of science) that “they (i.e. scientists) make laws” suggesting
confusion between scientific laws and the laws of the land. Despite demonstrating a more
informed conception that there is no certainty regarding the truth worthiness of scientific
knowledge, T106, maintained that scientists are engaged in discovering knowledge. The
belief of the remainder of the teachers who claimed that science reveals the truth appeared to
be underpinned by their faith in experiments, as demonstrated by T97:
Scientists have revealed the truth in the past through experiments; observations etc. and have evidence concerning their investigations. That is why I strongly agree with it because whatever they do there is truth in it.

In examining pre-college students’ understandings of the nature of science, Moss, et al., (2001) found that the students generally believed in the notion of experimental ‘proof’ for accepting scientific knowledge as true statements regarding natural phenomena. Similarly, the findings of Dekkers and Mnisi (2003) and Schwartz and Lederman (2002) suggest that teachers believe that theories and in particular, laws in science cannot go wrong if they are ‘proven’ experimentally.

In spite of demonstrating an infallible view of science, a majority of the Non-NMMU teachers indicated in the questionnaire that scientific theories change with time. However, during the interviews erroneous reasons were cited for the apparently informed conception held by the teachers. The varied reasons for theory change in science provided by the teachers, among others, included “improvements in theories”, “new discoveries”, and “change means addition” to new knowledge. Based on the analysis of the responses to the three statements (Statement 1, 6 and 7) during the interviews and in the questionnaire, it is reasonable to assume that the majority of the Non-NMMU teachers hold a realist conception regarding science.

The interview data suggest that the teachers were consistent in relation to their responses to the questionnaire statements regarding their views on the various elements of the scientific enterprise. Without exception, almost all teachers expressed the view that scientists follow a set and sequential model of investigation to develop knowledge. The untenable faith in the scientific method, concomitant with the belief that experiments provide irrefutable evidence, indicate an empiricist view of science. Analysis of the questionnaire data suggested
that teachers considered indigenous knowledge as being important in the domain of science because of the inclusion of IKS in the revised science curriculum (NCS). However, interview data suggest that a different world view, distinct from a scientific world view, which is shaped by cultural beliefs, may be the motivating factor for teachers to consider IKS as significant. The existing of such a world view is demonstrated when T97 responded to the question whether indigenous knowledge should be considered as scientific knowledge:

“I cannot say scientific method is the only way to study nature because I am an African. I know there are people that can invent thunder. There are people who only believe that thunder is natural but I know there are people who can invent thunder. The sangomas they can do that.”

Jegede (1993) and Cobern (1993) caution that an understanding of the epistemological differences between traditional and western scientific knowledge systems is critical when assessing the NOS conceptions of teachers in the non-western societies. In a study involving science teachers from various non-western cultures (Botswana, Indonesia, Japan, Nigeria and the Philippines), Ogunniyi, Jegede, Ogawa, Yondila and Oladele (1995) found that teachers hold world views shaped by their cultural backgrounds which is distinct from a scientific world view. According to the authors, the seemingly parallel coexistence of multiple world views does not appear to cause any internal conflict in teachers. However, it remains reasonable to suggest that the impact of a multiplicity of world views on the teaching and learning of science needs further investigation.

Sixty five percent of the Non-NMMU teachers interviewed believe that scientists are in pursuit of eternal ‘truths’ and are not ‘contaminated’ by personal bias or social and cultural influences. The image of science as being ‘pure’ appears to concur with the views expressed earlier on the nature of scientific knowledge. When examples are provided to illustrate
(Statement 8) whether two independent scientists draw the same conclusion after observing a natural phenomena like a forest fire or the spread of HIV/AIDS in the country, T110 responded espousing an informed understanding that cultural and social backgrounds (i.e. prior knowledge) influence the interpretation. However, for the statement which refers to the subjectivity involved in drawing conclusions (Statement 12) the same teacher gives a different response. According to him scientists are objective and personal bias should not play any role in interpretation since the interpretation is guided by the ‘scientific point of view’ and not by personal bias. The contradictory views expressed for the same aspect of NOS seem to suggest that the teacher tends to a give a more informed view for certain aspects of NOS when contextual examples that are meaningful to them are provided. In a study to investigate the world view conceptions of science student teachers in South Africa, Lawrenz and Gray (1995) found that very few students used contexts that were outside their personal framework when providing answers to general non-contextual questions. Those who expressed an informed view about the social influences on science, also portray an instrumentalist view of science as demonstrated by T123 that “scientists get together when there is a need like finding a cure for HIV and AIDS”.

In general the interview data indicated that Non-NMMU teachers seem to hold a more realist perspective regarding the social character of science in contrast to a relatively more informed perspective reflected in their response to the questionnaire. Consistent with the responses to the questionnaire, the majority of teachers believed that imagination and creativity do not play any role in the development of scientific knowledge and expressed the view that scientists are guided by a ‘set method’ (i.e. the scientific method) and experiments to support the claims. The conviction in the strength of observed data that ‘what you see is what you believe’ as indicated in the findings by Khishfe and Lederman (2006) appear to be the norm for the teachers in this investigation as well.
The teachers were unanimous in the belief that theories eventually become laws, suggesting that laws are ‘superior’ forms of knowledge and theories are conjectures which are not tested yet. The main reason cited during the interviews was that a theory is subjected to experimental verification and if “proven correct” by experiments, then theory acquires the status of being a law. An explorative study involving pre-service early childhood teachers by Akerson et al. (2008) reflects similar findings that theories are tentative while a law is proven and therefore a better form of science.

None of the teachers interviewed expressed an informed view that science attempts to provide explanations and that science and technology serve entirely different purposes. For most of them “They are one and the same because you prove scientific theory by using technology” as T123 interprets the relationship between science and technology. The prevalence of this misconception appears to impact on students as well. Citing findings from three different studies regarding young students’ image of science and technology, Driver et al. (1996) claim that science is generally viewed in an instrumental way and students do not see any distinction between science and technology.

The interviews assisted to gain a deeper insight into the sources of the participating teachers’ conceptions, particularly regarding the tentative nature of science, their views on IKS and the inferential nature of scientific theories. Analysis of the interview data gathered from the Non-NMMU teachers indicated that their views did not deviate significantly from the views reflected in their responses to the questionnaire items. However, the findings suggest that they tend to be leaning more towards an empiricist/realist position with respect to their NOS understandings than was reflected in the responses to the questionnaire. It should also be noted that, with the exception of one teacher using the example of the periodic table, none of the teachers substantiated their responses during interviews with examples using
science concepts nor they referred to any relevant aspect from the history of science. The findings from this study echo the comments from Cobern (1996: 596) that in responding to interview questions very few students “make little voluntary use of science concepts” and this is probably because the science concepts do no not form a meaningful part of their everyday life context.

3.2 BEd 1 teachers

Contrary to the views expressed by the BEd 1 teachers in the questionnaire, where nearly half of them indicated that science reveals the truth, during interviews this position seemed to have changed with slightly more than half of the teachers interviewed believing otherwise. However, the reasons articulated for the shift towards a more informed position, need close scrutiny. According to T20, ‘truth is relative because of subjectivity in observations, as illustrated in his comment that “…depending on individual views there cannot be an absolute truth”. But at the same this teacher believes that scientists ‘discover’ theories and that prior knowledge may not influence a scientist when collecting data “but when drawing a conclusion he will collect enough data to draw a conclusion and will not then use prior knowledge.”. This comment reflects a less informed understanding about the inferential nature of theories demonstrating a naive realist view. For T5, theories do not reveal the truth because they are not experimentally ‘proven’, yet asserted “I would have agreed if the statement had said scientific laws reveal the absolute truth”. For most teachers who expressed an informed view regarding the truth nature of theories, the reason seems to have been that, unlike laws, theories are not established forms of knowledge since they have not been ‘proven’ by experiments.

Most teachers supported the view that theories are discovered and that theories can change over time. The perception that theories change with time for T1 appears to have its
origins in the way the particulate theory of matter was presented when she was at school compared to the university course she was attending. In her schooling days she was told that there was no matter in an ‘empty’ room while at university she learnt that there is air in a room and therefore it is never ‘empty’. For others the reasons seems to be that theories are not proven yet. It seems to be a pervasive among the BEd 1 teachers that scientific theories are tentative hypotheses and are not verified by experiments. Although the BEd 1 teachers appeared to hold an informed with regard to their image of science, judging by the reasons provided to justify this position it appears that most of the teachers interviewed subscribe to a naive realist view of science.

As was reflected in the questionnaire responses, and in response to the nature of scientific theories discussed above, all teachers interviewed expressed a strong conviction the scientists follow a set procedure in developing knowledge. According to the teachers, what distinguishes science from other knowledge systems such as IKS, and gives science the credibility in their perception, is the use of experiments to verify the claims. Unlike the Non-NMMU teachers who seem to have endorsed the legitimacy of IKS as an alternate way of understanding nature, an anxiety seemed to have been developing in the minds of BEd 1 teachers with regard to alternate knowledge systems. The teachers appeared to question the validity of indigenous knowledge on the basis of evidentiary support. For example when T1 claims that in the earlier days “…we Xhosas knew nothing about science” but could make reliable predictions of the seasons and developed successful farming methods, but she alluded to the importance of evidence in accepting a knowledge system as being credible. The significance of the need for evidence is further illustrated in the comments of T3 when she placed her trust in western medicine because it is “scientifically tested in a laboratory” whereas traditional medicine is “not scientifically tested”.

