Exploring Grade Ten Physical Science Learners' Conceptions of Nature of Science

by

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ABSTRACT

The purpose of this study was to explore Physical Science learners' conceptions of nature of science. Grade ten learners were the focus in this study. They were the second group of learners who had experienced outcomes-based education in the General Education and Training band. The main research question that framed this study was: What are grade ten Physical Science learners' conceptions of nature of science? In order to answer the key research question this study also attempted to determine if learners held contemporary views of nature of science as accepted by the scientific community and as required by the new Natural Sciences curriculum and if there were differences in conceptions between groups such as male and female or different cultural groups namely Black and Indian learners. The research was conducted using a mixed methods approach where both qualitative and quantitative data were gathered. This study is embedded in a survey design. Quantitative data was obtained by administering a survey questionnaire to 190 grade ten Physical Science learners from seven different schools. Qualitative data was obtained from an open-format questionnaire, using a number of science-based scenarios, that was administered to a single class. The purpose was to obtain a deeper understanding of learners' nature of science conceptions in action. The findings of this study indicated that learners had mixed conceptions of nature of science. They possessed contemporary conceptions for certain aspects of nature of science but others were rooted in positivism. The results of this study concurred with the abundant international literature on nature of science. The findings have also revealed that there were significant differences for certain aspects of nature of science between the groups. Indian and Black learners had different conceptions for certain aspects of nature of science and so did the males and females. The intention of

this study was to provide baseline data and guidance to teachers on what conceptions or alternate conceptions learners have about nature of science. Limited research exists on nature of science in South Africa. This study opens up the possibility of more detailed research into learners' views on nature of science within the new reforms of our South African science curriculum.

PREFACE

The work described in this thesis was carried out in the School of Science, Mathematics and Technology Education, University of KwaZulu-Natal, from August 2004 to February 2009 under the supervision of Professor P. A. Hobden (Supervisor).

This study represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

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GLOSSARY

AAAS	American Association for the Advancement of Science
C2005	Curriculum 2005
FET	Further Education and Training
GET	General Education and Training
NCS	National Curriculum Statement
NOS	Nature of Science
OBE	Outcomes Based Education
RNCS	Revised National Curriculum Statement
SSAS	A Statement on Science for Australian Schools
STS	Science Technology Society
UK	United Kingdom
USA	United States of America

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DEDICATION

This dissertation is dedicated to my wife, Urmilla, and my loving sons, Jashlin and Drishend. Your enthusiasm and quest for knowledge motivates me to be a life-long learner.

CHAPTER 1

INTRODUCTION TO STUDY

The focus of this study is to explore Grade 10 Physical Science learners' conceptions of the nature of scientific knowledge and the scientific enterprise, which often is referred to as nature of science. In this thesis I will use the term nature of science and not *the nature of science.* A justification for this will be provided in chapter two. This study originated from my personal interest and experiences in science education as a teacher and as a student at tertiary level. I often use the quotation, "Science is seeing what everyone else has seen but thinking what no one else has thought", that I encountered in a science methods course, to initiate discussion in my Physical Science classes. In analysing this quotation a typical comment offered by learners is that we often look at nature but we cannot explain how it works. They add that scientists carry out investigations in laboratories to help us explain how nature works. More often than not learners offer views that are strongly positivist. I found that these views, although not limited to, are characteristic of learners who experienced the traditional South African content-driven science curriculum. Surprisingly there were several learners who experienced outcomes based education (OBE) in the general education and training band (GET) who also expressed similar views. I also found that when discussing socio-scientific issues learners supported their decisions based on emotions or moral values. Very rarely did they make scientifically informed decisions.

As a teacher in training and as a scholar I also perceived science to be a vast collection of unchanging facts that are discovered by scientists who are objective and unbiased. However I developed better understandings of the psycho-social dimension of science and how scientific knowledge is generated when I furthered my studies at honours and masters level and developed an interest in nature of science in science education. Through extensive reading around the subject I realised that nature of science has been one of the goals, albeit an elusive one, for many decades in science curricular internationally.

Furthermore there is growing research on both teachers' and learners' perceptions of this construct worldwide. However little is known about learners' views on nature of science within a South African context. Moreover one of the aims of the new science curriculum is that learners have understandings of nature of science that are accepted views within the scientific community. Nevertheless there is limited research to establish whether this is so.

1.1 IMPLEMENTATION OF CURRICULUM 2005

The introduction of Curriculum 2005 (C2005) in South Africa resulted in a shift to Outcomes Based Education (OBE). The purpose of curriculum change was to realise the aims of the constitution in post-apartheid South Africa and bring about social transformation (Department of Education, 1997). OBE encouraged a learner-centred and activity based approach to education (Department of Education, 2000). OBE was initially phased into grades R to 9, the General Education and Training Band (GET), whilst grades 10 to 12 experienced the old curriculum which focused on content at the expense of skills. In response to widespread criticisms of the new curriculum a review process resulted in the implementation of the Revised National Curriculum Statement (RNCS) for the GET band in South Africa (Chisholm, 2000), which again was phased into each grade starting from grade R. When this study was conducted grade 8 and 9 learners in the secondary school were experiencing C2005 and not the RNCS.

However there were little differences for nature of science, mainly limited to the collapsing of outcomes, between C2005 and the RNCS.

The implementation of C2005 heralded changes to the Natural Science curriculum (grades R to 9) which focussed on both content and the processes of science. World-wide reforms in science education especially nature of science had also filtered down into the South African Natural Science curriculum (Linneman et al., 2002). Although not explicitly stated one of the goals of all learning outcomes in the natural sciences is that learners develop informed views on nature of science (Department of Education, 1997). Furthermore in order to incorporate different world-views indigenous knowledge was included in this learning outcome to add an African perspective to nature of science (Department of Education, 1997). Teachers were required to teach current understandings of nature of science infused with indigenous knowledge. From my experience many had no idea what this meant since their tertiary education focussed on science content and teaching methods. At the same time teachers were attempting to understand the requirements of the new curriculum. It is within this context that this study was undertaken.

Outcomes-based education promotes a constructivist theory of learning. It is generally accepted as an approach that engages and utilizes learners' existing knowledge to construct new concepts and to incorporate new knowledge. Given this understanding it is therefore important that science educators know what conceptions learners hold as a result of experiencing GET in C2005 so that activities can be developed so as to challenge existing conceptions. Bell (2001) points out that many learners have deeply ingrained misconceptions about nature of science. In South Africa, research on nature of science is in its infancy since it is a new emphasis in science education. Research findings on learners' conceptions of nature of science from other countries cannot be totally transferable to the South African context since our context differs from other countries. We differ, to some extent, in terms of our cultural experiences, educational system, technology, demographics and social experiences. Consequently I considered it to be vital that research be undertaken within a South African context. Most nature of science research in South Africa has concentrated on teachers' perceptions of nature of science and has neglected learners' perceptions. This study will provide baseline data on what conceptions or alternate conceptions learners have about nature of science after experiencing GET phase.

1.2 THE STUDY

The purpose of this study was to explore grade 10 learners' conceptions of nature of science. To achieve this, the research centred on answering the question: What are grade 10 Physical Science learners' conceptions of nature of science? In order to answer this main research question I was guided by the following secondary research questions:

1. To what extent, if any, are the learners' nature of science views consistent with contemporary views and with those of Curriculum 2005?
2. Do different gender and cultural groups possess different views on nature of science?

A mixed methods approach, using a survey design, was considered to be the most suitable method to answering these questions. This approach entailed using both quantitative and qualitative methods to explore learners' conceptions of nature of science. Lederman (1992) has found that using both methods provides a better understanding of why learners have certain conceptions of nature of science. Ivankova, Creswell and Clark (2007) argue that mixed methods research serve to enhance a study with supplemental data and allows one to produce well validated conclusions. A survey using a closed questionnaire was used to obtain quantitative data. In order to probe learners' conceptions of nature of science further an open format questionnaire was then used to obtain qualitative data. For the purposes of this study the survey questionnaire will be referred to as Views about Science and the open format questionnaire Scenarios of Science.

Grade 10 learners were chosen to be part of this study since they were the second cohort of learners who had experienced C2005. These learners were from secondary schools in the Chatsworth area. The schools were chosen out of convenience as I teach in this area. The Views about Science questionnaire were administered to 190 learners in seven schools in this area and the Scenarios of Science to a single grade 10 class I taught. At the time of the study the learner population at the schools were predominantly Indian learners with some Black learners. Indian refers to learners of Asian decent while Black refers to learners who are black African for the purposes of this study. In this study they will also be referred to as cultural groups. Black learners are usually second language English speakers and in KwaZulu- Natal are mostly from the Zulu cultural group.

The responses from the Views about Science questionnaire were analysed statistically to ascertain what conceptions learners hold about different aspects of nature of science. An attempt was made to see if there are any differences in views between the two cultural groups (Indian and Black learners) and between male and female learners. In addition the Scenarios of Science were analysed qualitatively to obtain a better understanding of learners' conceptions and to make comparisons with the responses from the Views about Science questionnaire. As with all studies important concepts need to be identified and explained before I proceed.

1.3 NATURE OF SCIENCE: MAIN CONCEPTS

Nature of science examines how scientific knowledge is generated and how the scientific enterprise operates. It is multifaceted and includes philosophy, history, psychology and sociology of science. Furthermore it is a complex and contested terrain since members of the scientific community ascribe to different philosophies and hold varied views of nature of science. In addition personal values, social and political contexts subtly infiltrate the production of scientific knowledge. An understanding of nature of science is seen as a necessary component of scientific literacy.

Despite the complex and contested nature there is consensus among the scientific community that learners need to develop an understanding of certain aspects of nature of science (Collins, Osborne, Ratcliffe, Millar & Duschl, 2001). These aspects include and are not limited to (a) change and continuity are persistent features of science (tentative nature of science knowledge), (b) there is no single scientific method or approach, scientific approaches value evidence, logic, and good arguments, (c) scientific knowledge is the product of human imagination and creativity, (d) scientific knowledge has basis in empirical evidence, (e) empirical evidence is collected and interpreted based on current scientific perspectives (theory-laden observations and interpretations) as well as personal subjectivity due to scientists values, knowledge, and prior experiences, (f) cooperation and collaboration enables scientists to expose their ideas to criticism by other scientists, and stay informed about scientific discoveries around the world, (g) scientific hypotheses, theories and laws are different forms of statements that have no hierarchical relationship, and (h) the direction and products of scientific investigations are influenced by the society and culture in which the science is conducted (socio-cultural embeddedness). The curriculum is trying to deal with this accepted view. In this dissertation the aspects mentioned above will be regarded as the contemporary view of nature of science.

1.4 THE STRUCTURE OF THE STUDY

The introduction served to acquaint the reader with the rationale, background, objectives and the main concepts used in this dissertation. The literature is reviewed in chapter two under the following headings: nature of science, science education, learners' conceptions and science education, arguments for South African nature of science research, a brief summary of the literature and why this study contributes to nature of science research. The research methodology is presented in chapter three, which describes in detail the reasoning for choosing the research design, strategies for data collection, design and validation of research instruments, selection of research sites and sample and the methods of analysis. In chapter four the learners' responses to the instruments Views about Science and Scenarios of Science are analysed and the findings discussed. The summary, limitations and implications for future research form the basis for chapter five.

CHAPTER 2

LITERATURE REVIEW

Since this study focuses on nature of science this chapter begins with an attempt to define nature of science. This is followed by an overview of the different philosophies and the social dimension of science to show how different understandings of nature of science have evolved. The focus then shifts to science education beginning with a brief review of the history of both the goals and nature of science in science education. I proceed to examine the rationale of nature of science in contemporary science curricula. I will also discuss contemporary views about science as proposed by the scientific community and as required by the South African science curriculum namely Curriculum 2005. These contemporary views will be examined using a framework based on three strands: the nature of science knowledge, the nature of scientific inquiry and, the relationship between science and society as reflected in the science curriculum.

In this study, an attempt is made to determine if learners possess contemporary conceptions of nature of science. Consequently I will examine the literature on learners' conceptions and learning and its link to constructivism and conceptual change. Included will be an historical review of different instruments used to determine learners' nature of science conceptions and the results thereof. I will conclude with arguments for nature of science research within the South African context.

2.1 NATURE OF SCIENCE

2.1.1 Defining nature of science

The "term 'science' can be used to refer to a method of inquiry, a historically changing collection of practices, a body of knowledge, a set of claims, a profession, a set of social groups, and so on" (Longino, 1989, p. 45). However the term 'Nature of Science' refers to science as a way of knowing (Schwartz, Gfeller, & Lederman, 2001) and as noted by Mnisi and Dekkers (2003) it encompasses all issues addressed by philosophy, history, psychology and sociology of science. It provides "a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavours" (McComas, Clough, & Almazroa, 1998, p. 4). Using a constructivist perspective Bianchini and Solomon (2003) argue that by engaging in an ongoing interchange of perspectives and ideas we construct and reconstruct meaning therefore descriptions of nature of science have and should continue to change in the light of new questions, methods and findings. Given these broad characterizations it follows that "there is not *one single* nature of science or '*the nature of science*' that fully describes all scientific knowledge and enterprises" (Schwartz et al., 2001, p. 6). Consequently there is presently no general consensus among philosophers, historians, scientists and science educators on a specific definition for nature of science given that science is a complex and multifaceted endeavour (Abd-El-Khalick & Lederman, 2000; Lederman, 1999). Nevertheless Lederman (1992) points out that, "although the 'nature of science' has been defined in numerous ways, it most commonly refers to the values and assumptions inherent to science, scientific knowledge and/or the development of scientific knowledge" (p. 331). In this thesis the definition provided by Lederman will be used but the values and assumptions intrinsic to science and scientific knowledge will be seen through a multifocal lens namely philosophy, history, psychology and sociology of science.

2.1.2 An overview of the philosophies of science

Scientific knowledge is characterized by facts, laws and theories, but different conceptions about the nature and validity of scientific knowledge and how scientific knowledge is achieved is central to the debate surrounding nature of science. Conceptions about nature of science have not remained static over time but have changed throughout the development of science and systematic thinking about science (Lederman, 1998) due to major shifts in focus and emphasis in the fields of philosophy, sociology, and history of science (Abd-El-Khalick & Lederman, 2000). Accordingly, members of the scientific community subscribe to different philosophies and hold varied views of the nature of science. Therefore it is a complex and contested terrain. The philosophies that had an influence on science will be presented below.

1. Positivism/Inductivism

The start of the twentieth century gave rise to the classical approach or traditional view of the philosophy of science known as empiricism, logical empiricism, and logical positivism (Duschl, 1994). This view contends that science is a body of facts derived from unbiased observations of the environment and that observations are necessary to justify scientific theory (Ayayee & McCarthy, 1996). In other words, "all genuine knowledge is based on sense experience and can only be advanced by means of observation and experiment" (Cohen, Manion, & Morrison, 2000, p. 8). The laws and theories that make up scientific knowledge are thus derived from these observation statements (Chalmers, 1987). Two important elements of logical empiricism were the separation of observations from theories and the role of logic. Duchl (1994) points out " that a theory of science was considered a strong theory if and only if its theoretical statements could be logically justified by observational statements" (p. 444).