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The teachers’ attempts to evaluate knowledge claims on the basis of evidence that supports the claim, whether by experiments or other experiential evidence, seems to have origins in the science courses they attend. The main reason for this assumption is that the respondents liberally used examples of science concepts from the course material. The critical thinking displayed by the BEd 1 teachers appears to have developed a tension in them with respect to their allegiance to two different world views, i.e. a western mechanistic world view and an African anthropomorphic world view. This is evident in the comments of T1:

“Science says atmosphere is around us and filled with particles. There is no spirit in the atmosphere. To me there is a contradiction between scientific theory and religion. What is the real truth? What is religion? I am confused”

On the other hand T20, who exhibited adherence to the empirical nature of science, rejected the acknowledgement of IKS as being valid, as evident in his assertion that “It is only through the scientific method that information can be collected about nature”. How this tension impacts on the classroom practice of teachers needs further investigation.

Regarding the social character of science the teachers’ views seem to be congruent with their responses to the corresponding questionnaire item. With the exception of two teachers who believe that scientists must be apolitical since the development of scientific knowledge is grounded in a set procedure, responses from the majority of teachers reflected a relativist stance. Similar trends are reflected concerning the inferential aspect of scientific theories when most teachers accept that the same data can be interpreted differently by scientists because of the influence of prior knowledge held by different scientists. As was the case with the Non-NMMU teachers, the BEd 1 teachers also subscribed to the notion that theories eventually mature as laws after repeated and successful experimental verification. The prevalence among teachers of naive conceptions that theories are lesser forms of
knowledge, and that theories are tentative while laws are proven, is illustrated in the investigations into teachers’ conceptions of NOS by Akerson et al. (2008), Akerson et al. (2006) and Schwartz and Lederman (2002). With the exception of two teachers the majority of the teachers in this study believed that scientists resort to imagination and creativity only at the design stage of the investigation, concurrent with the views reflected in the questionnaire. For T5 scientists may be creative in developing knowledge but they (i.e. scientists) need to be “objective and not imaginative” a statement that indicates a naive conception about knowledge generation in science. Most of the teachers interviewed hold incorrect understanding about the relationship between science and technology with the majority assigning similar epistemological basis for both science and technology.

Interviews with the BEd 1 teachers suggest that they generally subscribe to a realist perspective regarding the nature of science and hold naive conceptions in relation to the distinction between science and technology, the creative aspects of knowledge development and distinction between theories and laws. However, they tend to demonstrate a more informed understanding with respect to the social and subjective nature of science. Compared to the Non-NMMU group, the BEd 1 teachers engaged in fairly informed discussions with extensive use of science concepts to motivate their arguments. As mentioned earlier, the richness in discussion can be attributed to the influence of the science course in which the teachers were exposed to various elements of NOS indirectly. Similar tendencies were observed in a group of pre-college students who demonstrated partial improvement in their NOS understandings by participating in project-based activities embedding implicit messages about NOS (Moss, et al., 2001).

“Although we believe the nature of science learning should be made explicit throughout science instruction, there may be an important role for implicit messages as well, as student conceptions did evolve in certain cases as described in this report”.

(Moss, et al.2001: 788)
The interviews with the BEd 1 teachers were held towards the end of the first year of the BEd programme. The responses during the interviews indicated that the teachers were beginning to critically examine and compare different knowledge systems. The discussion of the NOS concepts by being participants in the study appeared to have served as a stimulus to teachers to begin to think about epistemological and ontological issues related to science. Although the teachers indicated realist tendencies regarding science, the responses during the interviews indicated an inner conversation beginning to form at a metacognitive level about different knowledge systems. The investigation itself might have initiated a transformation among the BEd 1 teachers to think more deeply about issues related to science and scientific enterprise.

3.3 BEd 2 teachers

In contrast to the Non-NMMU and BEd 1 teachers, the BEd 2 teachers expressed the opinion that scientific knowledge does not provide immutable truths, which impact of the explicit instruction in NOS they received in the final year of the BEd programme. This was evident when they supported the claim by citing examples from the history of development of science. For example T77 used the historical debate between Galileo and a follower of Aristotle regarding the shape of the moon to assert that scientists are never certain about ‘truth’ while T75 highlighted the philosophy of falsification to reason that scientific theories can never be true statements about nature.

Similar to the other two groups of teachers the BEd 2 teachers also adhere to the belief that scientists discover theories and laws. Even teachers (T69, T70 and T85) who demonstrated clear understanding of the distinction between ‘discovery’ and ‘invention’ by citing appropriate examples, maintained that scientists discover laws rather than an informed view of scientific laws as “...products of human inquiry related to more to an act of creation.
than of discovery” (McComas, 2003: 148). The conception of scientific laws as reflected in some teachers’ comments projects a naive realist view of science based on the assumption that the work of scientists is to uncover the hidden realities of an external world and that experimental verification establishes the authenticity of the laws. It cannot be stated with certainty that all the BEd 2 teachers interviewed subscribe to a realist position based on their responses to this questionnaire item. There is still a measure of uncertainty regarding teachers’ use of the term ‘discover’ as reflected in the comment by T75 that a scientist uses his “existing knowledge to create something new”. Teachers were unanimous in their view that scientific theories change with time due to developments in technology as well as different interpretations in the light of new evidence. On the basis of the comments and supporting arguments to substantiate their views on statements one, six and seven, it becomes evident that generally the BEd 2 teachers held a more developed understanding, i.e., an understanding concurrent with current research findings regarding the nature of scientific knowledge. However, support for this observation would require additional evidence on how the teachers view knowledge creation in science.

With the exception of T85, the majority of the teachers subscribe to a naive view that scientists adopt either an inductive approach or a hypothetico-deductive approach in investigations. Koulaidis and Ogborn (1995) characterises the inductive approach as beginning with the observation of particular facts leading to a general law inferred from the pattern noticed and the law is then verified as being true on the grounds of empirical testing. The authors contend that hypothetico-deductivism, on the other hand, begins with a general statement and experiments and observations are conducted to test whether the statement can be falsified by looking for contrary observations. The allegiance to the inductive approach is evident when T70 comments:
“I agree with that one (referring to Statement 2) that there is a procedure used in science. You first collect the data using a number of samples and thereafter create a scientific law from the given information noticing the patterns of the result. Then you can deduce them to be the theory or scientific law”.

The conviction in a set procedure seems to be motivated by different reasons. T75 believes that scientists have to follow the “steps” they need to “convince others about your investigation, you have to show them what you have done” expressing the view that scientific claims need evidentiary support. T66 on the other hand believes the distinction between science and other ways of knowing about nature is because “science sticks to a step-by-step method”. Similar results were obtained by Moss, et al. (2001) where these researchers found that pre-college students perceive that knowledge development in science follows ‘a prescribed set of procedures’ or an ‘ordered process’. Two teachers (T75 and T57) appeared to indicate tendencies towards a hypothetico-deductive approach when they expressed the view that the theories developed could be falsified in future.

The firm belief held by the teachers in this study in the procedural aspect of science could be a major contributing factor for the significance they attach to the role of experiments in science. This could also be one of the reasons that teachers view that theories become laws after successful experimental verification. Almost every teacher highlighted the importance experiments in verifying laws and theories while a majority considered laws as superior forms of knowledge since they are proven by experimental methods. The prevalence of the naive view that experimentamation underpins the credibility of the knowledge developed in science among the teachers in this study parallels the findings of many researchers (Schwartz & Lederman, 2002; Liu & Lederman, 2002; Dekkers et al., 2004 & Akerson et al., 2008). Despite the fact that the NOS course material required the BEd 2 teachers to engage in
detailed discussions on the deductive philosophical perspectives of early Greek philosophers, as well as the theory of evolution, the teachers appeared to hold a limited view of science in the sense that scientists rely entirely on experiments to generate knowledge, reflecting strong empiricist tendencies.

Regarding the socio-political and cultural influences on science, the BEd 2 teachers expressed informed views citing various reasons such as the impact of paradigms to which scientists owe their allegiance (T57), the social and cultural backgrounds of scientists (T66), the political support for certain research programmes from governments (T70), the societal needs, e.g., finding a cure for HIV/AIDS in South Africa (T75) and so on. When responding to the statements related to the subjective nature of science, teachers expressed more informed view than the BEd 1 teachers stating that both observation and inference are influenced by scientists’ theoretical commitments and background beliefs citing appropriate examples from the Nature of Science course. Two teachers (T85 & T75) also linked subjectivity in science to the social and cultural backgrounds of the scientists. The relativist perspective held by most of the teachers regarding the social character of science was reflected in their support for indigenous knowledge to be considered as a valid form of knowledge to study the physical world. Similar to the BEd 1 teachers this group of teachers also argued for the legitimacy of IKS eliciting the successes in the use of traditional medicine and farming methods practised in the African continent for generations. However, T75 expressed reservations about incorporating IKS into the domain of science “…because it was not tested before, because in my mind, scientific knowledge should be something that is tested and approved” reflecting the view that empirical testing and public scrutiny are important to science. As mentioned before some of the BEd 1 teachers espoused similar views when they started identifying criteria for evaluation of different knowledge systems.
Compared to the Non-NMMU and BEd 1 teachers, the BEd 2 teachers displayed more contemporary conceptions with respect to the use of imagination and creativity by scientists in developing knowledge. The enhanced perception held by the majority of the teachers that scientists do not have access to complete information and would have to resort to be creative in developing ideas is reflected in the statement by T75 when he claims “...creativity is needed during design and planning but also when they are collecting the information they should be creative by looking at patterns that are developing in the table”. Three teachers (T55, T66 & T70) held the view that creativity is needed by scientists throughout the process of knowledge development but scientists should not be relying on imagination. The comment (T70) “Not imagination – that is a word that doesn’t fit here, because in this case seeing is believing” reflects strong positivist tendencies. Similar to the other two groups all the BEd 2 teachers interviewed held the notion that technology and science cannot be considered as separate.