The scientific community thus viewed scientific knowledge as certain knowledge made from completely objective observations and measurements. This is sometimes referred to as an inductivist approach (espoused by Bacon) to science where specific observations repeated under a wide variety of conditions can lead to the justification of a universal law or empirical fact (Chalmers, 1987; Meiring, 1995). For an inductivist, the source of truth is not logic but experience. Scientific facts and laws are therefore seen as unchanging truths to be discovered in nature (Richardson, 1979). However, Claxton (1991) argues that no amount of observation can prove a generalization true beyond all possible doubt and that not all "science consists of general statements and descriptive laws" (p. 61). This has traditionally been referred to as 'the problem of induction.' Chalmers (1987) further adds that the inductivist is wrong in that science does not start with observations since observations and experiments are guided by theory and that observations are fallible since they are private subjective experiences of individuals. Given the limitations of the inductivist or logical positivist approach to science other views began to emerge.

Deductive logical reasoning became a major feature of science since the scientific community believed that science is supremely logical. This approach was suggested to overcome the problem of induction, which "was considered to be rather embarrassing for science" (Richardson, 1979, p. 6). According to deductivism, (or hypothetico-deductivism) science proceeds by forming hypotheses, which may be produced by current theories or imaginative ideas, which are then tested (Nott & Wellington, 1998). Deductive reasoning accounts for the ability to explain and predict using universal laws and theories (Chalmers, 1987). From the beginning of the twentieth century leading up to the 1950s the scientific community's conception of the growth of scientific knowledge was dominated by the major empiricist philosophies of positivism, logical positivism and hypothetico-deductivism (Duchl, 1994).

2. Popper's Falsificationism

Karl Popper put forward the view that scientific knowledge develops in a logical process hence he proposed falsificationism as an alternative to inductivism. According to Chalmers (1987) "the falsificationist freely admits that observation is guided by and presupposes theory" (p. 38). Popper believed that theories should be constructed so that they can be exposed to falsification (Richardson, 1979). In other words, scientists should be carrying out experiments to falsify theories and not to verify them.

Popper used falsificationism to explain the growth of scientific knowledge. He explained that science progresses in the following way: theories are formulated initially as inspired guesses or tentative conjectures which are then subjected to rigorous experimental testing and if they survive the experimental and observational tests they can be retained for the time being but those that are falsified are abandoned and replaced by further speculative conjectures (Chalmers, 1987; Richardson, 1979). However Richardson (1979) argues that Popper's analysis of the growth of scientific knowledge is no different to the hypothetico-deductive system of explanation. Despite Poppers protests, Hung (1997) claims that Popper is usually grouped with logical positivists since he shares many fundamental views with them.

Falsificationism like induction also has limitations. Since observation statements are theory-dependent and fallible straightforward conclusive falsifications of theories are not achievable (Chalmers, 1987). Claxton (1991) contends that theories in contemporary science are complex and not straightforward statements of conjecture, which can simply be disapproved by the correct observations. He argues that, "one negative result, in real science rarely constitutes a decisive falsification of a clear-cut conjecture" (p. 68). Building on this, Chalmers (1987) argues that testing a theory involves more than testing the statements making up the theory. It includes "auxiliary assumptions, such as laws and theories governing the use of any instruments used" and "to deduce some prediction the validity of which is to be experimentally tested it will be necessary to add initial conditions such as a description of the experimental set-up" (Chalmers, 1987, p. 64). Furthermore, studies in the history of science indicate that if falsificationists' methodology were strictly adhered to, then many of the well-known scientific theories that exist would have been rejected in their initial stages (Richardson, 1979).

3. Post-positivism

In the 1950s, philosophers of science began to take seriously the evidence provided by the historical, sociological and psychological studies of science (Duchl, 1994). These analyses indicated that what was observed, measured, evaluated, or hypothesized in science was affected by the background knowledge and standards (theoretical perspectives) of the community of scientists (Duchl, 1994). In this post-positivism era scientific theories are viewed as historical and/or social products that can be understood and assessed only in the context of history (Hung, 1997). This philosophical shift toward considering the influence of theories, paradigms and social forces gave rise to a new philosophy of science of which Thomas Kuhn (cited in Abd-El-Khalick & Lederman, 2000) was the pioneer. According to Hung (1997) other proponents of this contemporary philosophy of science were Laudan and Lakatos.

Lakatos's view

Historical studies of science have revealed that since theories are complex they must be seen as organized structures. Using this as a basis and, in an attempt to improve on and overcome the objections of falsificationism, Imre Lakatos developed his view of science based on research programmes (Chalmers, 1987). Claxton (1991) associates Lakatos's view of scientific knowledge to that of a large tree. The roots of the tree are the assumptions, which form a framework of presuppositions that provide the language, perspectives and priorities that scientists accept and adopt. The trunk of the tree is the facts, which are seen as being relevant and uncontroversial. The top of the trunk are the speculative ideas or theories from which sprout 'twigs' of hypotheses and at the edges 'leaves' of observations and experiments (Claxton, 1991).

Lakatos's framework of analysing science had numerous merits and overcame many of the limitations of earlier analyses. Nevertheless it also had certain weaknesses. Whilst experimental tests determine the retention or rejection of competing hypotheses he provides no criteria for choosing between rival research programmes (Chalmers, 1987). Furthermore, his analysis was restricted to physics, which was used as basis to analyse a field of enquiry. Chalmers (1987) points out that according to Lakatos "any field of enquiry that does not share the main characteristics of physics is not science and is inferior to it from the point of view of rationality" (p. 107).

Kuhn's view

Thomas Kuhn also viewed scientific theory as a complex structure of some kind. His contemporary view of science, developed prior to Lakatos's view, is based on his examination of the historical process through which science is produced (Richardson, 1979). Kuhn's view of science also took into account the "sociological characteristics of scientific communities" (Chalmers, 1987, p. 89). According to Kuhn the notion of paradigm, which is the "establishment of an agreed set of standards and procedures as well as agreement on the meaning of terms" (Richardson, 1979, p. 10), which the members of a particular scientific community adopt, is central to the understanding of science and its growth (Hung, 1997). He contends that scientific knowledge develops through cyclic periods of consensus and dissensus among scientists (Duchl, 1994). Under the guidance and constraint of the paradigm science prospers (Hung, 1997). During the period of normal science the community of scientists are uncritical of the paradigm (Chalmers, 1987) but concentrate their efforts in ensuring that their work is "technically precise and logically tight" (Claxton, 1991, p. 75). When non-threatening anomalies arise they are either ignored or explained away (Hung, 1997). However, as anomalies accumulate the scientific community feels the pressure of a crisis (Hung, 1997) due to a lack of consensus resulting in competing theories and, adjustments to the paradigm (Claxton, 1991). Eventually one of these will be adopted and become a new paradigm. According to Kuhn, seeing, understanding, and recognising are all done within some paradigm therefore it is impossible for someone working within one paradigm to understand data obtained via another paradigm (Hung, 1997). He believes that facts are partly determined by the mind therefore Hung (1997) labels Kuhn's philosophy as constructivist.

4. Other views

Two other perspectives hold prominence namely the realist-instrumentalist debate and the rationalist-relativist debate. Theories in science are explanations that provide insights as to how phenomena in nature are thought to work. The realist-instrumentalist debate concerns what theories represent whilst the rationalism-relativism debate focuses on how theories are judged for acceptance or rejection (Loving, 1998). According to realists, the world exists independently of us and scientific theories do, or aim to, describe what nature is really like (Chalmers, 1987). However, instrumentalists claim that scientific theories are instruments or human constructions used by scientists to provide an adequate account of nature (Duchl, 1994). Chalmers (1987) asserts that for the naïve instrumentalist "it is not the business of science to establish what may exist beyond the realm of observation" (p. 148).

Rationalists and relativists judge scientific knowledge differently. According to a rationalist (or positivist), laws and theories derived from experiments are our descriptions of patterns we see in the real, external objective world (Nott & Wellington, 1998). Consequently empirical facts and observable phenomena are used to judge theories. Chalmers (1987) argues that a rationalist judges science from non-science in terms of the universal criterion. Thus an inductivist will judge something as science if it is inductively derivable from facts of observation. To a positivist scientific knowledge is more valid than other forms of knowledge. For a relativist the 'truth' of a theory depends on the norms and rationality of the individual or the community that subscribes to them as well as the experimental techniques used to test it (Nott & Wellington, 1998). Loving (1998) refers to psychological, social and cultural factors that are used by relativists to judge scientific theories. Accordingly, truth is not absolute but relative and it will vary among individuals and between different cultures. Thus the extreme relativist does not see science as superior to other forms of knowledge although some communities may place a high value on it.

Different philosophies of science have resulted in different conceptions of science within the scientific community. Consequently, issues such as the relations between observation and theory, between testing and discovery of knowledge claims, the growth and form of scientific knowledge, the objectivity and rationality of science as a way of knowing (Duchl, 1994) and the realist-instrumentalist and rationalist-relativist debates dominate contemporary epistemological and ontological discussions about science (Chalmers, 1987). These issues and philosophies have also filtered into the school science curriculum.

2.1.3 The social dimension of science

The social dimension of science examines the inter-relations between science and values and between science and culture. Whilst the philosophers of science have concentrated on scientific theorizing and scientific method, sociologists of science have focused on the social construction of scientific knowledge (Bauer, 1997). Philosophers, historians, sociologists, and feminist scholars of science have all questioned the assumptions that the scientific practice is characterized by the search for the truth about the world, individual intelligence, rational decision making based on empirical evidence, objectivity, ideological neutrality, and cultural universality (Hubbard, 1989; Keller, 1989; Longino, 1989; Matthews, 1998; Rosser, 1989). According to Hodson, (1993) "scientific and technological knowledge are, to a significant extent, culturally determined and reflect the social, religious, political, economic, and environmental circumstances in which science and technology are practiced" (p. 701).

Many sociologists and historians of science have identified an internal and external sociology of science sometimes referred to as private and public science. Roth and McGinn (1998) allude to scientists within the microcontext of the laboratory and macrocontexts that include funding agencies, networks, politicians, etc. The internal 'mythology and ritual' of the scientific community (Boyle, 1979) are the values which guide scientific research and are sometimes referred to as epistemic values (Allchin, 1998) or as Longino (1989) alludes to constitutive values which "are the source of the rules determining what constitutes acceptable scientific practice" (p. 47). The scientific enterprise is also embedded in personal, social and cultural values (Longino, 1989) therefore it is not value free or value neutral (Allchin, 1998). A similar view is expressed by Longino who argues persuasively "it is not necessarily in the nature of science to be value free" and "that the fabric of science can neither rule out the expression of bias nor legitimate it" (p. 50). In addition, scientific research is not exempt from ethical values and wider social values.

Merton identified *communism* (scientific discoveries and knowledge should be published and freely available to all), *universalism* (there are no privileged sources of scientific knowledge based on nationality, race, religion, class, age, sex or status), *disinterestedness* (science is done for the advancement of knowledge and not for personal stakes), *originality* (scientific research should always be novel) and *organized scepticism* (scientists take nothing on trust ie. scientific knowledge should be continually scrutinized) as institutional values or norms that characterizes scientific behaviour (Allchin, 1998; Boyle, 1979; Ziman, 1988). Although they embody an idealized pattern of rules governing scientific behaviour and have been criticized by sociologists, Boyle (1979) argues that they still reflect the views of most scientists. Ziman (1988) agrees that these norms have been verified by observation but they define an ideal pattern of behaviour, which scientists should endeavour to follow however they "inevitably conflict with a variety of other personal and social considerations, and can seldom, therefore, be practiced in full" (p. 87). Allchin (1998) identifies, from an historical analysis of science, other 'scientific' or epistemic values such as controlled observation, inventive experiments, confirmation of predictions, repeatability, and statistical analysis, in evaluating knowledge claims.

As mentioned above science is a social activity where individual scientists contribute to the collective knowledge (Wolpert, 1997) by following rules of membership within the scientific community (Hubbard, 1989). The domain of a scientist's cognitive resources, which are all the concepts, interpretive frameworks, motivations and values from personal and scientific experiences, shape his or her scientific contributions (Allchin, 1998). As such we must expect different interpretations and disagreements among scientists (Allchin, 1998) and more importantly they must acknowledge that their particular personal and social backgrounds and inevitable interests are part of their context of doing science (Hubbard, 1989). As explained above science is not an isolated body of knowledge but is influenced by outside society as well as the beliefs, attitudes and practices of scientists, which are often not publicly declared.

Scientific concepts and facts arise out of long social negotiations and modifications before agreement by the scientific community, even then the facts are not safe from refutation. Ziman (1988) contends that observations, hypotheses, theories, etc. of individual scientists do not constitute scientific knowledge, but must first be reviewed by peers who constitute self-appointed experts in the field. However, McComas (1996) argues that the fast pace of modern research has resulted in information not being scrutinized by referees but are officially published. Claxton (1991) supports this point of view when he remarks that although scientific claims are officially checked "in practice attempts at exact replication are surprisingly rare" (p. 78). Social moderation is a valuable source of quality control but it can also perpetuate prejudice and privilege by undermining theoretical opponents and holding back promising young scientists (Claxton, 1991). Boyle (1979) maintains that publicly scientists claim that they are motivated by a disinterested, generalized and impersonal need to extend the frontiers of knowledge but historical episodes in science indicate that scientists choose an area of research that provides maximum acknowledgement of their work.

Whilst scientists collaborate to share expertise (Wolpert, 1997) there is also intense competition for higher prestige and personal gain (Boyle, 1979). Collectivization and socialization has led scientists to work in research teams or for industrial companies. As a result, loyalty to the team or company can affect what scientists accept as scientific knowledge (Ryan & Aikenhead, 1992). Drawing on this Boyle (1979) cautions that the race for grants and the intense competition by laboratories, the military and industry have resulted in a distortion of values by some scientists. Despite protestations of humility by scientists, competition, recognition and prestige are the essence of the scientific enterprise. In addition, lesser-known scientists are given less credit for their work compared to famous scientists.

The high status of science inspires a belief in the solution of all problems and a belief in progress and improvement. Boyle (1979) remarks that societies are faced with practical problems that look to science for their solutions. He adds that the solution cannot be purely scientific since a whole complex of social and political considerations involving different interests need to be considered. He concludes that different interest groups will define and state the problem according to their political and social beliefs thereby imposing their own form upon the solutions proposed. Hodson (1993) asserts, "once it is acknowledged that science is a human activity, driven by aspirations and values of the society that sustains it, it is legitimate to ask whether different societies might define and organize science differently because their aspirations and values are different" (pp.700-701). Boyle (1979) concurs that other cultures have possessed quite different world-views based on different assumptions about the nature of reality.