The analysis of the interview data suggests that generally the BEd 2 teachers held informed views about the nature of science from both ontological and epistemological perspectives. This is indicated in the enhanced views expressed during the course of interviews that science cannot lay claim to ‘truths’ about nature, and that scientific theories are tentative and subject to revision. Their affirmation that scientists are influenced by the wider socio-political factors as well as by their theoretical commitments, and that scientists need to be creative in knowledge generation reflects the teachers’ developed understandings about scientific enterprise. However, the entrenched beliefs in the process model of science could be indicative of the science education they received in the past with the emphasis on the ‘scientific method’. The ‘scientific method’ could also be appealing to the teachers because of the perception that an established set of procedures provide structure and a secure foundation for knowledge development.
The data from the interviews show that compared to the two BEd groups, very few teachers from the Non-NMMU group offered any substantial explanation for the views espoused. Both BEd 1 and the BEd 2 teachers employed the use of appropriate reasons, often referring to the course materials, suggesting that teachers’ views were positively influenced by in-service programmes in science education, both implicitly and explicitly, to varying extents (greater in terms of explicit instruction). Greater commitment to post-modern/relativist view of various aspects of NOS exhibited by the BEd 2 teachers is probably indicative of the impact of explicit instruction is NOS that the teachers received. Analysis of the classroom observation data below help illuminate what impact, if any, the direct instruction in NOS has on the classroom practice of these teachers.

4. CLASSROOM OBSERVATIONS

In this section the classroom observation data as described in the previous chapter is examined in an attempt to glean the image of science that is projected by the teachers in their classroom practice. This assessment is important in two aspects, namely (1) to determine whether the classroom practice is aligned to the teachers’ views of NOS as expressed during the interviews and in the questionnaires and (2) to gauge whether the enacted science curriculum matches the vision of the revised curriculum (NCS).

4.1 Non-NMMU teachers

In an attempt to teach the relationship between the pressure and volume of a gas at constant temperature to a Grade 11 class, T106 began his lesson by writing the Boyle’s law statement on the board followed with a brief description of the ‘Boyle’s law apparatus’. The focus of the lesson was on “proving” Boyle’s law experimentally. The teacher had indicated in the interview a strong adherence to the scientific method but expressed that scientific
knowledge is not necessarily absolute. However, the teaching sequence indicated that the “method” leads to absolute knowledge since the law is “proven” by the method.

There were only twelve students in the class and the teacher did not take advantage of the small class to engage students in deeper discussions on the abstract concept of pressure to explore their existing ideas. There was no consideration of “pressure” as a theoretical concept and, instead, the concept was treated as a given, the value of which could be read off from a meter attached to the apparatus. This would seem to suggest that observations lead directly to facts in science, something cautioned by Lederman et al. (2002: 500) as “An understanding of the crucial distinction between observation and inference is a precursor to making sense of a multitude of inferential and theoretical entities that inhabit the worlds of science”. The absence of any discussion on the theoretical underpinnings of the causal relations between pressure and volume of a gas indicates a naive conception that laws are superior to theories and an account of phenomena is primarily based on scientific laws.

As stated before, one of the critical requirements of the revised science curriculum (NCS) is to develop the investigative skills of learners. This entails, among others, discussions concerning the influence of all relevant variables that have a bearing on the inquiry, the reasons to control certain variables, the notion of a fair test, identification of the independent and dependent variables, considerations regarding the validity and reliability of the results, presentation of results, etc. Such discussions do not usually form an integral part of traditional worksheet-based experiments. The teacher asked the students to note, without giving any reasons, the dependent and independent variables in the experiment for the purpose of drawing a graph to establish the relationship between pressure and volume. Locks-Horsley, Hewson and Love (2003) suggest that science teachers tend to adopt pedagogic practices modelled on the teaching they received as students, which usually do not reflect the
epistemological underpinnings of later curricular reforms. The teacher (T106) in this study exhibits similar tendencies in his attempts to meet the requirements of the new curriculum without deviating essentially from a recipe-like and worksheet-based practical activity.

The lessons observed for the two other Non-NMMU teachers were on chemistry. However, the topics and the Grades taught were different. T116 taught the properties of acids and bases to a Grade 7 class while the lesson of T96 was on redox (oxidation and reduction) reactions in a Grade 12 class. The two lessons provide an opportunity to compare the epistemologies of chemistry teaching in primary schools as well as senior secondary schools.

The lesson on acids and bases began by the teacher listing the common properties of acids and bases on the board and then proceeded to demonstrate the use of a litmus paper to identify the acid-base properties of substances. The chorusing of the facts written on the board by the learners several times indicates the belief that irrefutable scientific facts and principles are to be learnt by rote. Other than naming a few household substances which are acidic and basic, the teacher focused mainly on the properties of laboratory acids and bases giving the impression that the study of chemistry involves the use of special substances from special bottles (Fleming, 1998), which only serves to alienate young learners from developing an interest in chemistry and to view science as a boring subject. Educational researchers such as Fensham (1991), Fleming (1998) and Reid (2000), among others, encourage the introduction of relevant or contextual school chemistry curriculum grounded in the daily life experiences of young learners to promote scientific literacy and to enable the youth to make informed decisions regarding STS issues that affect their lives. According to NCS learners are expected to develop informed understandings of the impact of science and technology on human lives.

The Work Schedule, in the Natural Sciences Learning Area of the NCS developed for Grade 7 teachers by the Provincial Department of Education (Department of Education,
2008:29), clearly indicates that the topic on acids and bases should be taught by engaging learners in investigative activities using household acids, bases and indicators. In spite of the curriculum requirement, the fact that T116 resorted to demonstrations using only laboratory chemicals indicates that she lacked confidence in venturing beyond the safe confines of school science. Tobin (1996) suggests that teachers who perceive a gap between scientific ways and everyday ways of knowing see the culture of science as distinct from their own cultural values and would find it difficult to convey informed views regarding NOS to their students. However, concurrent with the relatively informed views expressed during the interview that sensory experiences can be misleading at times, the teacher explained to the students that the colour of a liquid is not a determining factor in distinguishing an acid from a base or a salt solution.

Although the learners were seated in small groups, they were not engaged in any productive group activity or discussion. It seems the teacher believed that the arrangement of learners in groups in the class to copy down notes from the board fulfils the curriculum requirement of group activities. Similar observations were made by Rogan (2004) in a study of eighteen video-taped science lessons in Mpumalanga schools and by Taylor and Vinjevold (1999) in South African schools in general. The author found the lessons to be mainly teacher-directed and there was no indication of any meaningful interaction between the learners despite being seated in small groups.

Consistent with a strong allegiance to the positivistic sentiments expressed during the interview, T96 started the lesson on redox processes by writing the definition of redox reactions on the board followed by chemical equations as examples of different redox reactions. The approach was mainly logico-deductive in the sense that the definition of redox reactions was used to point out the electron transfer process in each example and to highlight...
the mathematical operations to equate the number of electrons in the two ‘half-reactions’. There are a variety of natural phenomena (burning, rusting, discolouring of a peeled fruit etc.) that are familiar to students which can be explained on the basis of redox principle. However, the examples used by the teacher were limited to chemicals and materials found in laboratories, giving the impression to the students that scientific knowledge is developed in a laboratory environment and has little to do with daily life activities or experiences.

Johnstone (2006) notes that students experience difficulties in chemistry largely because learning in this subject entails integration of three different domains at the same time, i.e., the macro (the observations - reactions, colour change etc.), the sub-micro (the theoretical part – the interaction of atoms, molecules or ions) and the representational (the symbols of chemistry language – formulae, equations, graphs etc.). The most difficult part for the students is the sub-micro domain. To address this problem, the author suggests a balanced approach between the three domains with special focus on the interface between the macro and the sub-micro levels. The emphasis of the lesson on redox processes was at the representational (symbolic) level with minimal attention given to the theoretical explanation for the observations. This was evident in the teacher not providing an acceptable explanation based on electron transfer for the discolouration of magnesium or zinc when dipped in copper sulphate solution as well as the fact that most of the time spent during the lesson was to develop students’ manipulative skills in balancing chemical equations.

The two chemistry lessons were guided by the ‘transmission myth’ (Tobin, 1991) with the students faithfully copying the notes down from the board with minimal meaningful interaction between the teacher and the students or between the students themselves. It would seem both the teacher and the students believe that learning of science essentially involves the transmission of knowledge from the teacher to the student. In both lessons the focus was on
text book chemistry with hardly any connection to daily life experiences contrary to the stated purpose of the revised Physical Science curriculum (NCS) which aims the holistic development of learners by “...stimulating their curiosity, deepening their interest in the natural and physical world in which they live, and guiding them to reflect on the universe.” (Department of Education, 2003: 9).

4.2 BEd 1 teachers

Teacher (T16) linked the lesson on the water cycle to the daily life experiences of learners by asking them appropriate questions about sources of water and the origins of these sources. This strategy helps to promote the curiosity of learners besides implying that the purpose of science is to seek explanation for natural phenomena.