2.1.4 Other ways of knowing about the world

Since knowledge is socially constructed different ways of seeing can coexist. Western science is not the only legitimate knowledge producer (Semali & Kincheloe, 1999) since " there is not a singular or universal knowledge but there are 'multiple knowledges' " (Kyle, 1999, p. 8). It is false to assume that there is a universal scientific method or rules of logic as understood by philosophers to which all forms of knowledge must conform to be accepted as 'scientific' (Chalmers, 1987). Feyerabend (cited in Chalmers, 1987) provides justification when he argues that defenders of science cannot claim it to be superior without investigating the nature, aims and methods of other forms of knowledge. Hodson (1993) refers to this as "scientific racism" where certain groups will misuse scientific findings to support claims of superiority or create the notion that non-western science and technology is inferior.

2.1.5 The nature of science – a brief summary

Given the above it is obvious that when teaching we need to make learners aware of the development and the contested nature of science. However at least we do have general agreement on the following. There are a number of beliefs or schools of thought about nature of science. The earliest view about science is it discovers truths about the world and scientific knowledge consists of general statements that have passed the test of sufficient observation. However close scrutiny of historical events in science indicates that science is full of ideas, theories and explanations and invisible entities that nobody has seen and that science progresses through stages of development. Scientific knowledge is the result of a long, complex and irregular social process. The combined analyses by historians, philosophers and sociologists of science have revealed that the scientific enterprise is more complicated than what positivists believe. As a result different philosophical views about the nature and status of scientific knowledge have emerged termed the 'new' philosophy of science. It still involves evidence and observations but background knowledge, theoretical commitments, creativity and imagination, social forces and, personal factors all impact on the growth of scientific knowledge. Scientific inquiry takes place in a social, political and economic context therefore it cannot be value free or value neutral. Furthermore, there are two extreme stances towards science, the realists on one end and the relativists at the other end. Consequently there has been a shift in views from positivism through falsificationism to the 'new philosophy of science'. Nevertheless, currently there are two main doctrines influencing science education: the established dominant view termed 'logical positivism' and, and the current challenger of accepted ideas, or the 'new' philosophy of science.

2.2 SCIENCE EDUCATION

Traditionally science education has focussed on content to enable learners to pursue further studies in science and technology. Ziman (1988) points out that its main purpose was vocational since many jobs could not be performed without some degree of scientific knowledge. He concedes that in our technological civilization knowledge about science is as important as knowledge of science (Ziman, 1980). In other words one has to know about the general concepts in science (Ziman, 1980) as well as the nature of the scientific endeavour (Jenkins, 1997), its accomplishments, limitations and its methods (Thomas, 1997), to function effectively in contemporary society. This is often referred to as scientific literacy or public understanding of science in science literature (Fensham, 1997; Jenkins, 1997; Ziman, 1988). In order to achieve this Claxton (1997) argues persuasively that science education should provide everyone with the ability to "combine observation, experimentation, imagination and deliberation creatively and flexibly in the pursuit of solutions to personally relevant problems" (p. 80) so as to address the real-world needs of the twenty-first century. Millar (1997) concurs with this view and like many others (American Association for the Advancement of Science (AAAS)), 1993; Australian Education Council, 1994; Collins, Osborne, Ratcliffe, Millar, & Duschl, 2001; Jenkins, 1997; Lederman, 1998; Solomon, 1997) within the science community believe that understanding the nature of scientific knowledge serves as a vehicle to adequately equip learners to respond to socio-scientific issues which is a major purpose of contemporary science education.

2.2.1 Ideas in science education – a brief history

Most ideas or goals in science education have been around for some time although they may be expressed differently. According to DeBoer (1991) they include "intellectual goals of thinking and reasoning, the personal goals of appreciation and understanding, the practical goals that will help us in our life's work and in our role as intelligent citizens, and the futuristic goals of innovation and creativity" (p. xiii). Throughout the history of science education Bybee and DeBoer (1994) maintain that all goals can be grouped into three themes viz. scientific knowledge, scientific methods and, personal-social development. Understandings of nature of science have been historically associated with the goals of scientific methods and personal social development. What follows is a brief history of the ideas in science education to track these goals in order to see how nature of science has emerged from them.

During the nineteenth century intellectual development and learning scientific knowledge dominated science education. This century was a time of important scientific discoveries and the origins of many modern ideas in science education.

Reading, writing, arithmetic, languages and classical literature dominated the education curriculum prior to the mid-nineteenth century. Nevertheless, when science was taught it often had a theology approach where "the natural world was seen as a revelation of God's unfolding plan for the world" (Bybee & DeBoer, 1994, p. 360) and the emphasis was on factual knowledge. By the second half of the nineteenth century many prominent scientists argued for the inclusion of science into the school curriculum. They supported the meaningful learning of science concepts via direct contact with the natural world using the laboratory to develop skills in observation and inductive reasoning powers (DeBoer, 1991). By the end of the nineteenth century there was a move away from memorization towards meaningful understanding, use of the laboratory approach and, making science relevant to the everyday lives of the learners (DeBoer, 1991). Nevertheless throughout the nineteenth century the goal of personal intellectual development competed with the goal of learning science facts and information despite the acknowledgement of the importance of methods of science (Bybee & DeBoer, 1994). Millar (1997) aptly describes it as " portraying science in the classroom as a body of established knowledge which cannot be contested and to which the learner can make no critical or creative input, but must merely assimilate" (p. 92).

In the early part of the twentieth century the justification of science in the curriculum had shifted from its ability to develop ones intellectual skills to one that would develop an individual who would be a happy and contributing member of society (DeBoer, 1991). As a result the goal of scientific knowledge leaned towards social welfare whilst personal-social goals emphasized career awareness and vocational interests. Scientific methods were taught as means to develop general problem-solving skills that could be used as a tool to solve social problems. The early part of the twentieth century also saw the emergence of organized science disciplines of biology, general science, physics and chemistry. From the 1920s to the years leading to the early 1950s there was a shift in science education from disciplinary study towards social relevance and learner interest (DeBoer, 1991) however, there was a lack of agreement between an emphasis on subject matter and an emphasis on the application of the subject matter to the lives of the learners (Bybee & DeBoer, 1994). Despite these disagreements there were strong commitments to personal-social applications and the use of organizing themes to structure scientific knowledge (Bybee & DeBoer, 1994).

During the late 1950s and the early 1960s science education was dominated by understanding the structure of scientific disciplines and scientific knowledge again became the primary goal. Fensham (1997) points out that this is due to the influence of the general psychological learning theory. DeBoer (1991) attributes this to Bruners use of Piaget's theory of cognitive development in explaining that science materials developed and presented were consistent with a child's level of intellectual development. Consequently, this resulted in the same science concepts being taught with greater complexity as the learner progressed through the schooling system. It involved presenting abstract concepts of each science discipline as an induction into higher science-based studies. With regard to these curriculum efforts DeBoer (1991) writes:

> They presented the science disciplines as logically structured areas of human investigation, they dealt candidly with the nature of scientific research, and they encouraged students to think and act like scientists within the structure that was established. What the curriculum makers failed to do, however, was to consider a number of fundamental principles of curriculum and instruction. They did not take into account the importance of student interest or the pedagogical need to relate science knowledge not only to the broad unifying themes of the discipline itself but also to the experiential world of the student... (p. 171)

In the 1960s personal-social development, "the applications of science in society and the individual and co-operative processes in the scientific community (Fensham, 1997,

p. 120), were largely ignored in favour of structured knowledge where scientific methods like inquiry, problem-solving and critical thinking (Bybee & DeBoer, 1994) were used to encourage learners to think and act as scientists as a way of mastering scientific knowledge (DeBoer, 1991). By the end of the 1960s scientific literacy began to emerge as a theme in science education.

The 1970s saw the re-emergence and prominence of personal-social development goals in science education. Fensham (1997) alludes to industrialization, where different skills were required, multi-culturalism and the movement to raise participation of females in science as some of the reasons for the emergence of this goal. The needs of this period led Bybee and DeBoer (1994) to comment that, "Society needed scientific literacy, not a scientific elite" (p. 376). However DeBoer (1991) points out that although scientific literacy was the watchword of the 1970s the term for many science educators lacked precision and clarity. He adds that this was due to various definitions provided by the scientific community, nevertheless the concept implied a broad and functional understanding of science. However Bybee (1999) disagrees with this narrow conception. He maintains that scientific and technological literacy refers to a general education that involves a nominal, functional, conceptual, procedural and multidimensional understanding about the natural and designed world. The main themes of science education in the 1970s were social relevance, student interest, interdisciplinary relationships, interdependence of science and technology, and the human aspects of the scientific enterprise (Bybee & DeBoer, 1994).

From the end of the 1970s scientific literacy fell under the banner of science-technology-society (STS) and became firmly established as a progressive educational goal. Fensham (1997) contends that in the 1980s science education had become an established and active field of scholarly research resulting in a better understanding of the needs, beliefs and characteristics of science learners. Consequently new materials were developed in the European union, USA, Australia, New Zealand and Canada emphasizing socio-scientific issues (Fensham, 1997) due to a decline in learner enrolment in disciplinary-based science courses (DeBoer, 1991). This resulted in heated debates as to whether discipline-based or socially relevant science should be the focus of science education (DeBoer, 1991). The confusion about exactly what socially relevant science is and its perceived lack of status as compared to disciplinary science resulted in its limited use in the classroom. Fensham (1997) mentions that many leading academic scientists strongly opposed the STS approach claiming that it was pseudo-science and it undermined the Western scientific tradition. However, Bybee and DeBoer (1994) remark that opponents of the STS position on science literacy did not oppose social relevance but that courses were to be organized around contemporary social issues rather than scientific concepts. Nevertheless, 1980s was characterized by an organized study of the disciplines of science and processes of scientific investigation with the themes of interest, relevance and social benefit (DeBoer, 1991).

Whilst the goal of knowledge acquisition in science education had been prominent and stable, the scientific methods and the personal-social development goals had grown in importance in the 1990s (Bybee & DeBoer, 1994). Although the methods goal had embodied an empiricist view of science, which still persists, starting from observations and looking for patterns it has been reconceptualised in the 1990s to include open-ended investigations and the collection and evaluation of evidence (Millar, 1997). More specifically according to Lederman (1998) it incorporates scientific inquiry, which refers to the systematic approaches used by scientists to answer their questions of interest. The personal-social development goal has also been changed and updated due to psychologically based research (Bybee & DeBoer, 1994) to include development of intellectual skills, appreciation of the nature of science as a process of inquiry and the mastering of scientific knowledge in a meaningful way for future use (DeBoer, 1991). It is gaining more prominence via the STS and scientific literacy movements. By the twenty first century there has been a move for equal footing of all three science goals.

2.2.2 Nature of science in science education – a brief history

Matthews (1998) maintains that since the early nineteenth century it had been hoped that science learners not only know science but also internalize the scientific spirit and know and appreciate something of nature of science. However these were mere aspirations within the scientific community that were not explicitly stated in science curricula. Lederman (1992) asserts that nature of science objective can be traced back to 1907 via the scientific method and processes of science goal in science education. However Hodson (1993) claims that prior to 1960 the science curriculum was primarily concerned with the acquisition of scientific knowledge. Support for this point of view comes from Duschl (1994) who points out that although the definitions of inquiry were being changed and new views were emerging from the philosophy of science in the 1950s they were not adopted in the science curriculum materials that were being prepared. McComas et al. (1998) concur that the National Society for the Study of Education stated nature of science explicitly as a major aim of science teaching in 1960. In the first half of the twentieth century, understanding nature of science was equivalent to understanding 'the scientific method' (Abd-El-Khalick & Lederman, 2000). This according to Sutton (1989) meant reports of laboratory work had four components namely aim, method, results and conclusions, which gave the impression that science is essentially doing things and describing what happens, a vestige of empiricism.

According to Matthews (1998) nature of science was implied but not explicitly stated during the 1960s in USA science curricula in the statement 'understanding the structure of science'. Understanding nature of science was seen as an 'internal' matter for those who were majoring in science. Other researchers see references to nature of science in the 1960s via the re-emergence of practical inquiry (Lederman, 1992), which science teachers claimed to be teaching as an investigational type of science (Sutton, 1989) and science process skills (Abd-El-Khalick, 2000). Sutton (1989) argues that since there was a lot more laboratory work there was an increased use of worksheets resulting in a dominance of doing over thinking. Like DeBoer he raises concerns about how scientific research was being portrayed and the role of thinking.

> This raises problems in wider education, where there is a need for a fuller story, both about the thoughts that scientists had, and about the thoughts that the learner has. It may not matter in the research world if the whole story is not told in a journal report, but in school the suppression of first thoughts, conjectures, preliminary beliefs, hopes or reasons for doing an experiment could be both a misrepresentation of science and an interruption in the development of the learner's own thought (Sutton, 1989, p. 142).

In 1970s scientific literacy emerged as a term to describe an education in science for all that was relevant to the lives of the learners and that focussed on socially important issues. DeBoer (1991) mentions that nature of science was listed as one of the themes that could help in fostering scientifically literate youth. However Matthews (1998) maintains that it was only in the 1980s and 1990s that nature of science was written into most definitions of scientific literacy and it became a hoped-for part of the education of all learners, not only those pursuing pure science. Although the philosophy of science during 1970s was going through a 'Kuhnian revolution' these changes were not being reflected in school science education curricula (Duschl, 1994) – conceptions of science processes and scientific methods still had their origins in inductivist and empiricist philosophies (DeBoer, 1991). Nevertheless, universities characterized "scientific knowledge as being tentative, public, replicable, probabilistic, humanistic, historic, unique, holistic and empirical" (Abd-El-Khalick & Lederman, 2000, p. 667).

The 1980s was a fruitful period in terms of research into science education. Many questions were raised concerning the relative value of learning the processes of science, the products of science and, the strategies that could be used to accomplish these goals (DeBoer, 1991). The result was a focus on socially relevant science with the creation of a STS approach. This together with the debates centred on multicultural science, environmentalism, constructivism, feminism and non-Western sciences brought nature of science back on to the science education stage (Matthews, 1998). A process approach was used to mirror the work of scientists where an experiment "is portrayed as a straight forward means of testing suggested explanations of patterns which have emerged from observational data" (Millar, 1989, p. 39). However this was in conflict with current philosophical and sociological accounts of science, which indicated that neither the inductivist nor hypothetico-deductivist view could provide an adequate account of what scientists do. The process approach did not reflect the theory-laden nature of observation, role of human creativity in developing explanations, and the role of the scientific community in authenticating scientific claims, which were the contemporary views on science (Abd-El-Khalick, 2000).

By 1990 it was acknowledged that science curricula represented a distorted image of science that was outmoded in terms of the philosophy of science underpinning them (Ayayee & McCarthy, 1996). Consequently there appeared to be agreement among major reform movements in science education about the importance of enhancing conceptions about nature of science. The Benchmarks for Science

Literacy (American Association for the Advancement of Science (AAAS), 1993) had outlined three themes - the scientific world view, scientific inquiry and the scientific enterprise, whilst A statement of Science for Australian schools (Australian Education Council, 1994) included a working scientifically strand that also contained three components - using science, acting responsibly and, investigating, that underlie an adequate understanding of nature of science.

The science education community in the twenty first century have acknowledged that if learners are to become scientifically literate, authentic conceptions of nature of science must be conveyed to them. Accordingly science education is being re-examined globally. The need to empower learners to develop new ideas and investigative skills that contribute to self-regulation, personal satisfaction and social responsibility and the organizing of established science content around a small number of central themes permeate recent curriculum development.

2.2.3 Rationale for nature of science in contemporary science education curricula

What is evident from nature of science literature (AAAS, 1993; Australian Education Council, 1994; Bell, Blair, Crawford, & Lederman, 2003; Collins et al., 2001; Lederman, 1999) is that an understanding of nature of science will enable students to be more knowledgeable consumers of science, which will empower them to make more informed decisions when scientific claims and data are involved. Collins et al. (2001), Thomas (1997), Wolpert (1997) all agree that contemporary society require its members to engage in critical dialogue about political and moral dilemmas posed by science and technology and arrive at informed decisions. The South African Natural Sciences curriculum state that it should "contribute to the development of responsible, sensitive and scientific literate citizens who can critically debate scientific issues and participate in an informed way in democratic decision-making processes" (Department of Education, 2002c, p. 29). Thomas (1997) points out that in order to achieve this learners must not only know the "facts of science but also its accomplishments, limitations and its methods" (p. 163). Science and technology pose questions that seem to require complex and specialized knowledge, which only a few possess. Collins et al. (2001) have concluded in their study that in order to equip learners to respond to socio-scientific issues learners should be provided with some insight into the difficulty of generating reliable and consensual understanding of the natural world. They add that learners require the ability to distinguish whether an argument is sound, and to differentiate evidence from hypotheses, conclusions from observations and correlations from causes. Given these reasons it appears this can only be achieved if there are deep understandings of scientific concepts, the processes of scientific inquiry, and nature of science (Bell et al., 2003).

McComas et al. (1998) have suggested four additional reasons, further to improving decision-making, for the inclusion of nature of science in science curricula. These include that nature of science assists, in the learning of science content, in understanding how science operates, in making science more interesting and, in enhancing instructional delivery. Linneman, Lynch, Kurup, and Batwini (2002) argue persuasively that for the science educator the rise of science, the conduct of science, its influence on values and priorities and its relation to social responsibility are difficult to discuss without reference to some understanding of nature of science itself. Such an understanding is considered to be a significant aspect of scientific literacy.

Furthermore there is a growing body of research on multicultural science and doing science as a feminist. Longino (1989) argues that feminist scientific practice acknowledges political considerations as relevant constraints on reasoning, identifies bias and can eliminate that bias to produce better, good, more true or gender free science. Keller (1989) supports a similar argument by pointing out that the exclusion of feminine from science has resulted in a historical definition of science as "incontrovertibly objective, universal, impersonal and masculine" (p. 42) whist Hubbard (1989) alludes to feminists acknowledging subjectivity, the influence of personal and social backgrounds and vested interests in doing science.

Hodson (1993) has stated that an inclusive multicultural science education must include different philosophical and sociological perspectives on the purposes and procedures of scientific practice that reflect a global view of nature of science. He adds that there is a prevalent myth that science is exclusively European or North American as a result contributions of scientific achievements by non-westerners have been trivialized or falsely attributed to westerners. Nature of science provides a platform to discuss other ways of doing science that would yield alternate accounts of nature (Millar, 1989) from both feminist and non-Western perspectives. Contemporary science curricula recognise that "aspects of scientific knowledge are constructed from a particular cultural or gender perspective" (Australian Education Council, 1994, p. 16) and important contributions to the advancement of science, mathematics, and technology have been made by different kinds of people, in different cultures, at different times (AAAS, 1993).

Lederman (1992) points out that despite the lack of consensus concerning the specific content to be included in current science curricula, or the instructional strategies to be used, there is considerable agreement that science education should include some explicit nature of science instruction. A Delphi study, conducted by Collins et al. (2001), consisting of acknowledged experts within the science community in the United Kingdom have arrived at some consensus as to certain nature of science elements that are relevant for school learners. However, they claim that "some or all of these elements might be contentious within the philosophical community, it is possible to argue that they represent a partial or simplified view of the NOS" (Collins et al., 2001, p. 6).

2.2.4 Contemporary views about science and Curriculum 2005

The renaissance, in terms of the philosophy of science in education, experienced by other countries has filtered down to the new South African outcomes based science curricula, which explicitly addresses nature of science. An analysis of the study by Collins et al. (2001) reveals 18 important nature of science themes an 'expert' science community proposes should be explicitly taught in schools and included in science curricula. There were nine-top rated themes for which there was consensus: Scientific methods and critical testing; Creativity; Historical development of scientific knowledge; Science and questioning; Diversity of scientific thinking; Analysis and interpretation of data; Science and certainty; Hypothesis and prediction; Cooperation and collaboration in the development of scientific knowledge.

Contemporary science curricula like Benchmarks for Science Literacy (1993) and A Statement on Science for Australian Schools (SSAS) (1994) display similar themes. Nature of science themes recommended by Collins et al. (2001) were similar to those found by McComas and Olsen (1998) in their detailed analysis of international science standards documents from USA, Australia, UK, New Zealand and Canada. Analysis of the National Curriculum Statement (NCS) Physical Sciences (Department of Education, 2003), Revised National Curriculum Statement (RNCS) Natural Sciences (Department of Education, 2002b), Curriculum 2005 Assessment Guidelines: Natural

Sciences, Senior Phase (Department of Education, 2002c) and Curriculum 2005 - Natural Sciences Curriculum Framework: Senior Phase (Department of Education, 1997) reveal similar themes identified by the scientific community in the Collins et al. (2001) study.

In order to facilitate a comparison with the natural science curriculum I used a framework for analysis based on three strands – the nature of science knowledge, the nature of scientific inquiry and the relationship between science and society. A similar structure using science process skills, scientific knowledge and science and society is reflected in the Natural Sciences Curriculum Framework (Department of Education, 1997). The discussion that follows illuminates how the fundamental nature of science themes proposed by the scientific community and other modern curricula are reflected in Curriculum 2005 and illustrates the contemporary nature of the South African science curriculum. Although the themes are discussed in specific strands it must be noted that the different themes are linked and interrelated to each other and they have common characteristics that permeate the three strands.

1. The nature of science knowledge

Collins et al. (2001) maintain that the scientific community associates the theme science and certainty with the provisional nature of science suggesting that there is more to be discovered. They elaborate on this theme by stating that:

> Pupils should appreciate why much scientific knowledge, particularly that taught in school science, is well established and beyond reasonable doubt, and why other scientific knowledge is more open to legitimate doubt. It should also be explained that current scientific knowledge is the best we have but may be subject to change in the future, given new evidence or new interpretations of old evidence (Collins et al., 2001, p. 19).

The Benchmarks for Science Literacy allude to learners understanding that the main body of scientific knowledge is very stable and grows by being corrected slowly and having its boundaries extended slowly (AAA, 1993) whilst A Statement on Science for Australian Schools (SSAS) maintains that present understandings need continually to be re-evaluated and imaginatively transformed to provide better understanding and greater predictability (Australian Education Council, 1994). The NCS Physical Sciences also ascribes priority to this theme and it states: "Scientific knowledge is tentative and subject to change as new evidence becomes available and new problems are addressed" (Department of Education, 2003, p. 14). Collins et al. (2001) point out that the science and certainty theme are linked to the themes of characteristics of scientific knowledge and the cumulative and revisionary nature of science. They explain these themes, as scientific knowledge is universal, general and cumulative and building on that which is known. Scientific explanations are based on models whilst new theories and methods are often resisted they may be ultimately accepted based on their explanatory and predictive power. The NCS Physical Sciences state that learners be able to "evaluate the limitations of the explanatory power of scientific models and of different theories" (Department of Education, 2003, p. 14). Curriculum 2005 makes explicit references to evolutionary nature of scientific knowledge and the use of models and theories:

> Knowledge process in science is an ongoing process that usually happens gradually, but occasionally knowledge leaps forward as a new theory replaces the dominant view. Science and technology pull and push each other in a complex relationship that pushes back the knowledge frontier, and provides new processes and products for society. While the major generalizations and principles of science have stood the test of time, there is openness to new theories and knowledge (Department of Education, 2002d, pp. 16-17).

Also Curriculum 2005 - Natural Sciences Curriculum Framework: Senior Phase state:

> Too easily science can be seen as a body of immutable truths and therefore as absolute and without change. Learners need to know that science is a human activity, dependent on assumptions which change over time and over different settings. By realizing the changing nature of scientific knowledge, both learner and teacher will be supported in their aim of linking everyday knowledge with scientific interpretations and so create a better understanding of the world (Department of Education, 1997, p. 16).

The scientific community explains that the theme empirical base of scientific knowledge is essential to help learners recognize that scientific knowledge is characterized by empirical evidence (Collins et al., 2001). The RNCS Natural Sciences points out that while empiricism has been effective in generating effective and reliable scientific knowledge it has also been challenged by many as a limited way of understanding the world since it ignores questions of meaning and value (Department of Education, 2002b). Given this reasoning C2005 identifies with the empirical base only in terms of disciplined observation, careful analysis, precision, rigor, logical reasoning and fairness. References are made to learners accessing a variety of sources, using a variety of instruments or devices and evaluating and analyzing data in terms of validity and appropriateness of methods and techniques (Department of Education, 1997). Curriculum 2005 also acknowledges the existence of different world-views like traditional and indigenous knowledge systems in understanding the world:

> ...science is not a neutral discipline, but that it is influenced by the culture in which it takes place. Furthermore, science cannot necessarily be seen as the only way of making sense of the world around us. Other cultural means of clarifying the world, such as through language, religion or art, should be seen as having validity and benefit, just like science (Department of Education, 1997, p. 15).

2. The nature of scientific inquiry

The scientific community view the theme scientific methods and critical testing as a core process on which the whole structure of science is built. They point out that the experimental method is what defines science (Collins et al., 2001). According to the scientific community:

> Pupils should be taught that science uses the experimental method to test ideas, and, in particular, about certain basic techniques such as the use of controls. It should be made clear that the outcome of a single experiment is rarely sufficient to establish a knowledge claim (Collins et al., 2001, p. 16).

However they are also careful to point out that "science uses a range of methods and approaches and that there is no one scientific method or approach" and "that in some instances scientists need to develop new methods, or adapt an old one, to test a particular idea" (Collins et al., 2001, p. 18). This is associated with the theme diversity of scientific thinking. The Benchmarks for Science Literacy also point out that while there is no fixed set of steps that all scientists follow, scientific investigations usually involve precision and rigour, disciplined observation, collection of relevant evidence, careful analysis, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence (AAAS, 1993). Similar views are reflected in the NCS Physical Sciences which states that learners be given the "ability to work in scientific ways" (Department of Education, 2003, p. 9). The scientific community link scientific methods and critical testing to the themes of science and questioning, hypothesis and prediction, analysis and interpretation of data, observation and measurement, and, creativity (Collins et al., 2001). Curriculum 2005 also identifies with these themes and asserts that science has been characterized by observation, codifying and testing ideas about the natural world where there is some sort of check or proof. According to Curriculum 2005:

> To be accepted as science, certain methods of inquiry are generally used. They promote reproducibility, attempts at objectivity, and a systematic approach to scientific inquiry. These methods include formulating hypotheses, and designing and carrying out experiments to test the hypotheses. Repeated investigations are undertaken, and the resulting methods and results are carefully examined and debated before they are accepted as valid (Department of Education, 2002b, p. 4).

Collins et al. (2001) maintain that scientific knowledge claims do not emerge simply from the data but through a process of interpretation and theory building that can require sophisticated skills. It is therefore possible for scientists legitimately to come to different interpretations of the same data and therefore, disagree. Abd-El-Khalick (2000) provides justification for this when he points out that scientists' theoretical and disciplinary commitments as well as their training and experience influence their interpretation of the available evidence and consequently the kind of answers or inferences they construe as the most plausible or valid. To understand the complexity of analysis and interpretation of data the NCS Physical Sciences states that learners be able to "seek patterns and trends, represent them in different forms, explain the trends and use scientific reasoning to draw and evaluate conclusions and formulate generalisations" (Department of Education, 2003, p. 19). The Benchmarks for Science Literacy aptly describes the use of questioning in science when it states, "As new questions arise, new theories are proposed. New experiments are conducted, new observations made and new analyses performed may result in challenging existing theories leading to modifications or very rarely to the invention of new theories" (AAAS, 1993, p. 5).

The use of questioning and the methods of science are also articulated in C2005 via process skills.

> Raising questions about a situation involves thinking of questions which could be asked about a situation, recognizing a question which can be answered by scientific be involved in rewording a vague question to make it into a testable prediction, deciding which variables matter in the problem or question, planning how to change one variable and keep the other variables constant, planning what variables to measure and how to measure them, knowing how to improve the accuracy and validity of the measurements, making inferences from results, and evaluating someone else's plan for a fair test (Department of Education, 2002b, p. 14).

Scientists use their imagination and creativity to invent constructs, models, theories, and explanations to account for empirical observations and patterns in observable phenomena. A Statement on Science for Australian Schools (Australian Education Council, 1994) points out that scientific understanding also advances by creative leaps of the imagination, inspired haunches and guesses while The Benchmarks for Science Literacy maintains (AAAS, 1993) that progress in science depends on intelligence, hard work, imagination and even chance. The scientific community makes explicit reference to the creativity theme.

> Pupils should appreciate that science is an activity that involves creativity and

> imagination as many other human activities and that some scientific ideas are enormous intellectual achievements. Scientists, as much as any other profession, are passionate and involved humans whose work relies on inspiration and imagination (Collins et al., 2001, p. 16).

Curriculum 2005 ascribes priority to this theme via understanding science as a human endeavor (Department of Education, 2002a).