Evaporation and condensation form the theoretical basis to account for the water cycle, but are difficult concepts to explain to young children. Although the teacher attempted to provide evidence for evaporation using the analogy of boiling water, it appeared that she lacked a deeper understanding of the processes of evaporation and condensation. This was clear when she pointed out to them that the “visible steam” from boiling water was evidence for evaporation ignoring the effects of condensation as well as implying that evaporation takes place only when water boils. De Boo and Asoko (2000) caution that the incorrect use of analogies by teachers does more harm than good and results in learners developing wrong ideas about abstract concepts. The teacher’s poor understanding of the concepts might have prompted her to encourage the learners to repeat several times, “When sun shines on water, it evaporates”, with emphasis on the word “evaporates”. This suggests that inadequate understanding of the foundational concepts in science may serve as a barrier to effective classroom practice, despite the teacher exhibiting an informed understanding of several NOS conceptions in the interview. A case study of two beginning secondary science teachers by
Schwartz and Lederman (2002) showed that limited subject matter knowledge impedes the efforts of a teacher to include NOS conceptions in a lesson.

It was observed during group discussions that the teacher remained at the front of the class without showing any interest in listening to the learners’ views in their groups. When the different groups presented their answers, the teacher was interested only in the correct answer ignoring the answers which were not compatible with scientific views. The search for the “right answer” seems to give the impression that science does not entertain multiple interpretations instead of the view that science seeks evidentiary support to accept or reject an interpretation. This conflicts with the tacit understanding displayed by the teacher earlier in the lesson about the role of evidence in substantiating claims. Besides projecting a distorted image of science, this action impacts negatively on the affective domains of learning and eventually results in learners desisting from expressing their views unless they are certain that the answers will be acceptable to the teacher, i.e., the authority. Another implication of the quest for the right answer, as noted by Akerson et al. (2006), is that the learners do not commit themselves to the idea itself and instead encourages them to store the ideas for later retrieval in an exam or a test which promotes the rote-learning of facts in science.

The teacher used a jar containing water closed with a petri dish to illustrate the water cycle, i.e. she used a physical representation to illustrate the model that scientists use to promote an understanding this natural phenomenon. Although the discussion on different aspects of the investigation was inadequate, the shift from traditional experiments to investigative activities suggests that the teacher was making an effort to implement a critical element, i.e., scientific investigations, of the new curriculum (NCS) in her teaching.

T25 started her lesson by using innovative analogies and demonstrations to teach phases of matter and phase changes in a Grade 7 class. The teaching strategies reflected the
views she expressed during the interview that “scientists have to be creative in coming up with explanations”. This was evident when she demonstrated the crushing of a piece of chalk to chalk powder to illustrate the particle nature of matter and used inflated balloons to convey the idea that a gas occupies space. Frequently she switched from English to mother tongue (isiXhosa) to explain abstract concepts to the learners. The participation of learners in the demonstrations indicated a shift from traditional teacher-dominated experiments and an attempt towards a more learner-centred teaching approach envisaged in the new curriculum. However, the participation of learners was at the level of conducting demonstrations. There was no meaningful engagement of learners at the conceptual level indicating the stranglehold of the ‘transmission myth’ mentioned earlier. This was also evident in the emphasis given to the definitions and scientific principles written on the board which the learners had to repeat several times. Generally, the classroom practice of T25 was congruent with her views expressed at the interview on the nature of scientific knowledge.

The teaching of change in phase of matter was limited to the observational level of the phenomena using examples of melting of ice and boiling water in a kettle to indicate the obvious change from solid to liquid and from liquid to gas (there was no discussion on phase changes in the reverse order). Mortimer and Scott (2003) assert that classroom actions limited to an account of phenomena in terms of observable features which they call ‘empirical descriptions’ do not represent a model of effective teaching. According to the authors effective teaching should constitute theoretical explanations to develop an understanding in learners of the phenomenon observed. The fact that the teacher did not discuss the critical role of energy as one of the main causal factors to explain phase changes in matter is indicative of an inadequate view of science. A possible explanation would be that this topic is placed in the Natural Science Learning Area of the curriculum under the theme Matter and Materials (Department of Education, 2008) in which the particulate nature of matter is given importance.
where as the function of energy is under a different theme, Energy and Change (taught in a
different school term). This suggests that the teacher held a compartmentalised view of
science partly influenced by the structure of the curriculum.

The practice of children chorusing the scientific laws and principles written on the
black board displayed in the classrooms of the two BEd 1 teachers as well as in the
classrooms (primary schools) of the observed Non-NMMU teachers seems to be a common
feature of teaching and learning at the primary school level in the South African context. Julie
Gess-Newsome (1999) notes that the emphasis on the vocabulary (scientific terms) and the
products of science (theories and laws) suggest a positivist conception of science held by the
teachers. As opposed to the Non-NMMU teachers, the BEd 1 teachers made an attempt to
involve learners in investigative activities to acknowledge the importance of inquiry processes
in science to construct knowledge. Considering the tendencies towards a process view of
science in contrast to a complete commitment to a product view, the classroom practice of
BEd 1 teachers reflected a more informed view of NOS than the Non-NMMU teachers.

4.3 BEd 2 teachers

The intended purpose of the lesson to the Grade 5 class on living and non-living things
was to teach how plants and animals adapt to the changes in environment and habitats.
However, most of the time the lesson taught by T77 appeared to focus on the distinction
between living and non-living things (a Grade 4 topic) based on the observable characteristics
of each category. This was evident in the eagerness shown by the learners by putting up their
hands to answer simple questions from the teacher to differentiate between living and non-
living things referring to a list on the board.

Throughout the lesson the teacher gave special attention to clarify meanings of
scientific terms as well as certain words which carry different meanings in the scientific
context as opposed to the everyday use of the word. For example after commenting to the learners that “In science we use certain terms like environment” the teacher went on to explain the meaning of the term, environment, using the metaphoric use of the word as in school environment before describing the natural environment of animals and plants. He identified the factors that would qualify for a place to be called school environment indicating how inferences are drawn from observations. The importance given to the distinction between the everyday use and scientific use of language suggests that the teacher holds a more informed perspective with respect to everyday understanding and scientific understanding of phenomena. Whenever it was considered to be necessary the teacher switched to isiXhosa, making a conscious effort to assist learners in migrating from everyday world to the world of science.

Although the classroom behaviour of T77 reflected an enhanced view on some aspects of NOS, the teaching largely remained at the level of ‘empirical description’ (Mortimer & Scott, 2003) with the teacher focusing on describing the observable features of living organisms and very seldom resorted to the underlying causal factors to explain phenomena. In this respect the teaching resembled that of the two BEd 1 teachers described earlier. The only exception to this model of teaching was exhibited when the teacher explained the adaptation of plants to changes in environment by establishing the relationships between plant growth and the availability of sunlight, water and nutrition.

Although the learners were seated in groups, similar to the classroom culture (in the primary school classrooms) observed for the BEd 1 and Non-NMMU teachers, there was no meaningful interaction between the learners. Only the teacher asked questions in the class and there was not a single instance when the learner raised a question for the teacher. The type of questions asked by the teacher did not require the learners to intellectually engage with the
content and could be answered in single word responses. Mortimer and Scott (2003:34) describe this type of classroom communication as “Interactive/authoritative approach”. The classroom talk showed that there was interaction between the teacher and the learner as opposed to the traditional “chalk and talk”. However, the teacher remained the authority of knowledge in the class and the learners’ alternative conceptions remained unattended, resulting in the learners’ resorting to memorisation of facts in science. The positivist tendencies displayed by the teacher in the classroom actions concur with his comments at the interview that “two people will observe exactly the same” and that “scientific theories reveal the absolute truth about nature”.

T85 started the lesson on the formation of tides by engaging learners in discussions around the conditions that make the sustenance of life possible on earth. In contrast to the classroom actions described above the teacher mostly asked open-ended questions to facilitate discussion and to probe learners’ pre-conceptions. During the course of discussion he highlighted the importance of moderate temperature and the presence of air and water as significant factors to support plants and animals on earth. The classroom discourse underscored the empirical basis of science, i.e., science requires substantial evidence to make claims. For example the comparison of abundance of life in the temperate regions with the scarcity of life forms in the polar and desert regions suggested an informed view of science where theories are inferred explanations and facts are not obtained directly from observations.

It was clear that the teacher’s classroom practice closely resembled the views expressed during the interview and in the questionnaire regarding the tentative nature of scientific theories as well as the role of imagination and creativity in developing scientific knowledge. Considering the implication of the distance of the planet Pluto from the sun on the average temperature on the planet, the teacher remarked, “It is unlikely that life is possible on
Instead of explicitly stating that life is not possible on other planets, the remark suggests that scientific knowledge cannot be viewed as absolute and in the absence of complete data scientists make use of imagination and creativity in developing plausible theories. Arguing against treating NOS concepts as tenets (established forms of knowledge), Clough (2007) proposes a conception of science which should include an understanding of science as tentative but durable. The author suggests that the key to develop a deeper understanding of NOS conceptions in students is to explore different aspects of NOS as questions (and not as tenets) arising from a context. This was evident in the kind of questions posed by T85 in the class, for example, “How can we say life is not possible on the planet mercury?”

The teacher paid careful attention to explain the complexities involved in the formation of different types of tides caused by the gravitational forces of the moon, the sun and the earth in relation to their distance from each other and their sizes. It was evident in the classroom actions that the teacher acknowledged the complex nature of interrelationships between theoretical entities and the need to integrate different concepts in establishing causal relationships to account for natural phenomena.

T75 engaged the Grade 9 learners in a number of investigative activities to help them to develop an understanding of basic concepts in electricity. One of the highlights of the classroom discourse was that the learners did not exhibit any inhibition in expressing their views and the teacher noted key ideas on the board, irrespective of whether they were correct or incorrect. The classroom culture was conducive for learners to air their views freely and it was evident when the teacher reminded learners that “nobody laughs at others’ answers”. The purpose of writing learners’ ideas on the blackboard was to revisit these ideas later for discussion in the light of evidence gathered from the investigation. The communication
between the teacher and the learners resembled an “interactive dialogic approach” which, according to Mortimer and Scott (2003: 69) “is the fundamental principle that developing understanding is a dialogic process”. Subsequent to the predictions made by the learners regarding which connections would light up a bulb, the teacher engaged them in discussions about why certain connections lit up the bulb and others did not on the basis of empirical evidence from the investigative activity. The positive vibe observed in the class suggests that the communicative approach adopted in the teaching sequence assisted learners to engage intellectually with the scientific content.