3. The relationship between science and society

The relationship between science, society and the environment is embodied in the third learning outcome of the RNCS Natural Sciences which states "the learner will be able to demonstrate an understanding of the relationships between science and technology, society and the environment" (Department of Education, 2002a, p. 40). The evolutionary nature of scientific knowledge is closely related to the theme historical development of science. The scientific community maintains that this theme highlights science as a human activity and provides insight as to how ideas were developed and tested in the past and influenced by the demands and expectations of that society (Collins et al., 2001). A Statement on Science for Australian Schools (SSAS) concisely points out that, "aspects of scientific knowledge are constructed from a particular cultural or gender perspective" (Australian Education Council, 1994, p. 16). According to the NCS Physical Sciences the "study of historical, environmental and cultural perspectives on science highlights how it changes over time, depending not only experience but also on social, religious and political factors" (Department of Education, 2003, p. 14). Curriculum 2005 acknowledges that learners should be able to provide examples of peoples' contributions of science through the ages and link the development of scientific theories to the needs and beliefs of a society at a certain time and place (Department of Education, 1997).

Although scientific decisions are certainly based on empirical evidence and basic assumptions, they are also guided by values, which are discipline-centered, and values which are external to the discipline of science (Ryan & Aikenhead, 1992). Collins et al. (2001) argue that "pupils should appreciate that choices about the application of scientific and technical knowledge are not value-free; they may, therefore, conflict with moral and ethical values held by groups within society" (p. 14). An analysis of Curriculum 2005 reveals that learners are required to recognize bias in science and technology. It explicitly states that:

> …science is not value-free and can be misused or abused. On the one hand science can create inequities and show bias, on the other hand science can also help to redress such situations. Ethical issues often have a science component to them; learners need to develop the ability to use scientific perspectives among other perspectives to evaluate ethical issues (Department of Education, 1997, p. 18).

Similar ideas are reflected in the Australian science curriculum which requires learners to be aware that areas of science that are pursued and the applications of science tend to reflect the values and interests of dominant groups, marginalizing the interests of other groups (Australian Education Council, 1994).

Collins et al. (2001) argue that the scientific community stresses the importance of the social process in science through the theme cooperation and collaboration in the development of scientific knowledge. They maintain that this theme embodies the process of critical peer review in science, group activity and collaboration and international and cross-cultural character to science knowledge. Nevertheless, SSAS cautions that though they share ideas, methodologies and concerns they also compete for funds and recognition (Australian Education Council, 1994). One of the important characteristics of C2005 is group work to promote cooperation and collaboration. This theme is given priority in the science curriculum where learners are required, in groups, to access information, formulate investigative questions, design plans of action, debate possible solutions, re-evaluate through brainstorming and communicate findings, decisions and conclusions to experience the social activity in science. Curriculum 2005 also challenges the perception that science is predominantly a Euro-centric discipline by including contributions made by other cultures like Indians and Chinese to science.

2.2.5 Science education – a brief summary

Science education is firmly entrenched in the school curriculum. It has been characterized by three goals viz. knowledge acquisition, scientific methods and the personal-social development goals. The history of science education reveals that it has been organized around science disciplines as developed by scientists over years. It is these disciplines that provide us with concepts for understanding our world and predicting probable outcomes of our interaction with the world. Historical ideas in science education also reveal that learners would learn the processes of science, which entails practicing many of the skills scientists use and linking theory with experimentation. In addition to learning the processes and products of scientific inquiry they would recognise the power of these to explain the world around them and in helping with discussions about the relationships between the principles of science and daily events. Consequently contemporary science education includes science content, science processes and the social context of science.

In order to represent a contemporary image of science, science education is being re-examined globally to include a significant component of nature of science. However, nature of science is fluid and dynamic and remains a difficult and problematic construct to deal with. Nevertheless, despite being a contested domain, there exists some consensus within the scientific community as to certain nature of science themes that are relevant for school learners. These themes were analysed using a framework based on three broad strands: the nature of science knowledge, the nature of scientific inquiry and the relationship between science and society. An analysis of C2005 using this framework revealed that the new South African science curriculum represents contemporary views held within the broader scientific community.

2.3 LEARNERS' CONCEPTIONS AND SCIENCE EDUCATION

This study focuses on learners' conceptions of nature of science. It is therefore vital to understand the role of learners' conceptions in learning and how C2005 view these conceptions. The discussion that follows elaborates on these two aspects and a historical review nature of science research is provided. Specific findings regarding learners' conceptions of nature of science within South Africa will be mentioned when the findings of this study are discussed.

2.3.1 Learners' conceptions and learning

An approach to learning science that has gained much support in science curricula is the constructivist approach, which has been influenced by the view of cognitive theorists. It draws largely on the work of Ausubel, Novak , von Glaserfield, Vygotsky and others (Wandersee, Mintzes, & Novak, 1994). Ausubel (cited in Cobern, 1995) has demonstrated that what the learner already knows has a powerful influence on the meaning a learner makes of any learning situation. Driver (1989) maintains that a constructivist perspective is when individuals progressively build up and restructure their schemes of the world around them via their own mental activity, experience with the environment and social interactions. It involves negotiation and interpretation (Cobern, 1995). Learners' ideas or conceptions play an organizational role in their construction of new knowledge and their interpretation of new information (Driver et al., 1994). If we can find out what individual learners currently think then we can acknowledge their varying views (Cobern & Loving, 1998) therefore, "teachers should be on the lookout for naïve theories or incorrect knowledge held by students" (Tobin, 2004, p. 178). Tobin (2004) cautions that constructivism is often misunderstood to mean that any construction is viable as another. He maintains that knowledge is viable not only personally but also in social contexts in which actions occur which supports Vygotsky's theory (cited in Duschl & Hamilton, 1998) that individual development cannot be understood without reference to the social environment in which the learner is embedded. Driver, Asoko, Leach, Mortimer, and Scott, (2004) concur that learning science involves both personal and social processes. They add that:

> On the social plane, the process involves being introduced to the concepts, symbols and conventions of the scientific community. Entering into this community of discourse is not something that students discover for themselves any more than they would discover by themselves how to speak (Driver et al., 2004, p. 65).

Driver et al., (2004) therefore maintain that if learning conventional science ideas is seen as the social construction of knowledge then teachers need to make available to learners the appropriate experimental evidence, the cultural tools and conventions of the science community. They argue that this becomes a challenge if the science view the teacher presents is in conflict with the learners' prior knowledge. Teachers therefore need to develop learning tasks which specifically address the changes learners need to make in their conceptual schemes and give learners sufficient time and opportunities for revisiting the ideas in a range of contexts (Driver, 1989).

Within a multicultural society learners from different cultures have varied experiences they bring into the science classroom and therefore have competing accounts of natural phenomena. According to Jegede and Aikenhead (2004) within this environment learners need to move from their everyday life-world to the world of school (Western) science. Often many learners experience problems crossing these cultural borders. One of the strategies proposed by Jegede and Aikenhead (2004) is to encourage learners to identify their own ideas and beliefs to assist teachers develop cross-cultural teaching strategies. Duschl and Hamilton (1998) assert that conceptual change is possible if there is discourse embedded in meaning negotiation and appropriation processes. They add that in meaning negotiation learners make explicit their beliefs, meanings and understandings related to a particular activity where they negotiate common or agreed upon meanings while appropriation involves teachers taking learners' meanings and reflecting on his or her interpretation within a conversational context and employing them within the science learning activity (Duschl & Hamilton, 1998).

2.3.2 Curriculum 2005 - a learner centered curriculum

In C2005 the goals of scientific knowledge and scientific method are important but there is also an emphasis on the goal of personal-social development. It seeks to "create a lifelong learner who is confident and independent, literate, numerate, multi-skilled, compassionate, with respect for the environment and the ability to participate in society as a critical and active citizen" (Department of Education, 2002a, p. 3). Curriculum 2005 is learner-centred and therefore favours constructivist teaching practices. Curriculum 2005 Teacher Support Material states that "awareness of learners' points of view help educators challenge learners, making school experiences both contextual and meaningful" (Department of Education, 2000, p. 13). Learners are encouraged to develop skills in answering questions and solving problems, making decisions and taking action. The RNCS Natural Sciences states that, "learner's imagination, curiosity and ability to ask questions will increase and broaden"

(Department of Education, 2002b, p. 9). The importance of prior knowledge is emphasized in the Assessment Guidelines Natural Sciences where baseline assessment is encouraged to gauge learners' prior knowledge and diagnostic assessment "to find out about the nature and cause of barriers to learning experienced by specific learners" (Department of Education, 2002c, p. 6). Furthermore, C2005 recognizes that learners possess different world-views since it states, "several times a week they cross from the culture of home, over the border into the culture of science, and then back again" (Department of Education, 2002b, p. 12).

2.3.3 Learners' conceptions and nature of science

Exploring learners nature of science conceptions can assist teachers understand how learners view science and plan appropriate interventions to challenge existing conceptions. Johnstone and Southerland (2002) claim that learning must be conceptualised in order for certain learning to take place and this is dependent on the content to be learned and the learners' view of this content. Hammerich (1998) explains why nature of science conceptions are important:

> Students' conceptions of nature of science are linked to how they learn science material. The concept of the nature of science is a foundation for the knowledge base for teaching and learning science. It is likely that the nature of science is a global conception that frames a learner's total scientific knowledge (p. 128).

From a constructivist perspective one cannot assume that learners have the same conception of science, nor are their conceptions current. Given this reasoning it appears that "the nature of science is especially vulnerable to what students already know, how they view the nature of knowledge that they are learning, and how they view the learning process of that knowledge" (Johnstone & Southerland, 2002 p. 9). Bell (2001) asserts that alternative conceptions are the result of years of science instruction focusing on the products of science, rather than the values and assumptions inherent to the development of scientific knowledge. To further exacerbate the problem learners are exposed to textbooks and other curricular material rife with alternative conceptions. It is therefore important for teachers to determine what conceptions of nature of science learners have so that lessons and activities are developed to challenge such conceptions.

2.3.4 Learners' conceptions of the nature of science – a historical review of international research

In countries abroad there has been prolific research in learners' conceptions about the nature of science spanning 40 years as alluded to by Lederman (1992) in his historical review of nature of science research. Although a large number of instruments have been developed to evaluate learners' understandings of nature of science most instruments, according to Lederman, Wade and Bell (1998) only assess certain aspects of nature of science since they focus on areas beyond the scope of nature of science. There has been a gradual move of research on learner conceptions from quantitative approaches, characteristic of early science education research, to qualitative, open-ended approaches (Lederman, 1992). Despite the research instrument being used the research conclusions have been consistent (Lederman et al., 1998) – "learners did not possess adequate conceptions of the nature of science or scientific reasoning" (Lederman, 1992. p. 335).

Lederman et al. (1998) claim that instruments used to assess learner conceptions prior to 1960 have questionable validity. The most extensive attempt, during this period, to evaluate learners' understandings of nature of science was undertaken by Mead and Metraux (cited in Lederman, 1992). Their sample contained 35 000 essays on the topic 'What do you think about science and scientists?'. A qualitative analysis indicated that learners displayed negative attitudes towards science. In 1961 Cooley and Klopfer (cited in Lederman et al., 1998) developed the Test on Understanding Science (TOUS) which became the most widely used pencil and paper assessments on understandings of nature of science. They concluded that secondary school learners had little understanding of the scientific enterprise and scientists. Lederman (1992) points out that other researchers like Aikenhead (1972, 1973), Broadhurst (1970), Korth (1969), Mackay (1971) and Millar (1963) (all cited in Lederman, 1972) used the TOUS instrument and confirmed that learners had inadequate conceptions of nature of science. Bady (1979) investigated learners' understandings of the logic of hypothesis testing and concluded that such learners have simplistic and naively absolutist views of the nature of scientific hypothesis and theories and therefore do not truly understand nature of science. Using the Views on Science-Technology-Society (VOSTS) research tool Ryan and Aikenhead (1992) surveyed in excess of 2000 grade 11 and 12 Canadian learners and concluded that these learners lacked authentic views on nature of science. In their study Bell et al. (2003) used a modified version of the open-ended Views of Nature of Science, form B (VNOS-B) and interviews to assess senior secondary learners conceptions of nature of science and scientific enquiry. They concluded from their pretests that learners' understandings for the most part were inconsistent with contemporary interpretations of nature of science. Bell et al. (2003) found that learners expressed an overemphasis on the empirical nature of scientific knowledge. According to their research learners perceived scientific laws to be absolute knowledge, expressed the misconception that laws and theories are the same kind of knowledge, did not express understandings of the theory-laden nature of data interpretation, overlooked the effects of social and cultural contexts in which scientific investigations are embedded and, failed to recognize the role of creativity throughout all stages of scientific investigations.

2.3.5 Learners' conceptions and science education – a brief summary

A contemporary view of learning in science education is constructivism, which views all knowledge as reality reconstructed in the mind of the learner. A prominent feature of this approach is using learners' prior knowledge, imagination and experiences together with the opportunities provided by the teacher, in helping learners construct meaning and making sense of their ideas. Using this approach, given that a major aim of science education is to introduce learners to science concepts and science practices, conceptual change is only possible if learner conceptions are made explicit. Curriculum 2005 acknowledges that learners have their own ideas (prior knowledge) that they bring to the science classroom. Curriculum 2005 seeks and values learners' preconceptions, which are seen as windows into their reasoning, a characteristic of constructivist education. Analysis of research spanning almost half a century has shown that numerous instruments have been developed and used to assess learners' conceptions on nature of science. They all have concluded that learners' conceptions of science and the scientific enterprise are outdated since they do not reflect contemporary understandings of nature of science held by the scientific community.

2.4 ARGUMENTS FOR SOUTH AFRICAN NATURE OF SCIENCE RESEARCH

The discussion that follows provides reasons for nature of science research within South Africa. A teacher undertook this study therefore a rationale for teachers as researchers is provided. Furthermore this study uses integrated approaches.

2.4.1 The study of nature of science is a new South African focus

Science teaching has been reconceptualised to depict realistic and contemporary views of science. This has filtered into the South African curriculum where science teachers are expected to teach about nature of science. According to Dekkers (2004) "The NOS is an exciting but caustic new element in South Africa's curriculum for the Natural Sciences" (p. 153). As a result there are few studies that explore teachers' conceptions (Dekkers, 2004; Dekkers & Mnisi, 2003; Ayayee & McCarthy, 1996; Kurup, Webb, Meiring, & Webb, 2004; Linneman et al., 2002; Meiring, 1995) and even fewer that explore learners' nature of science conceptions (Ayayee & McCarthy, 1996; Chelin, 2003; Dekkers, 2006) in South Africa. Current conceptions of nature of science are embedded (Mnisi & Dekkers, 2003) in all three learning outcomes - scientific investigations, constructing science knowledge and, science, society and the environment, of the Natural Sciences curriculum (Department of Education, 2002b). Consequently the RNCS (Department of Education, 2002b) requires learners to develop an adequate understanding of key aspects of nature of science:

> The learner will be able to demonstrate an understanding of the interrelationships between science and technology, society and environment. The learner understands science as a human endeavour: compares differing interpretations of events (Grade 7); identifies ways in which people build confidence in their knowledge systems (Grade 8); recognises differences in explanations offered by the Natural Sciences Learning Area and other systems of explanation (Grade 9) (Department of Education, 2002b, pp. 58-59).

Wandersee et al., (1994) argue that a working knowledge of discipline-specific alternative conceptions research is basic to the professional preparation of science teachers. Furthermore the RNCS (Department of Education, 2002b) states that, "The Natural Sciences Learning Area deals with the promotion of scientific literacy" (p. 4). Many researchers (Bell, 2003; Collins et al., 2001; Lederman, 1999; Thomas, 1997) in science education note that an understanding of nature of science is a key element to achieving scientific literacy.

2.4.2 The argument for an integrated approach to nature of science research

This study uses both qualitative and quantitative methods to determine South African learners' nature of science conceptions. Lederman et al. (1998) argue that while standardised instruments can reveal something about learners' views of nature of science, they cannot tell us everything we need to know. They point out that the problem does not lie with the test but rather with those interpreting it in a biased manner. Too much attention was placed on numerical scores and labelling participants' nature of science views as 'adequate' or 'inadequate' (Abd-El-Khalick & Lederman, 2000) as opposed to constructing profiles of beliefs represented by the numbers (Lederman, 1992). Furthermore conceptions of nature of science have changed with developments in history, philosophy, and sociology of science (Abd-El-Khalick & Lederman, 2000) therefore there is no singularly preferred or informed nature of science (Lederman, 1992). Lederman et al. (1998) advocate using a combination of research methodologies to adequately assess understandings of nature of science. These allow respondents to justify and/or elaborate their positions on nature of science (Abd-El-Khalick & Lederman, 2000), provide more in depth and valid assessments of learner's conceptions and afford the researcher with a more contextual view of the factors which mediate one's conceptions (Lederman, 1992).

2.4.3 The argument for teachers as researchers

One of seven roles outlined in the Norms and Standards for Educators (Department of Education, 2002b) is that of scholar researcher. When teachers are researchers at schools they have the privilege of being 'insiders' rather than 'outsiders' and it affords them the opportunity to improve their classroom practices. Historically teachers in South Africa have been excluded as key players in debates on the reconstruction of education despite their potential power as agents of transformation (Wickman, 1994). Many teachers are products of a system of teacher education that undermined their professional autonomy and curricular competence (Baxen & Soudien, 1999). Nevertheless, many developed their intellectual resources to critically assess their professional practice independently (Baxen & Soudien, 1999). Wickman (1994) argues that the research process encourages teachers to engage in wider debates on educational and social reconstruction and to transform their work from that of mere technicians to critical theorists. However, many teachers are sceptical of undertaking research since academic researchers generally place little value on research conducted by teachers (Wickman, 1994). Nevertheless, Keeves (1998) maintains that there are many benefits for teachers who undertake research. He claims that the research activity adds to the theory and knowledge base necessary to improve teaching; the findings create a climate of inquiry and systematic improvement is developed in schools; it fosters a cooperative climate; it promotes better practice within schools and fosters teacher development; and it helps teachers to identify problems and to search for solutions to those problems in a systematic way.

2.4.4 The argument for South African nature of science research – a brief summary

Three arguments for nature of science research in South Africa have been forwarded. Firstly, the study of nature of science is a new focus in the South African science education curriculum, consequently there is limited literature pertaining to the study of nature of science within a South African context. Secondly, nature of science research must incorporate both quantitative and qualitative research methodologies in order to obtain an in depth understanding of learners' nature of science conceptions so as to facilitate classroom intervention. Thirdly, nature of science research enables teachers to fulfil their roles as researchers, which develops them professionally and empowers them to critically evaluate their practices. As classroom practitioners they are in an ideal position to identify challenges and provide practical solutions.

2.5 A BRIEF SUMMARY OF THE LITERATURE

Nature of science describes the character of science and how science functions. Since scientific knowledge is constantly being questioned, re-evaluated and tested different views about how this knowledge is developed have emerged. Changes in conceptions of nature of science have mirrored major shifts in focus and emphasis in the history, philosophy and sociology of science. There is no single accepted philosophical view of nature of science but the 'new' philosophy of science offers a view that is more consistent with current scientific practice. It rejects formal logic as the main tool of scientific analyses rather science history and the science community are looked to for such analyses. Furthermore it invokes sociological, psychological, or cultural elements in attempting to describe the scientific endeavour. Rather than merely examining actual scientific practice, it attempts to situate scientific issues, claims and practices within their larger social and cultural contexts. Historical accounts of science acknowledges science as a human activity and provides a lens as to the ways in which ideas have been tested and developed in the past and the ways in which this has informed developments in science. These accounts have revealed that nature of science is dynamic, complex and multifaceted. As a result different conceptions of nature of science have emerged and will continue to emerge as affirmed by historians, sociologists, philosophers, and other members within the scientific community. Nevertheless consensus does exist within the scientific community as to certain aspects of nature of science that are essential for science education.

From the inception of science education adequate understandings of nature of science have appeared, either implicitly or explicitly, in different science education ideas and goals. It has been linked to scientific method, scientific process and inquiry and more recently to scientific literacy. Despite continued interests in nature of science in science curricula, textbooks still seem rigidly bound in communicating the body and terminology of knowledge in science rather than the way that science knowledge comes to exist. As a result empiricism still has a strong influence on the conception and teaching of science. Contemporary science education is faced with many challenges some of which include multicultural science, environmentalism, constructivism, feminism, non-Western sciences, scientific literacy and declining enrolment in science-based disciplines. The scientific community believes that these challenges can be met by understanding nature of science. Accordingly helping learners develop adequate understandings of nature of science have recently been re-emphasized in major reform efforts in science education. The South African outcomes-based science curricula have mirrored such efforts via C2005.

An analysis of the South African science curriculum revealed that C2005 subscribes to contemporary views of learning like constructivism. It acknowledges that learners develop many conceptions about the scientific world throughout their life experiences and these conceptions have consequences in the course of the development of science teaching. Subsequently C2005 supports learning experiences that challenge learners' ideas, encouraging them to reflect on these in the light of accepted scientific knowledge and interpretations. A framework of analysis based on three strands: the nature of science knowledge, the nature of scientific inquiry and the relationship between science and society revealed that the new South African science curriculum reflect contemporary views within the scientific community. A requirement of C2005 and the scientific community are that learners develop the following conceptions about nature of science:

The nature of science knowledge: Scientific knowledge, including facts, theories, and laws is created tentatively, arduously, and with great ingenuity by groups of scientists. It is not an objective, literal description of reality, but instead is an uncertain way of imagining or representing certain aspects of reality. Scientific knowledge has basis in empirical evidence nevertheless it is inferential, creative and culturally embedded. Empirical evidence is collected and interpreted based on current scientific perspectives (theory-laden observations and interpretations) as well as personal subjectivity due to scientists' values, knowledge, and prior experiences. Human creativity and imagination is used in the invention of explanations and theoretical models. A model is an imagined mechanism or process that is created by scientists to help them to think about the unknown in terms of the familiar. Scientific knowledge changes as new evidence is brought to evaluate existing theories and laws or when old evidence is reinterpreted. Although change and continuity are persistent features of science, the main body of scientific knowledge is stable, well established, reliable, and grows by being corrected slowly. Scientific understandings is not the only way of making sense of the world since many different cultures have contributed and continue to contribute to our understanding of the physical and biological world.

The nature of scientific inquiry: Despite popular belief there is no single scientific method or approach nevertheless, all scientific approaches value precision, rigour, evidence, logic, and good arguments. Science is the continual and cyclical process of asking questions and seeking answers therefore formulating hypotheses and designing and carrying out investigations to test the hypotheses characterize scientific inquiry. Hypotheses are widely used for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of the data. However results of similar scientific investigations seldom turn out exactly the same due to differences in methods, or circumstances in which the investigation is carried out, or because of uncertainties in observations or unexpected differences in the things being investigated. Whilst scientists value dispassionate observation and analysis their work is also determined by imagination, and even chance. As a result scientists' explanations about what happens in the world come partly from what they observe and partly from what they think. Consequently it is possible for scientists to legitimately come to different interpretations of the same data and therefore disagree.

The relationship between science and society: Historical analysis has revealed that scientific knowledge is a product of social, religious, political, economic, and environmental circumstances. Furthermore, different people from different cultures have contributed to the advancement of science. Although the scientific enterprise is guided by discipline-centred values it is also embedded in personal, social, cultural values. Consequently science is not value neutral and scientists are no less biased than others are about their perceived interests. Scientists work in groups to seek out possible sources of bias however there is no guarantee against bias. Given that science is a social enterprise new knowledge claims are generally shared and, to be accepted by the scientific community, must survive a process of regulation and evaluation within the scientific community i.e. undergo critical peer review. Despite collaboration and cooperation within the scientific community there is also fierce competition.

The traditional South African curriculum focused on the development of science concepts but nature of science was a 'hoped for' goal. However, C2005 explicitly addresses this shortcoming by including nature of science as one of its three outcomes. Accordingly nature of science is a new focus for South African teachers and research in this field is in its infancy. It is argued that a multiple method approach using both quantitative and qualitative data is required to understand both teachers and learners views about nature of science and to improve teaching and learning in the science classroom. There is agreement that through research, teachers take ownership of the curriculum, are effective agents of transformation and, are more reflective of their practices (Department of Education, 2002b; Keeves, 1998; Wickman, 1994).

2.6 WHY THIS STUDY CONTRIBUTES TO NATURE OF SCIENCE RESEARCH

The importance of this study is reviewed by making reference to much needed nature of science research on learners' conceptions. The value of this study, due to the period when this research was undertaken, is also discussed.

2.6.1 Lack of South African nature of science literature

A distinct feature of the old South African science curriculum was the learning of science concepts drawn from the disciplines of Physics, Chemistry and Biology. Accordingly research has been directed primarily at learners' understanding of these concepts. Alternative conceptions of science concepts, how learners acquire these ideas and how learners' ideas about natural phenomena might be changed are well documented. Nature of science, indigenous knowledge and the influence of an African worldview is a new focus in the South African science curriculum. Much of the research around these areas has been directed at South African teachers' conceptions whilst research directed at learners' notions of science is lacking. In light of this, research into learner conceptions about nature of science is essential in "purposively planning and executing instruction designed to facilitate students' construction of scientifically valid understandings" (Bell, 2001, p. 3). This research project provides much needed baseline data on what conceptions or alternate conceptions learners have about nature of science within a South African context. The results can be used by South African science teachers to purposely plan and effect instruction to enable learners develop understandings consistent with contemporary views on nature of science. Furthermore, the data collected can provide a basis for further descriptive and or experimental research.

2.6.2 Unique timing of the research

The focus of C2005 is to enable learners to be scientifically literate as well as promote self-development by understanding scientific knowledge and the practices of science. It is widely acknowledged (AAAS, 1993; Australian Education Council, 1994; Bell et al., 2003; Collins et al., 2001; Lederman, 1999; Thomas, 1997; Wolpert, 1997) that an understanding of nature of science promotes scientific literacy. This study was conducted using the second cohort of learners since the inception of C2005 and it reveals learners' conceptions of nature of science within the context of the new curriculum. Furthermore it provides some insight as to whether the intentions of the new science curriculum, especially those dealing with nature of science, are being achieved in some South African cluster schools. This research was also conducted at a time when teachers were preparing for a new FET curriculum where prior knowledge of learners is paramount to informing practice. Hence knowledge of learners' notions of science in the GET phase can help teachers in the FET phase to purposively plan for instruction, discussion, specific questioning and guided reflection so as to force the learner to reflect on his/her own conception of some aspect of nature of science, and then actively compare this to another, competing (and more informed) conception of nature of science.

2.6.3 Research conducted within the context of resistance to curriculum change

Many science teachers pre-service training was based on traditional methods of teaching and learning which had a bias towards content and empiricism. These very same teachers are charged with teaching C2005 which is underpinned by constructivist pedagogy and contemporary philosophies in science. However poor training and the lack of support have resulted in teachers reverting to familiar ground – the previous content laden South African curriculum. This study aims to include learners' conceptions of nature of science within the context of schools resisting curriculum change.

2.6.4 The focus of this study

The primary research question that framed this study was: What are grade 10 physical science learners' conceptions of nature of science? Two secondary research questions that guided this study were: To what extent, if any, are the learners' nature of science views consistent with contemporary views and with those of C2005? and, Do different gender and cultural groups possess different views on nature of science? To generate a response to these questions learners were firstly required to complete a questionnaire related to nature of science. Secondly, a set of scenarios related to science was presented and learners were requested to provide written answers to questions based on these scenarios. Furthermore, respondents had to offer explanations for their choice of answers. This study does not assert to be anything more than simply an exploration into some South African grade 10 Physical Science learners' notions of science and the scientific enterprise and an analysis of learners conceptions of science within the framework of Curriculum 2005. In the following chapter the research design used and the research methods that were employed to answer the research questions are described in detail.

CHAPTER 3

RESEARCH DESIGN

This chapter will provide a concise description of the research design used in this study. The operational plan adopted by to undertake various procedures to ensure valid, objective and accurate answers to the research questions will unfold (Kumar, 1999). What follows is a description of the research approach selected followed by the methodology used, instruments used to collect data, strategy for data analysis as well as the sampling strategy. I will provide an explanation of the suitability of the research design to answer the primary research question: What are grade 10 Physical Science learners' conceptions of nature of science?

3.1 THEORETICAL FRAMEWORK

This study follows a post-positivist/realist paradigm (Seale, 2004b) which assumes that reality is multiple, subjective and to a certain degree mentally constructed by individuals (Nieuwenhuis, 2007a). It occupies the space between positivism and constructivism (Guba & Lincoln cited in Niewenhuis, 2007a). A post-positivist paradigm is underpinned by a critical realist ontology, which subscribes to the belief that "reality does exist but can never be perfectly understood" (Nieuwenhuis, 2007a, p.65). According to Henning, Rensburg and Smit (2004) a post-positivist paradigm is used mostly in a quantitative research approach, and to a limited extent in qualitative descriptive content analysis. This study uses a mixed methods approach that uses both quantitative and qualitative modes of inquiry.

3.2 PURPOSE OF THE STUDY

According to Cohen, Manion and Morrison (2007) the purpose of research should inform the methodology and research design. The purpose of my study, as mentioned in the introduction, was to ascertain South African grade 10 Physical Science learner's conceptions of nature of science within the context of an outcomes based curriculum after its second year of implementation. In order to obtain a better understanding of learners' conceptions about nature of science this study was also guided by the following secondary research questions:

1. To what extent, if any, are the learners' nature of science views consistent with contemporary views and with those of Curriculum 2005?
2. Do different gender and cultural groups possess different views on nature of science?

I decided that the most suitable approach to answer the research questions would be a mixed methods approach.