The Nuffield Primary Science SPACE Project (1995) advocates an activity-based teaching approach to provide opportunities for children to reconstruct their ideas.

It is essential that the children change their ideas only as a result of what they find themselves, not by merely accepting ideas which they are told are better.

(Nuffield Primary Science SPACE Project, 1995: 5)

The science modules in the BEd course have been designed in a similar manner on a constructivist epistemological perspective. One of the science modules explicitly addresses the common alternative conceptions that children tend to hold regarding electricity and suggests appropriate activity-based teaching strategies to address children’s misconceptions in this area. The teaching sequence and strategy employed by T75 revealed that the BEd programme had made a positive impact on the teacher’s classroom practice. Similar results were observed in a study by Tsai (2006) on the effects of science education courses on 58 teachers (36 in-service and 32 pre-service science teachers) in Taiwan. According to the author (Tsai, 2006: 363) the study showed that “the instruction about student alternative conceptions and conceptual change theories was more helpful than direct instruction about the philosophy of science in changing teachers’ views about science”. However, the classroom practice of T75 would seem to indicate an integration of NOS conceptions assimilated from
both direct and indirect (focusing on misconceptions, conceptual change, etc.) instructions in NOS.

Besides providing opportunities for learners to modify their ideas by engaging them in activities, the classroom actions of the teacher described above reflected his belief in the social nature of knowledge production. Instead of resorting to teacher demonstrations in an overcrowded classroom where group work was virtually impossible he invited different groups of learners (with female learners specifically included in each group) to the front of the class to perform the activities. When a group could not perform an activity, for example connecting bulbs in series, he invited a second group to join the first group to show them how the connections are made. On noticing that the learners used wires instead of the metal strips provided for connections on the circuit board kit used, he showed the class how to use metal strips for the connections and asked them to clap for him as well (the learners clapped on successful completion of each activity) for “finding something new”.

Although the science modules in the BEd programme were designed to specifically address the challenges of teaching and learning of science in the context of the revised curriculum (NCS), teachers were supported in developing an informed understanding of the concepts related to the science content. By comparing the brightness of the bulbs in different series connections the teacher helped learners to draw the inference that a cell in different circuits provides the same amount of energy which is ‘shared’ by the bulbs. The fact that the teacher related the difference in brightness of the bulbs to the concept of energy rather than the common erroneous conception of current being shared (Shipstone, 1985), something emphasised in the module on electricity. In a case study to identify the subject and teaching knowledge that primary school teachers can use to develop children’s understanding of electricity, Summers et al., (1998) found that a teacher needs to possess scientifically
acceptable understanding of the concepts as well as an understanding of the ways and means of making these concepts accessible to learners. Similar results are reflected in the case study of two beginning secondary science teachers by Schwartz and Lederman (2002:230) when the authors propose that “…strong subject-matter knowledge and strong knowledge of NOS are both essential if we wish to improve the frequency of teachers’ inclusion of NOS into classroom instruction”. The classroom practice of T75 which suggests an informed understanding of NOS conceptions resonates with the findings of Schwartz and Lederman (2002).

5. **CHAPTER SUMMARY**

The analysis of the responses from 136 teachers to questionnaire items directly related to the ontological character of science suggests contradictions in teachers’ views regarding the nature of scientific knowledge. This is evident as a majority of the participating teachers indicated an informed view that scientific theories may change with time, albeit for incorrect reasons cited by the Non-NMMU and BEd 1 teachers, while about half of the teachers suggested that science reveals the truths about nature and a majority subscribe to the view that scientists are engaged in the discovery of knowledge. It is noted, however, that the contradiction is less prominent in the case of the BEd 2 group with more of these teachers espousing a developed view of scientific knowledge compared to the Non-NMMU and BEd 1 groups. The change in the views of the BEd 2 teachers can be attributed to the impact of the explicit instruction in NOS they received.

It is noted that teachers held eclectic views with respect to the various elements of scientific enterprise indicating consistency in certain aspects and contradiction in other aspects. For example a majority of teachers (particularly the BEd 2 and BEd 1 groups) subscribe to an informed view that the development of scientific knowledge is influenced by
socio-cultural factors as well as the theoretical assumptions held by scientists, which is congruent with their views on the inferential nature of science. But the subjective aspects of science appear to be at odds when the majority of teachers view that development of scientific knowledge is a rational, step-by-step process involving very little creativity on the part of scientists. A second example is that a large majority of teachers showed their confidence in experimentally validated knowledge which is congruent with their view that scientists do not resort to imagination and creativity in knowledge creation. But at the same time the teachers do not consider the knowledge thus developed as durable. It is noted that most teachers, except the BEd 1 group, support the view that IKS should be considered as scientific knowledge indicating a multicultural view of science and yet almost all teachers advocate a universal method in knowledge production as the distinguishable feature of science.

The questionnaire data indicated that despite the inconsistencies and contradictions shown, more BEd 2 teachers (compared to the Non-NMMU and the BEd 1 groups) display informed understandings in certain aspects of NOS. The NOS conceptions for which a developed view is exhibited are that scientific theories are tentative, science does not necessarily reveal the truth about nature, socio-cultural factors influence the development of scientific knowledge, scientific theories are inferred from observations and that scientists use their imagination and creativity in formulating theories. However, the BEd 2 teachers were similar to the other two groups, reflecting a less informed view about scientific processes, the distinction between theories and laws and the relationship between science and technology.

The BEd 1 teachers exhibited more relativist conceptions regarding the truth nature of theories and the social character of science than the Non-NMMU teachers. However, compared to the Non-NMMU group, the BEd 1 teachers are less certain that theories can change and that generation of scientific knowledge involves human imagination and
creativity. A general trend showing better understandings of the relativist nature of certain NOS conceptions is seen across the three groups, i.e., Non-NMMU to BEd 1 to BEd 2. These NOS aspects are related to the truth implication of scientific knowledge, the socio-cultural influences on science and the inferential nature of scientific theories. It has been noted that in these NOS aspects a statistically significant difference between the groups was noted with a minimum of 20% more BEd 2 teachers displaying an informed understanding over the Non-NMMU group.

The scrutiny of the interview data shows that the views expressed during the interviews were generally consistent with the teachers’ NOS conceptions elicited from the responses to the questionnaire. This consistency was noticed with respect to all questionnaire items for each of the three groups of teachers except regarding the truth content of scientific theories as understood by the BEd 1 teachers. During interviews the BEd 1 teachers expressed a more developed view that scientific theories would not reveal the truth showing a deviation from the initial response to the corresponding item in the questionnaire. However, the reasons articulated for the shift in position were inappropriate. One of the two reasons provided was that science does not reveal the truth because scientists are influenced by personal bias implying an inadequate conception of the validation of scientific claims by the community of practitioners and the second reason was that theories are not yet experimentally verified (with some teachers suggesting that scientific laws are true statements) indicating a common misconception that laws are validated forms of theories. It is noted that the misconception can also arise from incorrect language use rather than conceptual issues. For example the Non-NMMU teachers displayed an informed understanding that theories change because for them “change” meant addition of new knowledge.
It has been pointed out that interviews provide access to a deeper and clearer understanding of reasons underlying teachers’ conceptions of NOS and the search for the reasons is facilitated by the use of contextual examples that are meaningful to the teachers’ daily life experiences rather than general statements. It became apparent during the interviews that some teachers consider IKS as important and on par with science not only because of the new curriculum imperatives, but largely due to a world view rooted in cultural perspectives.

The impact of implicit and explicit instructions in NOS on the BEd 1 and BEd 2 teachers respectively was quite evident when appropriate examples from either the science modules or the NOS course material were used extensively by the two groups of teachers in support of their views on science. Very rarely the Non-NMMU teachers referred to an example from the history or the content of science to substantiate their responses. The interview data indicate that the philosophical positions held by the three groups of teachers regarding the various components of NOS expressed in the interviews are similar to those reflected in their responses to the questionnaire items.

It is seen that the classroom practice of Non-NMMU teachers was largely based on the transfer of text book knowledge from the teacher to the learners with the emphasis on scientific principles and laws giving the impression that science is a collection of irrefutable facts to be learnt. The practice of science in the classroom as a clinical activity disconnected from the daily life experiences of learners provides further evidence to this view. Although the teachers expressed developed understandings on the social and the inferential nature of science in their responses to the questionnaire and in interviews there was no evidence of these understandings in their classroom behaviour. Tsai (2002) and Adams (2006) note that the teachers’ beliefs about NOS are informed by their beliefs about the teaching and learning
of science as much as their views of learning and teaching of science inform their NOS conceptions. It would seem that the classroom actions of the Non-NMMU teachers are largely influenced by their beliefs about the teaching and learning of science and not by their views of NOS. The reliance on worksheet-based experiments to verify known laws and principles indicates pedagogic practices outside the framework of the revised curriculum (NCS).

Compared to the Non-NMMU teachers the classroom behaviour of the BEd 1 teachers indicated a tangible shift from teacher-directed activities to a more learner-centred approach by involving learners in classroom demonstrations as well as discussions around the application of scientific principles in everyday life. However, the search for the “right” answer and treating scientific concepts in separate silos suggest that the teachers’ ideas about science are not consistent with the views expressed at the interviews and their conceptions of NOS are in a developmental stage. It is observed that inadequate understandings in science content form barriers to engage in pedagogic practices in accordance with improved views in NOS.