3.3 RESEARCH APPROACH

Science teachers and science educators openly acknowledge that all knowledge in the field of science educational research is relative and necessitates multiple realities (Keeves, 1998). I have used a mixed methods approach (Ivankova, Creswell, & Plano, 2007) that encompasses both quantitative and qualitative modes of inquiry since it gives the best possibility of providing meaningful answers to the research questions. The purpose of using both approaches in this study was to strengthen the data gathering and analysis process so that the different findings could be compared and contrasted (Ivankova et al., 2007). Both approaches also serve as a triangulation strategy (Denzin, 1988) to enhance confidence in the research findings.

Using both quantitative and qualitative approaches can often strengthen research designs (National Research Council, 2002). Keeves (1998) contends that these two approaches are complementary in their purpose and are not in opposition to each other. Using a single approach like a quantitative approach limits the depth of an investigation, as it is unsuitable for probing deeply into an issue (Dornyei, 2003). The advantage of using different approaches is that it not only approaches the research differently since they have different strengths and weaknesses but asks different questions, and hence generating quite different answers (Patton, 2002; Shulman, 2001). However, Shulman (2001) warns that whichever approach is used it must follow disciplined rules or procedures which I have done.

Ivankova, Creswell and Plano (2007) identify four mixed methods designs viz. explanatory design, exploratory design, triangulation design and embedded design. This study uses the triangulation design since both qualitative and quantitative data were collected at the same time to determine learners' conceptions of nature of science. Spicer (2004) and Cohen et al. (2000) both define triangulation as combining two or more methods of data collection in the study of some aspect of human behaviour in order to crosscheck results for consistency and offset any bias of a single research method. Denzin (1988) maintains that interpretations built upon triangulation are certain to be stronger than those that rest on the more constricted framework of a single research method. As a result both quantitative and qualitative data collection methods were used in this study to map out more fully the complexity of learners' conceptions of nature of science.

3.4 STRATEGY OF INQUIRY

Lederman et al. (1998) point out that one should use different research methodologies to assess learners' understandings of nature of science. Empirical research in the form of a small-scale descriptive survey was used to obtain answers to the research questions and to gain data to measure and analyse variations between groups (Bloch, 2004). McMillan and Wergin (2002) note that whilst descriptive research is valuable, educational research must go beyond mere description to examine comparisons and relationships among variables. Although this study is mainly descriptive in nature it is also comparative. In keeping with the mixed methods approach quantitative data was collected using a survey questionnaire, and qualitative data was collected using an open format questionnaire.

According to Rosier (1988) the purpose of surveys is either to obtain descriptive information or to examine relationships between various factors. In addition to these two purposes Cohen et al. (2007) identify a third purpose which is, "identifying standards against which existing conditions can be compared" (p. 205). The main purpose of my survey was to describe the conceptions learners have about science and some relationships between groups (gender and culture) will also be examined. School classrooms were representative of schools in the area in which the research was undertaken. I felt that descriptive survey design was the most suitable way of obtaining information from all school classes in the sample. It allowed me to collect the same data from each school so that variations between learners could be measured (Bloch, 2004).

One of the strengths of survey design is that it enables one to make generalizations to the wider population provided that a suitable sampling design is used (Mouton, 2001). However Cohen et al. (2007) explain that although small-scale surveys can be undertaken, generalizability from small-scale data is slight. Given this constraint, generalizations in this study will be made with regard to the target population but not to a wider population. A limitation of survey design is a lack of depth and insider observation (Mouton, 2001), which prevent the specificity, uniqueness, and complexity of a particular situation from being portrayed (Cohen et al., 2007). As a result I felt it was also necessary to collect qualitative data. Qualitative data collection was undertaken to gain another perspective into learners' views on nature of science and to help understand and interpret the results obtained from the questionnaire.

Validity and reliability are crucial criteria in assessing the quality of a research study (Seale, 2004b). Cohen et al. (2007) point out that validity and reliability take different forms and meanings in quantitative and qualitative research. Since this study utilizes a mixed methods approach both meanings will be addressed. Validity will be ensured for the quantitative component by using an effective sampling strategy, utilizing a suitable questionnaire and, appropriate use of statistics for data analysis (Cohen, Manion, & Morrison, 2007). In addition to the researcher checking that all aspects of nature of science were covered the questionnaire was also reviewed by my supervisor to establish internal validity. External validity refers to the extent to which findings of the study can be generalized to the wider population or other situations (Seale, 2004b). Since this study is primarily done to understand learners' conceptions within a particular area, generalizations will be made about the target population to which the learners belong.

Nieuwenhuis (2007b) refers to credibility and trustworthiness as the qualitative equivalent of validity and reliability. In this regard Lincoln and Guba (cited in Seale, 2004b) propose credibility and transferability as criteria that address validity whilst dependability parallels reliability. Durrheim and Wassenaar (2002) describe credibility as the assurance that the researchers findings are convincing and believable. Consequently, detailed descriptions as well as negative or inconsistent findings will be presented to allow readers the opportunity to assess the researcher's interpretations and warrant for the assertions. This will add credibility to the study. Seale (2004b) argues that transferability is established if sufficient information is provided so that the reader can assess if the research findings are transferable to new contexts. To ensure transferability rich data on participants' nature of science views as well as the setting in which this occurred will be provided. Triangulation will be used to ensure reliability.

3.5 ETHICAL ISSUES

As a novice education researcher I had to be aware of a number of ethical issues before commencing my study. Ali and Kelly (2004) assert that ethical issues in social research centres on how the rights of participants and researchers are to be balanced against the potential benefits to society. Cohen et al. (2007) suggest that ethical considerations involve procedural issues as well as "how the research purposes, contents, methods, reporting and outcomes abide by ethical principles and practices" (p. 51). An ethical clearance form was submitted to receive ethical clearance from the university. Permission was obtained from principals of schools that were used as research sites. Approval was also obtained from teachers and head of science departments with regard to assisting in administering the questionnaire, using learners for the study and giving up some of their contact time with learners. They were also informed about the purposes of the research and what was to be done with the information. All teachers had given me their full support and expressed a willingness to assist in the research process. The teachers administering the questionnaire were given a letter on ethical practice (Appendix C) to read out to learners. With regard to the qualitative component of the research, permission was obtained from my school principal and the head of the science department. Learners were informed about the purposes of the research and consent was sought from them to participate in the research project.

3.6 STRATEGIES FOR DATA COLLECTION

The rise of qualitative techniques in research on nature of science has decreased the dependence on standardized instruments (Lederman, 1992) since it allows researchers to assess not only respondents' views on nature of science, but reasons for adopting those views as well (Abd-El-Khalick & Lederman, 2000). Given this reasoning this study adopts both qualitative and quantitative techniques to address the primary and secondary research questions. Cohen et al. (2000) add that quantitative methods strive for objectivity, measurability and predictability whilst qualitative methods strive to understand and interpret the world in terms of its actors.

For the quantitative technique the researcher used a survey questionnaire containing closed questions. These questionnaires were handed out to seven schools participating in quantitative data collection. Cohen et al. (2000) maintain that structured questionnaires generate responses that enable comparisons to be made across groups in the sample since they are amenable to quantitative treatment and analysis. The purpose of the structured questionnaire in this study was to determine learners' conceptions of nature of science and to determine if there were differences in conceptions between genders and between cultures. Both Cohen et al. (2000) and Molenaar (1982) concur that closed questions do not discriminate on the basis of how articulate respondents are especially when respondents' opinions are not well crystallised. This influenced me in constructing a structured questionnaire, as some of my respondents were Black learners. These learners spoke English only at school since it was not their home language. Cohen et al. (2000) assert that, "rating scales are particularly useful for tapping attitudes, perceptions and opinions of respondents" (p. 225). As a result I designed a structured questionnaire (Appendix A) consisting of bipolar agree-disagree statements that made use of a Likert scale (Anderson, 1988) measuring positive, neutral and negative positions to collect their understandings.

Other advantages of questionnaires Kumar (1999) point out are that they are convenient and inexpensive since they save time and human and financial resources. Furthermore, questionnaires reduce biasing error and provide greater anonymity for respondents, as there are no interviewers involved (Bloch, 2004). In addition, the researcher was physically removed from the respondents as respondents' teachers administered questionnaires. Some limitations of self-completion questionnaires are that they have low response rates (Bloch, 2004) and respondents may consult others to fill out the questionnaire (Kumar, 1999). The researcher considered this and decided to personally collect completed questionnaires from research sites. Furthermore, I appealed to science teachers administering the questionnaires to explain the relevance and importance of the study to their learners to ensure a high response rate. In order to ensure that I obtained learners' personal conceptions of nature of science I requested that teachers remind respondents that they are to not consult each other, which was also an instruction on the questionnaire.

According to Bloch (2004) qualitative methods is characterized by open-ended questions, which Ivankova (2007) concurs allows participants to "share their views about and experiences with the phenomenon" (p. 257). For the qualitative technique I utilized an instrument containing semi-structured and open-ended questions related to six science-based scenarios (Appendix B), which the researcher designed. The format was free responses where participants had to give reasons for their choices to the semi-structured questions. The purpose of this instrument was to obtain a better understanding of learners' nature of science conceptions.

Cohen et al. (2000) argue that it is important for participants to know the kind of responses being sought by researchers from open-ended questions. Given this argument I used the context-based science scenarios to help set the scene in order to direct participants' responses to a specific concept in nature of science. Some of the scenarios were intentionally made to be controversial. This was done to provoke reaction in the respondents that could lead to a revelation of their true perceptions. The participants for qualitative data collection were grade 10 class I taught and each learner had to respond to all six scenarios. Patton (2002) points out that although qualitative methods produce a wealth of detailed information thereby increasing the depth of understanding, they reduce generalizability. The unit of analysis for qualitative data collection, my own class, has similar characteristics to the classes used for quantitative data collection. As a result generalizations will be made with regard to learners in classes in similar areas and not to a wider population (Nieuwenhuis, 2007b).

An advantage of open-ended questions is that it provides a wealth of information and allows participants to express themselves freely (Kumar, 1999), to explain and qualify their responses rather than selecting from pre-set categories of responses (Cohen et al., 2007). In this study the purpose of the scenarios instrument was to acquire a richer and more complete understanding of learners' conceptions of nature of science. Some limitations of open-ended questions are that they require more time to complete; responses are difficult to code and complete and, not all participants can express themselves equally well (Cohen et al., 2007). The researcher took these limitations into account and collected qualitative data after year-end examinations when there was no formal school timetable operating. As result participants had sufficient time to complete their responses. However, in hindsight this may not have been a good choice since some participants rushed to complete their responses so that they could go home early. Nevertheless, to obtain useful quality data the whole class as opposed to selecting a few representative learners were used.

Qualitative interviews (Nieuwenhuis, 2007c) were not selected as a mode of data collection for the following reasons. Firstly, there were time constraints for data collection. Secondly, the data was collected subsequent to final examinations. Finally, from my experiences of working in this community I have learnt that parents are not willing to grant permission for co-curricular or extra-curricular activities after school due to a high crime rate in this area. Kumar (1999) points out that some populations, for a number of reasons, may not feel at ease with a particular method of data collection.

3.7 NATURE OF SCIENCE QUESTIONNAIRE

3.7.1 Designing the questionnaire

There are numerous instruments that have been developed to assess learners' views on nature of science. Lederman et al. (1998) in their analysis of various instruments argue that many instruments address areas beyond the scope of nature of science whilst those instruments that focus on nature of science are restricted to a certain aspect of nature of science or contain too many items. One of the most common and valid pencil and paper instruments to assess learners' understandings of nature of science is Views on Science-Technology-Society (VOSTS) questionnaire designed by Ryan and Aikenhead (1992). Like Tsai (1999) I found VOSTS too demanding and time-consuming for South African grade 10 learners since it contains one hundred and fourteen items. Furthermore, many of the items relate to Canada or the United States (Lederman et al., 1998).

Accordingly I decided to design my own structured questionnaire (Appendix A) using a Likert scale consisting of bipolar agree-disagree statements since it is a convenient way to measure a construct (Maree & Pietersen, 2007b). Kumar (1999) suggests that when constructing Likert scales one should decide on the number of categories and whether one wants to use words or numerical scales. I opted to use both since the numbers would give the respondents an idea of the degree of intensity and the words would assist those respondents who cannot express themselves on a numerical scale. According to Anderson (1988) a larger number of response options increase the internal consistency of the scale. As a result I opted for a three-directional (positive, negative and neutral) and a seven-point numerical scale ranging from +3 to -3. Respondents were required to indicate their level of agreement or disagreement by circling a number on the seven point rating scale. Pietersen and Maree (2007b) warn that one of the threats to validity of an instrument is that some respondents may agree to all items. Given this reasoning the researcher formulated both positive and negative statements in the questionnaire.

I developed a questionnaire containing 26 statements by adapting and modifying ideas from VOSTS (Ryan & Aikenhead, 1992), American curriculum documents (AA AS, 1993), South African curriculum documents (Department of Education, 2002b, 2003g), the Nature of Science Profile (Nott & Wellington, 1998) and the Test of Basic Scientific Literacy (Laugksch & Spargo, 1996). This was done in order to ensure that the instrument covered all aspects of nature of science, which Pietersen and Maree (2007b) refer to as content validity. Face validity (Kumar, 1999) was also undertaken since each statement was carefully scrutinized by the researcher to determine if it was related to concepts in nature of science. Seale (2004b) suggests consulting people with practical or professional knowledge to assess how well questions indicate the concept. As a result my supervisor was also consulted to assess validity of the statements.

Guided by the consensus reached within the scientific community (Collins et al, 2001) and by nature of science researchers (Abd-El-Khalick & Lederman, 2000; Chalmers, 1987; Lederman, 1992; McComas et al., 1998; Ryan & Aikenhead, 1992) I chose to include statements related to the nature of scientific knowledge (content of science), the nature of scientific inquiry (process of science) and the relationship between science and society (social institution of science). The researcher is aware that some statements may belong to more than one strand and have categorized them according to where they most commonly fit. The purpose of grouping the statements into three strands was to link them to a similar framework used in the science curriculum and to facilitate answering the primary and secondary questions that framed this study. Kumar (1999) asserts that attitudinal scales measure the intensity of respondents' attitudes and provide techniques to combine the attitudes towards different aspects into one overall indicator which "reduces the risk of an expression of opinion by respondents being influenced by their opinion on only one or two aspects of that situation or issue" (p. 128). Consequently the researcher constructed a number of statements that were related to each strand used in the questionnaire.

The statements also included nine themes proposed by the scientific community: Scientific methods and critical testing; Creativity; Historical development of scientific knowledge; Science and questioning; Diversity of scientific thinking; Analysis and interpretation of data; Science and certainty; Hypothesis and prediction; Cooperation and collaboration in the development of scientific knowledge (Collins et al., 2001).