A pedagogy grounded in constructivist epistemology was observed with the BEd 2 teachers in the way they engaged learners in discussions around open-ended questions to explore learners’ views. An emphasis on theoretical explanations to account for causal factors rather than focussing on laws and principles as observed with the other two groups of teachers was evident in the classrooms of the BEd 2 teachers. However, it must be noted that none of the teachers referred to IKS related issues in their classroom discussions even when the science content area under investigation seemed appropriate for such discussion.

As opposed to a teacher-directed empiricist tradition reflected in the classrooms of the Non-NMMU teachers, the classroom actions of the BEd 2 teachers indicated a developed view of NOS conceptions. The engagement of learners in meaningful discussions and
investigative activities grounded in an informed understanding of NOS observed in the classrooms of the BEd 2 teachers suggest that they are more informed about the principles and guidelines of the new curriculum (NCS) than the other two groups of teachers. Based on the findings from this study it is reasonable to conclude that explicit instruction in NOS contributed positively towards the teaching and learning of science in the observed classrooms of the BEd 2 teachers.
CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

1. INTRODUCTION

This study took place in the context of comprehensive curricular reforms in South Africa where the vision of the new science curriculum is to promote scientific literacy in schools. Research in science education suggests that the promotion of scientific literacy is contingent on teachers’ holding informed understandings of the nature of science (NOS) to guide their classroom practice. Research has also shown that the teachers’ NOS views reflect their philosophical positions with respect to the nature of scientific knowledge and the scientific enterprise, and that these philosophies influence the image of science portrayed in the classroom (Koulaidis & Ogborn, 1989; Alters, 1997; Lederman, 1999). As such, it was considered important to attempt to determine the understandings of the NOS held by a sample of teachers in the Eastern Cape and to investigate whether these ideas are reflected in their classroom practice, as well as examining the effect of implicit and explicit instruction in NOS on these teachers’ beliefs and activities.

2. CONCLUSIONS

As discussed in the previous chapter the participating teachers held mixed, often contrasting, views with regard to their conceptions on the nature of scientific knowledge and how they perceive scientists develop ideas. The quantitative data suggest that the majority of the teachers who did not receive explicit instruction in NOS (the Non-NMMU and BEd 1 groups) perceive scientific theories to be true accounts of nature, believe that scientists are
engaged in discovering facts about nature, and show tendencies towards an absolute view of science. However, inferences about the teachers’ understandings are tempered by their proficiency in the English language, particularly in the instance of understanding the distinction between discovery and invention in science (Clough, 2007).

What is apparent is that there are a number of complex inconsistencies in the teachers’ views of science and certain aspects of the scientific enterprise.Nearly 100% of all the participating teachers believed that the development of scientific knowledge is a rational, step-by-step process which indicates a strong allegiance to inductive methods and that, other than during the initial planning stages of an investigation, scientists do not make use of imagination and creativity but rely solely on experiments to validate their claims. Although the majority conceived knowledge development in science as a rational and sequential process, more than half also believed that scientists are influenced by social, cultural and personal considerations. On the one hand engagement in science is viewed as being sterile, objective and rational and on other hand scientific activity is perceived as being influenced by human frailties and other influences. An extension of the latter belief is the multicultural view of science held by two-thirds of the teachers in this study, i.e. that there are different ways of understanding the physical world and that indigenous knowledge systems (IKS) can be viewed as scientific knowledge.

Most of the teachers did not see a distinction in the functions of theories and laws in science and instead perceive that theories mature to become laws after repeated and successful experimental verification. Ninety percent of the participants perceived no difference between science and technology suggesting confusion between the functions of these two aspects of human enterprise.
Interrogation of the qualitative data gathered from interviews did not reveal any noticeable shift in teachers’ views of NOS from their responses to the questionnaire. However, the interviews suggested that the reasons articulated for the enhanced views by a number of teachers in two of the NOS conceptions, i.e., the tentative nature of theories and the truth nature of theories, are probably based on incorrect assumptions. Many teachers believe that scientific theories change because theories are not yet “proven” by experiments while laws are verified and therefore permanent “truths”. This corroborates the earlier inference that teachers hold naive conceptions regarding scientific theories and laws. The critical role of experiment seems to be foremost in teachers’ conception of science, something which was made explicit by all the teachers interviewed. As was found in the study of the Limpopo teachers (Dekkers & Mnisi, 2003), the Eastern Cape teachers also believe that for nature and natural phenomena to be considered valid the explanations must be based on authority; experiment being the authority in science and a traditional healer or Sangoma being the authority in IKS. These dual views of validating knowledge claims appear to be both recognised by, and unproblematic for, the teachers concerned.

The classroom practice of both Non-NMMU and BEd 1 teachers were based largely on teacher-directed demonstration activities (although the BEd 1 teachers made some attempt to engage learners in investigations) with an emphasis on definitions and laws to be learnt rather than trying to develop an understanding of the principles involved. Particularly in the non-NMMU classrooms, the focus of the worksheet-based experiments remained at the level of “proving” scientific laws to be true without engaging the learners in discussions linked to the underlying theoretical factors or causal relations. There was no meaningful interaction between the teachers and the learners, or among the learners themselves, indicating the traditional pedagogic practice of transmission of knowledge from the authority (the teacher) to the learner. Although the teachers expressed informed views about the tentative, social and
inferential aspects of NOS during the interviews, there was no evidence of these considerations in their classroom actions, suggesting that their classroom practices do not reflect their NOS views, something that has been pointed out in similar studies by Laplante (1997), Tobin and McRobbie (1997), and Lederman (1999).

The classroom behaviour of the teachers who had been explicitly exposed to notions of the NOS and constructivist approaches (the BEd 2 group) focused on developing explanations for observed phenomena with the support of empirical evidence and the integration of relevant theoretical principles. These practices engaged learners in productive discussions or an “interactive/dialogic” communicational approach to open-ended questions (Mortimer & Scott, 2007). The other NOS aspects implicit in the classroom actions of the BEd 2 teachers were that scientific knowledge is not necessarily absolute, that scientific theories are inferred from observations, that different people can interpret a phenomenon differently, and that knowledge creation in science is a social activity.

A comparison of the classroom practice of the three groups of teachers provides an answer to the third question in this study, viz. that the classroom actions of teachers do not closely reflect their espoused understandings of NOS. The Non-NMMU teachers, and to a large extent the BEd 1 teachers, tend to use teacher-directed activities with emphasis on the products of science and very little by way of explanation. Their learners were not involved in investigative activities nor were they engaged in meaningful discussions, although an attempt was seen to be made towards this end in the BEd 1 classrooms. There was little attempt by these teachers to connect the science content taught to the daily life experiences of the learners. The empiricist tradition of verifying known laws and principles in science practised in these classrooms suggest that the Non-NMMU and the BEd 1 teachers were not fully equipped to teach science as envisaged in the revised curriculum. On the other hand the
classroom practice of the BEd 2 teachers, which was underpinned by a more informed understanding of NOS conceptions, engaged their learners in activities more likely to meet the needs of the new South African curriculum. Despite the importance accorded to the infusion of IKS in the science classrooms in the National Curriculum Statement (NCS), there was no evidence of this taking place in any of the classrooms observed, nor was there any discussion on issues related to the impact of science and technology on society.

Inferences drawn from the data generated suggest that the teachers in this study hold eclectic views and do not subscribe to any particular philosophical perspective with regard to the ontological implications of science, or show adherence to any specific epistemological view. Concerning the image of science, in certain respects, i.e., science reveals the truth or scientists discover theories and laws, the teachers tend to be ontological realists (Nola, 1988) and in certain other respects, e.g., science is tentative, they appear to be relativists (Klee, 1997). Similar tendencies are shown with respect to the epistemological aspects of science. An allegiance to methodological relativism (Chalmers, 1999) is indicated when majority of all teachers believe that IKS should be considered as scientific knowledge, whereas as strong positivist/empiricist tendencies (House, 1991) are displayed by the fact that nearly all the teachers in this study subscribe to the view that science follows a set procedure and that theories and laws in science are to be tested by means of experiments and observations.

The Non-NMMU teachers indicate positivist/empiricist tendencies. They focused on observations at the phenomenal level with very little attention being given to the underlying causal relations. The BEd 2 teachers used a more constructivist approach leaning towards a relativist position at both ontological and epistemological levels (Guba, 1992). At the same time the classroom behaviour of the BEd 2 teachers stressed the importance of theoretical
explanations to help their learners understand the underlying causal factors in an observed phenomenon, which in turn indicates that these teachers are more realists in this perspective.

The conclusions and inferences drawn from the data in this study indicate that explicit instruction in NOS received by the BEd 2 teachers contributed positively towards the development of a more informed understanding of NOS. This was evident in their responses to the questionnaire and in interviews where they used relevant and contextual examples from both the content and history of science to support their NOS conceptions. Compared to the Non-NMMU and BEd 1 teachers, the BEd 2 teachers displayed improved understandings with respect to the ontological views of science, the social and subjective character of science and the role of imagination and creativity in the generation of scientific knowledge. In these aspects of the NOS statistically significant differences were found between the three groups of teachers (Non-NMMU, BEd 1 and BEd 2), with the classroom actions of the BEd 2 teachers reflecting more informed NOS views. Pedagogical practices grounded in constructivist epistemology which engages learners in investigative activities and meaningful discussions showed that the enacted curriculum in the classrooms of the BEd 2 teachers more closely resembles the intentions of the new curriculum (NCS). In turn, the BEd 1 teachers, who had been exposed implicitly to aspects of NOS and constructivist approaches via modelling by their tutors, exhibited more learner centred practices in their classrooms.

3. LIMITATIONS OF THIS STUDY

The conclusions drawn in this study should be viewed in the light of the limitations that mainly rural and peri-urban schools participated in this study, and that teachers from urban schools were not represented. In this sense the teachers in this study do not represent schools from the broad socio-cultural milieus of the Eastern Cape Province. However, it must be noted that the majority of the schools in the Eastern Cape are situated in the rural and peri-
urban areas of the province. Secondly the selection of teachers for interviews and classroom observation was made on the basis of convenience sampling, rather than on statistical considerations. Thirdly only one classroom observation was made per selected teacher. This has the disadvantage that observations made about teachers’ NOS conceptions in relation to their classroom practice were to a certain extent dependent on the science topic taught on the day of observation. Lastly the teachers’ views on the new curriculum (NCS) with respect to science teaching and learning were not explicitly sought in the interviews. The teachers’ conceptions of the NCS could have provided a more authentic picture of the factors which assist or impede their ability to implement the new curriculum in their particular contexts.

4. **RECOMMENDATIONS FOR FURTHER RESEARCH**

During the study it was noted that weak understandings in science content impede a teacher’s efforts to include NOS aspects in the lesson despite holding informed views in NOS. This observation has not been factored into the overall assessment and is something which deserves further attention. Also, all the teachers in this study are second language speakers of English and therefore more liable to being confused by the meanings of certain everyday terms when used in the scientific context. The issue of teaching and learning in a second language on the development of deeper understandings of NOS is a wide and important field of research if an authentic understanding of science education in the majority of schools in the Eastern Cape in particular, and in South Africa in general, is to be attained. Finally, further study is also required to explore the reasons as to why IKS is considered as important by teachers, but not attended to in their classrooms.

5. **CONCLUDING REMARKS**

Research studies, both locally (Dekkers & Mnisi, 2003; Dekkers, 2006) and internationally (Gess-Newsome, 2002; Khishfe & Lederman, 2006; Akerson & Hanuscin,
2007), indicate that professional development programmes which focus on improving teachers’ NOS conceptions impact positively on their ability to implement modern science curricula. The findings of this study supports these accounts in that the improved understandings of the NOS displayed by the BEd 2 teachers are attributed to their participation in a professional development programme which exposed them to explicit instruction in NOS, as well as implicit instruction in pedagogic practices related to science content teaching. However, what is equally evident is that possession of certain aspects of informed understandings of the NOS do not mean that these understandings are translated into classroom practices in an appropriate manner.

During interviews with the teachers it became clear that there is a dialectic tension with regard to the integration of IKS in the science classroom and understandings of NOS and that some teachers began to evaluate the epistemic worth of different knowledge systems in relation to the methods of inquiry and validation of knowledge claims. Despite the importance given to IKS in the revised South African science curriculum (NCS), and the teachers’ expressed view that IKS should be treated as science, there was no mention of IKS related matters in any of the science classrooms observed. The conspicuous absence of discussion on IKS can be attributed to either the teachers’ lack of pedagogic skills in integrating IKS in a science lesson, or possible perceptions that the epistemic worth of IKS is not on a par with science because of problems posed by validation processes which produces internal conflict.

In light of the above, the caveats raised by Good and Shymansky (2001) that the statements about NOS given in the United States of America’s curricular documents "Benchmarks for Scientific Literacy" (1993) and "National Science Education Standards" (1996) portray science in contrasting ways, must be taken into account. These authors show that, depending on which NOS aspects one considers as important in the documents, one can view
science from a modern/realistic perspective or from a postmodern/relativistic perspective, with each perspective having its own implications for science education. They contend that science is universal and that the acknowledgement of different ways of knowing i.e., local knowledge or IKS as being scientific, can be problematic on epistemic grounds. As such, they argue for a modern/realist approach to science education in the initial stages. These authors do not suggest that discussion on the issue of other ways of knowing are not important in a science classroom, but propose a balanced view of NOS to be presented, starting from a modern/realist position whereafter the more relativist statements can be understood within a supporting framework of what they consider to be the main underpinning understandings of NOS. Michael Clough (2007) suggests a similar approach to the teaching of science to avoid students from becoming confused by apparently conflicting images of science.

The arguments raised by Good and Shymansky (2001) and Clough (2007) are pertinent in South African context because a number of NOS views expressed in *Benchmarks* and *Standards* also appear in the National Curriculum Statement (NCS). In the light of the recent controversy with respect to HIV/AIDS in South Africa, when antiretroviral treatment were not made accessible to AIDS patients in public hospitals on the grounds that HIV does not cause AIDS and good dietary habits based on indigenous plants are effective in curbing the spread of the disease, relativist views of science can be used to support the arguments of AIDS denialists, with far reaching consequences for the population at large (Webb et al., 2005). As such, Goode and Shymansky’s approach of providing a firm foundation for understanding the NOS within a modern/realist perspective before emphasising the postmodern/relativist aspects of the scientific enterprise is probably a sensible approach within the South African and other contexts, and is something that should be taken into account by curriculum developers.
REFERENCES


Rogan, J.M. (2006). How much curriculum change is appropriate? Defining a Zone of Feasible Innovation. Published online 27 November in Wiley InterScience (www.interscience.wiley.com)


APPENDIX A

Views of Science Questionnaire

There are no right or wrong answers to the following statements.

Please read each statement carefully and then circle the option (Strongly Disagree, Disagree, No Opinion, Agree or Strongly Agree) that best describes your view on that statement.

<table>
<thead>
<tr>
<th>#</th>
<th>Statement</th>
<th>Circle your view</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scientific theories reveal the absolute truth (i.e. there is no uncertainty about the truth).</td>
<td>• Strongly Disagree • Disagree • No Opinion • Agree • Strongly Agree</td>
</tr>
<tr>
<td>2</td>
<td>The development of scientific knowledge is an orderly, rational and step-by-step process (i.e. scientists first collect data, and then generate theories by looking for patterns in the data).</td>
<td>• Strongly Disagree • Disagree • No Opinion • Agree • Strongly Agree</td>
</tr>
<tr>
<td>3</td>
<td>Scientists perform experiments/investigations when trying to solve problems. They use their imagination and creativity only during the planning and design of these experiments/investigations.</td>
<td>• Strongly Disagree • Disagree • No Opinion • Agree • Strongly Agree</td>
</tr>
<tr>
<td>4</td>
<td>The theories developed by scientists are influenced by the social, political and cultural contexts (situations) prevailing at that time.</td>
<td>• Strongly Disagree • Disagree • No Opinion • Agree • Strongly Agree</td>
</tr>
<tr>
<td>5</td>
<td>After repeated and successful experimental verification, a scientific theory becomes a law.</td>
<td>• Strongly Disagree • Disagree • No Opinion • Agree • Strongly Agree</td>
</tr>
<tr>
<td>6</td>
<td>Scientists discover theories and laws.</td>
<td>• Strongly Disagree • Disagree • No Opinion • Agree • Strongly Agree</td>
</tr>
<tr>
<td>7</td>
<td>Scientific theories may change with time.</td>
<td>• Strongly Disagree • Disagree • No Opinion • Agree • Strongly Agree</td>
</tr>
<tr>
<td>#</td>
<td>Statement</td>
<td>Circle your view</td>
</tr>
<tr>
<td>----</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>8</td>
<td>Two independent scientists make the same conclusion from observing a natural phenomenon (e.g. draw the same conclusion after observing a forest fire).</td>
<td>• Strongly Disagree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Disagree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No Opinion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Agree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Strongly Agree</td>
</tr>
<tr>
<td>9</td>
<td>The “Scientific method” is the only way to study nature and natural phenomena.</td>
<td>• Strongly Disagree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Disagree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No Opinion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Agree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Strongly Agree</td>
</tr>
<tr>
<td>10</td>
<td>Indigenous knowledge (i.e. knowledge held by different cultures) cannot be regarded as scientific knowledge.</td>
<td>• Strongly Disagree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Disagree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No Opinion</td>
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<tr>
<td></td>
<td></td>
<td>• Agree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Strongly Agree</td>
</tr>
<tr>
<td>11</td>
<td>Science should be thought of as separate from technology.</td>
<td>• Strongly Disagree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Disagree</td>
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<td></td>
<td></td>
<td>• No Opinion</td>
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<tr>
<td></td>
<td></td>
<td>• Agree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Strongly Agree</td>
</tr>
<tr>
<td>12</td>
<td>Observations made by a scientist can be objective, but the conclusion drawn from the observation is subjective.</td>
<td>• Strongly Disagree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Disagree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No Opinion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Agree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Strongly Agree</td>
</tr>
</tbody>
</table>
## APPENDIX B

### Classroom Observation Schedule

<table>
<thead>
<tr>
<th>Teacher Name: ........................................................................................................</th>
<th>Gender: ..........       Qualifications: ..............................................</th>
</tr>
</thead>
<tbody>
<tr>
<td>School Name: ...............................................................................................</td>
<td>School Category (Peri-urban/Rural)...............................................</td>
</tr>
<tr>
<td>Grade level: ...................................................................................................</td>
<td>No. of learners: ..............................................................</td>
</tr>
<tr>
<td>Learning Area: ...............................................................................................</td>
<td>Date of observation: ..........................................................</td>
</tr>
<tr>
<td>Topic and key concepts: .......................................................................................</td>
<td></td>
</tr>
</tbody>
</table>
NOS Aspect 1: # 2 & # 9 (The “Scientific Method”)

The development of scientific knowledge is an orderly, rational and step-by-step process. / “Scientific Method”

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<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>- Learners seated in rows</td>
<td>- Learners seated in groups; do teacher directed activities / discussion</td>
<td>- Learners engaged in scientific inquiry activities</td>
<td>- Learners engaged in SI inquiry activities</td>
</tr>
<tr>
<td>- Teaching style ‘chalk &amp; talk’ (transmission of text book knowledge)</td>
<td>- Limited discussion among learners</td>
<td>- Some discussion on different aspects of investigation</td>
<td>- Classroom discussion on all aspects of the investigation</td>
</tr>
<tr>
<td>- Starts with definitions/statement of laws</td>
<td>- Emphasis on sequential steps in doing the experiment</td>
<td>- Importance of evidence pointed out</td>
<td>- Discussion on the merits/demerits of alternative ideas</td>
</tr>
<tr>
<td>- Worksheet-based and guided practical to verify known laws</td>
<td>- Limited explanation for each aspect of expt.</td>
<td>- Learners’ ideas are acknowledged, but no further discussion of ideas</td>
<td>- Discussion on methods of inquiry</td>
</tr>
<tr>
<td>- There is only one sequential way of solving a problem</td>
<td>- Focuses on concepts and verification of concepts</td>
<td>- Discussion on alternate methods of inquiry</td>
<td>- Emphasis on evidentiary support</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Complex nature of knowledge development is evident in the lesson</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Integration of concepts to develop understanding</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Learners encouraged to critically examine claims</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Learners engaged in the reflection of the process</td>
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</tbody>
</table>
**NOS Aspect 2: # 1 & # 7 (Tentative nature of scientific theories)**

Scientific theories reveal the absolute truth. / Scientific theories may change with time

<p>| | | | |</p>
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</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Science provides correct answers</td>
<td>- Science cannot go wrong</td>
<td>- Scientific explanations are based on evidence</td>
<td>- Theories are inferred explanations of observations</td>
</tr>
<tr>
<td>- Search for ‘truth’</td>
<td>- Science may not have answers for all questions</td>
<td>- Discussion of various factors that may determine the outcome</td>
<td>- Learners are engaged in interpreting data</td>
</tr>
<tr>
<td>- There are only ‘right’ or ‘wrong’ answers</td>
<td>- The ultimate aim of science is to uncover the truth</td>
<td>- There can be only one interpretation that is correct</td>
<td>- Multiple interpretations are acknowledged</td>
</tr>
<tr>
<td>- Focus on textbook knowledge</td>
<td>- Textbook knowledge is still the final authority</td>
<td>- What you “see” may not be the reality</td>
<td>- Observations support the theoretical claims</td>
</tr>
<tr>
<td>- Knowledge in the textbook as final authority</td>
<td>- The aim of scientists is to “prove” their ideas</td>
<td>- Limited discussion on “macro”/”micro” interface</td>
<td>- Evidentiary basis for theories</td>
</tr>
<tr>
<td>- No mention of the historical perspectives related to the development of knowledge</td>
<td>- Limited discussion on theoretical claims</td>
<td>- Learners’ predictions are tested against evidence</td>
<td>- Theories change or get modified with new evidence</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Learners engaged in causal reasoning</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Historical perspectives related to the context are discussed</td>
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</tbody>
</table>
### NOS Aspect 3: # 3 (Imagination and creativity in the development of scientific knowledge)

Scientists use their imagination and creativity throughout the process of developing scientific knowledge.

<table>
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<th><strong>3</strong></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Learners are not engaged in problem-solving activities</td>
<td>Learners engaged in problem solving based on structured step-by-step model</td>
<td>Limited discussion on problem-solving activities</td>
<td>Learners engaged in problem-solving activities (“open” investigations) in order to highlight the role of imagination and creativity at all stages in the investigation.</td>
</tr>
<tr>
<td></td>
<td>No classroom discourse</td>
<td>Teacher directed activities</td>
<td>Still there is a set method based on formulaic approach</td>
<td>Classroom discussion encouraging creative ideas of learners in solving problems</td>
</tr>
<tr>
<td></td>
<td>No opportunity for acknowledging creative ideas and different perspectives of learners</td>
<td>Simple converging type questions asked by teacher</td>
<td>Relevant questions to stimulate classroom discussion</td>
<td>Discussion of the merits and demerits of different problem-solving strategies</td>
</tr>
<tr>
<td></td>
<td>Facts as given in the text book are provided</td>
<td>Learners encouraged to formulate hypothesis</td>
<td>Discussion on the merits/demerits of different hypotheses</td>
<td>Discussion on multiple interpretation of data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Discussion on the planning and design of investigations</td>
<td>Symbolic language in science highlighted and explained</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The use of symbolic language in science noted</td>
<td>Conclusions drawn by learners are discussed and scrutinised</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Use of appropriate analogies</td>
</tr>
</tbody>
</table>
**NOS Aspect 4: # 8 & # 12 (Observation and inference)**

Two independent scientists make the same conclusion from observing a natural phenomenon. / Observations can be objective while conclusions from an observation is subjective

<table>
<thead>
<tr>
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<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Do not engage learners in scientific inquiry activities</td>
<td>Learners engage in SI activities, but interpretations of the data is teacher directed</td>
<td>Learners are given opportunity to interpret data, but the merits/demerits of interpretations are not discussed</td>
<td>Theories are inferred from observations</td>
</tr>
<tr>
<td></td>
<td>What is seen is the fact</td>
<td>Alternative views are not considered</td>
<td>Alternative views are discussed</td>
<td>The fallibility of observations (deception of the senses) noted</td>
</tr>
<tr>
<td></td>
<td>Different perspectives are not acknowledged</td>
<td>Observation in experiments must match the information in the text book</td>
<td>Discussion on the distinction between observation and inference</td>
<td>Multiple interpretations are acknowledged and discussed</td>
</tr>
<tr>
<td></td>
<td>The cultural or social aspects of science are not discussed</td>
<td>Simple conclusion drawn as evident from the data, no discussion</td>
<td>Learners engaged in SI activities</td>
<td>Subjectivity in drawing conclusions is noted</td>
</tr>
<tr>
<td></td>
<td>No link to historical developments in science (e.g. world wars)</td>
<td></td>
<td>Learners engaged in testing predictions</td>
<td>Acknowledges the influence of prior conceptions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reasons provided to establish relevance of inferences drawn</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The veracity of inference checked against data</td>
</tr>
</tbody>
</table>
## NOS Aspect 5: # 5 & # 6 (Scientific theories and laws)

After repeated and successful experimental verification, a scientific theory becomes a law / Scientists discover theories and laws.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>- No distinction drawn between theories and laws</td>
<td>- Distinction between theories and laws is noted</td>
<td>- A theory may not be true but a law states the permanent truth</td>
<td>- Theories are presented as explanations to account for data/observations</td>
</tr>
<tr>
<td>- Hierarchical view of theories and laws</td>
<td>- More emphasis on the “what” and little emphasis on the “why”</td>
<td>- A theory as an educated guess</td>
<td>- Distinction between theories and laws are highlighted</td>
</tr>
<tr>
<td>- The role of theories and laws in science is not mentioned</td>
<td>- Theories can change</td>
<td>- Theory is temporary but a law is permanent</td>
<td>- Laws describe relationship in observable phenomena</td>
</tr>
<tr>
<td>- Laws are given a superior status to theories</td>
<td>- But a theory eventually becomes a law after repeated and successful verification</td>
<td>- Learners engaged in the “why” aspects</td>
<td>- Theory as explanations for laws</td>
</tr>
<tr>
<td>- Definitions and laws are stated upfront</td>
<td>- Law is implied as a result of successful verification of a theory</td>
<td>- Relationship between variables noted</td>
<td>- Tentative nature of both theories and laws are noted</td>
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<td></td>
<td>- Both “what” and “why” questions included in discussion</td>
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<td>- Explanation provided for the relationship between variables</td>
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### NOS Aspect 6: # 4 (Social and cultural characteristics of science)

Theories developed by scientists are influenced by the social, political and cultural contexts prevailing at the time.

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<td>No historical perspectives on the development of SK</td>
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<td>Historical perspectives related to the content discussed and highlighted</td>
<td>Scientific activity as a human endeavour</td>
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<td>Scientists are depicted as objective</td>
<td>Equitable distribution of questions between boys and girls</td>
<td>Brief description on the relevant scientist</td>
<td>Encourages learners to assess peers’ views</td>
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<td>Gender stereotyping reflected in interaction with learners (E.g. questions asked mainly to boys)</td>
<td>Scientific terms noted without any explanation</td>
<td>Learners work in groups to solve problems</td>
<td>Scientific inventions related to cultural, social and political contexts</td>
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<td>Female learners are positively encouraged to participate in discussions</td>
<td>History of developments in science highlighted wherever relevant</td>
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<td>The distinction between everyday use of a term and in the scientific context is made</td>
<td>Topical issues such as current focus of research (E.g. HIV/AIDS, Global warming etc.) relevant to the lesson noted</td>
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<td>The use of scientific language explained as indicative of the social character of science</td>
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**NOS Aspect 7: # 10 (IKS)**

Indigenous knowledge cannot be regarded as scientific knowledge.

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<td>Western science is the only way to understand nature</td>
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<td>Learners engaged in discussion of other ways of knowledge production, e.g. IKS</td>
<td>Integration of IKS in the lesson</td>
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**NOS Aspect 8: # 11 (Science, Technology and Society)**

Science should be thought of as separate from technology (STS issues).

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APPENDIX C

Statistical analysis (ANOVA) for non-NMMU, BEd 1 and BEd 2

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APPENDIX D

Descriptive statistics for non-NMMU, BEd 1 and BEd 2

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