The purpose of incorporating the nine themes was to assist in ascertaining if learners held contemporary views on nature of science shared within the scientific community (Collins et al., 2001) and expressed in Curriculum 2005.

Seven questionnaire statements related to the nature of scientific knowledge (content of science):

Statement 15: Important contributions to the advancement of science have been made by people from different cultures (e.g. African, Indian, Chinese, etc.).

Statement 17: Scientific facts can never change but scientific theories can change.

Statement 18: There are certain physical events in the universe that science can never explain.

Statement 19: Traditional medicine-making can be considered as genuine scientific research.

Statement 20: In science the testing, revising, and occasional discarding of theories, new and old, never ends.

Statement 22: Science is one of several ways of knowing about the world. We can also learn about the world through our indigenous knowledge from our culture.

Statement 26: Science knowledge usually grows slowly through contributions from many scientists.

Eight questionnaire statements related to the nature of scientific inquiry (process of science):

Statement 1: There is a fixed set of steps that scientists follow in scientific investigations.

Statement 2: Results can change each time you do the same scientific investigation because of different methods, different materials used and sometimes because the thing being studied actually varies.

Statement 5: It is important to do the same scientific investigation many times before accepting the results as correct.

Statement 8: Scientists have no idea of what will happen in an experiment before they actually do the experiment.

Statement 9: Scientists use creativity and imagination when doing scientific investigations.

Statement 10: Scientific discoveries usually result from a logical series of investigations but science is not completely logical. There is an element of trial and error, hit and miss, in the process.

Statement 21: Scientists' explanations about what happens in the world come partly from experimental evidence and partly from creativity and imagination (ie. from what they think).

Statement 23: Scientific models (e.g. the model of DNA or the atom) are not real (ie. not directly observable) but are created by scientists to explain what they think may be happening and to predict observations.

Eleven questionnaire statements related to the relationship between science and society (social institution of science):

Statement 3: Community or government agencies should tell scientists what to investigate.

Statement 4: Scientists try to identify possible bias (unfairness) by checking each other's results and explanations but there is no guarantee against bias.

Statement 6: Two scientists can have different explanations and interpretations for the same set of observations because of their background, personal beliefs and values.

Statement 7: Religious views of scientists do not influence scientific research because scientists will research topics which are of importance to science and scientists, regardless of religious views.

Statement 11: Scientists are open-minded, logical, unbiased, objective and honest in their work.

Statement 12: Scientists should consult the well-versed public when making decisions which affect our society (e.g. producing a chemical which make it impossible for police detecting alcohol on your breath).

Statement 13: When a research team makes a discovery, it is all right for them to announce it to the press before other scientists have discussed it.

Statement 14: Scientific discoveries made by women will tend to be different to those made by men because, by nature or by upbringing, females have different values, viewpoints, perspectives, or characteristics (such as sensitivity toward consequences).

Statement 16: It is not necessary for scientists to communicate with other scientists about their work.

Statement 24: New ideas in science are often rejected by the scientific community.

Statement 25: Scientific evidence can be biased (distorted) by the way that data are interpreted, recorded, reported or selected.

3.7.2 Pilot questionnaire

Cohen et al. (2007) point out that questionnaires are more reliable if they are well constructed and properly piloted. In order to achieve reliability and validity the questionnaire was piloted in two phases. During the first phase I administered the questionnaire to five randomly chosen grade 9 learners in the school I worked. The learners selected were of mixed ability. I had known this because I previously taught these learners. I opted for a grade lower than my target group since any modifications suggested should be valid for respondents in a higher grade. The purpose of the first phase was to determine if the statements were open to different interpretations or were ambiguous. I selected a small sample because I intended to hold a focus group interview subsequent to their responses to the instrument. According to Tonkiss (2004):

> At the stage of developing or piloting research, one or more focus groups can help researchers to formulate qualitative interview schedules: defining terms, raising themes for inclusion in a topic guide, clarifying wording or order of questions, or assessing participants' understanding of key concepts and language (p. 196).

I conducted and recorded a whole group discussion for each questionnaire statement. The focus group was asked the following questions: How can we improve the questionnaire to make it suitable for learners in your age group? Does any statement confuse you? Can we improve the language? and, Did you initially leave out any questions but attempt it later? Why? Based on my discussion with the focus group there was general consensus that certain words like 'bias', 'informed public' and 'legitimate' were confusing or misunderstood. Certain group members felt that some statements were too long. There was a general discussion within the group about underlining words or parts of statements. They claimed that this helped them focus on the important parts of the statements and made responding easier. As a result of the discussion and comments made by the focus group I effected some changes to the statements. A second pilot study was then undertaken using the modified questionnaire.

For the second phase I chose to pilot the questionnaire to Grade 10 Physical Science learners that were not part of my sample for final data collection. The main purpose of the second pilot was to try out the coding system for data analysis and to study common patterns of unexpected or non-responses (Cohen et al., 2007). I selected a school from Chatsworth where the majority of learners were Black and for whom English was a second language. The researchers aim was to check if these learners could understand the statements and answer the questionnaire. Although my intention was to target the entire class of 25 learners only 16 learners were willing to participate. Space was provided at the bottom of the questionnaire for respondents to comment on the language used, problems experienced in understanding any statements and other comments they would like to make. General comments made by respondents were that they enjoyed answering the questionnaire and that they experienced no problems. Some respondents did not make any comments. The questionnaire was administered and collected by the pilot groups' Physical Science teacher. According to the teacher the pilot group found the instructions easy to understand and they were able to complete the questionnaire without assistance within 30 minutes. I captured the questionnaire data and analysed the scores to determine if there were any outliers or unusual trends. Since there was no indication of any problems experienced by the second pilot group I chose not to alter the questionnaire.

3.7.3 Views about science questionnaire – response rate

The questionnaire "Views about Science" (Appendix A) was administered by physical science teachers, to grade10 Physical Science learners in seven schools during a science lesson. Each teacher was given the following instructions: They should allow learners adequate time, about 30 to 40 minutes, to complete the questionnaire individually. Learners must be reminded to read the instructions carefully before attempting the questionnaire. They were to read the letter on ethical practice to learners. Teachers also had to assure learners that their names would not be revealed to anyone but were needed by the researcher for instances if any clarification was required. The response rate was relatively high since most learners (92%) returned the questionnaire.

Table 3.1 Response rates of questionnaires per school

Schools	Given	Returned	% Returned	Male	Female	Black	Indian
1. School A	25	25	100	16	9	0	25
7. School B	30	28	93	18	10	0	28
6. School C	35	29	83	13	16	4	25
4. School D	20	17	85	6	11	7	10
5. School E	35	34	97	11	23	16	18
3. School F	33	29	88	25	4	5	24
2. School G	28	28	100	8	20	16	12
Total	206	190	92	97	93	48	142

3.7.4 Views about science questionnaire – data used for analysis and method of analysis

As mentioned earlier, the questionnaire rating scale consisted of values from +3 to –3 with seven response categories to cater for those participants who may have difficulty in making fine distinctions between categories. Numerical values from 1 to 7 were assigned to each response option to facilitate processing of the data. Non-responses to a statement were assigned a zero value. For a favourable statement (positive attitude) seven corresponded with the category very strongly agree and one with very strongly disagree whilst for an unfavourable statement (negative attitude) the scoring was reversed that is very strongly disagree was coded seven and very strongly agree coded one (Anderson, 1988). Statements 1, 7, 8, 11, 13, 16 and 17 required negative responses therefore their scores were reversed. Altogether 190 completed and returned questionnaires were coded and the data was captured on computer using a spreadsheet. This served as my primary data. The data was then checked for errors in data entry and frequency counts were undertaken to detect out of range values. Seale (2004a) refers to this as cleaning the data.

The coded data was analysed using Statistical Package for Social Sciences (SPSS) software. Kumar (1999) asserts that statistics in research assists the researcher make sense of the data, explores relationships and interdependence between variables, ascertain the strength of relationships and place confidence in findings. The first analysis involved descriptive statistics (Hawkins, Jolliffe, & Glickman, 1992) of individual responses, responses of different genders, and responses of the two race groups. This was undertaken to summarise and organise the data in a meaningful way so that the researcher could understand the properties of the data. Cohen et al. (2007) argue that descriptive statistics report what has been found in a number of ways but are limited since one cannot make inferences or predictions. In the second analysis the data was therefore subjected to inferential statistics (Hawkins et al., 1992) so that the researcher could probe the descriptive statistics further. This entailed the use of t-tests. In regard to the use of t-tests, which assumes interval data, with ordinal Likert scale items, in a recent review of the literature on this topic, Jaccard and Wan, (1996) summarize, "for many statistical tests, rather severe departures (from intervalness) do not seem to affect Type I and Type II errors dramatically" (p. 4). Consequently I felt the use of parametric statistics on the seven-point scale as justified. The purpose of the t-tests was to investigate whether or not the conceptions of nature of science for males and females and for the two race groups differ.

3.8 SCENARIOS OF SCIENCE

3.8.1 Designing the scenarios

Most activities in nature of science were developed abroad mainly to assess teachers' understanding of this construct. Furthermore, the few activities developed for learners require a prolonged period of implementation. Consequently I found these open-ended activities unsuitable given that there were time constraints to collect data and that South African learners would find these activities difficult. Consequently I designed my own open format questionnaire containing six scenarios (Appendix B) that I felt learners would relate to and find easy to understand.

The scenarios were designed by using ideas from a teenage education magazine "Root yourself in Africa" (Matthyser, 2004) and the book "Nature of science in Science Education" (Boersema, 1998). In designing the scenarios, it was kept in mind that learners not only respond to them as short answers, but also allow them to explain why they have made their choice, so that more useful information could be obtained.

There were spaces between questions where the learners were requested to write their responses, with the proviso that they could write on the back of the papers or on loose pages if the spaces provided were insufficient. The focus of these scenarios included the three strands of content (nature of scientific knowledge), process (nature of scientific inquiry) and social institution of science (the relationship between science and society). Scenarios two and four pertained to the nature of scientific knowledge, scenario five to nature of scientific inquiry and scenarios one, one point three and three pertained to the relationship between science and society. Although each scenario has been categorized as belonging to a strand it must be noted that each scenario is not mutually exclusive to a strand. Responses to these scenarios were expected to further provide richer and more useful data as to learners' conceptions on nature of science.

3.8.2 Piloting the scenarios

I elected to pilot the scenarios in my own school given that it would be easier to gain access to participants. The pilot was carried out during the period when learners were writing year-end examinations. To avoid a relatively small sample both grade 9 and grade 11 learners were approached to pilot the open-ended questions (scenarios). A grade lower than the target population viz. grade 9 and grade 11 learners of a lower ability level, were targeted since it was felt that if these learners could provide sufficiently valid answers then the scenarios would be suitable for Grade 10. The six scenarios were administered to nine learners from grade 9 and four learners from grade 11 who were who were prepared to attempt the scenarios in their study period during examinations. Since it was not possible to interview learners during the examination period I also chose to include a teacher in the pilot. A female science teacher chose to answer the scenarios when she was not involved in marking papers or invigilating. I engaged in an informal discussion with the teacher after she had completed the open format questionnaire. She provided valuable input with respect to the scenarios used and the construction of the open-ended questions.

Analysis of the responses and feedback from the teacher indicated that some statements and questions were vague. The changes made were: question 1.2 was reworded so that learners could differentiate between the decision makers and implementers of research; in question 1.3.1 the word "own" was included to emphasize that these were personal religious beliefs; in scenario two 'Brighter' is proven to make clothes cleaner was included; question 3.4 and 5.3 was made more explicit to elicit specific and not vague responses. Since it was not possible to do a second pilot the modified scenarios (Appendix B) were used to collect qualitative data.

3.8.3 Scenarios of science – response rate

I administered the open format questionnaire titled "Scenarios of Science" (Appendix B) during five science lessons, when new work was being taught for the next year, following the period of final examinations. The purpose for using five lessons and not one lesson was to spread out the activities so that learners would not find answering them overwhelming. Furthermore I felt that they were more likely to provide detailed answers if this was done. Approximately 15 minutes was allocated in each lesson for learners to complete the open-ended questions relating to each scenario. Although I indicated that they could use more time if needed, none of the learners required extra time. During the first lesson I explained the purpose of the study and informed them that their participation was voluntary and this would not affect their marks. I also thanked them for offering their time since other learners were at home during this period. During each lesson the instructions on the first sheet (Appendix B) was re-read as a reminder in the event that they had forgotten them. I also indicated that the activities were not to be discussed with each other since I was interested in their views. After completion of the open format questionnaire learners indicated that they had enjoyed the activities. They also commented that it inspired them to ask more probing questions about how science knowledge is acquired and applied. All learners (100%) 16 males and 8 females returned the open format questionnaire.

3.8.4 Scenarios of science – data used for analysis

The data I used for analysis were the responses given to the semi-structured and open ended-questions relating to the scenarios of science. I found like Babbie (1990) that some respondents gave answers that were essentially irrelevant to my intent and without interviews it was not possible to probe these responses. As mentioned earlier reasons were given for not using interviews as a mode of data collection. Nevertheless, given that "open-ended questions catch the authenticity, richness, honesty, candour and depth of response" (Cohen et al, 2000, p. 255). I found sufficient responses from the scenarios to provide reliable data. Furthermore, responses from the scenarios served as secondary data since the structured questionnaire "Views about Science" served as my primary data.

3.8.5 Scenarios of science – method of analysis

The data was typed into a word processor using Microsoft word and responses from all participants were rearranged per question. The data was read and reread in order for the researcher to form a clearer understanding of the information. The data was then coded using preset themes or categories on nature of science as described by the scientific community (Collins et al., 2001). Content analysis was conducted by looking for specific words within the text for which themes could be identified. Niewenhuis (2007c) describes content analysis as a process of looking at written data from different angles in order to identify keys in the text to help understand and interpret the data. He points out that although traditionally it refers to the analysis of written documents, books, brochures, etc. it can also be used to analyse qualitative responses to open-ended questions on surveys, interviews or focus groups. The themes will then be compared with that of the quantitative data in order to make inferences.

3.9 RESEARCH SITES AND SAMPLING

The sampling population (Kumar, 1999) for this study was grade 10 physical science learners from a historically Indian suburb of Chatsworth. Since the purpose of this study was to determine if learners possessed contemporary views on nature of science, learners experiencing the new outcomes-based South African curriculum were targeted. More specifically, I chose to include Grade 10 Physical Science learners in this study. I made this decision based on three reasons: Firstly, these learners were not involved in external examinations conducted by the education department. Consequently it would be easier to gain access to these learners, as teachers would not object if these learners were used for data collection. Secondly, they were the second cohort of learners that experienced C2005. It is assumed that by the second year of implementation teachers generally have a better understanding of the requirements of a new curriculum. Finally, I was currently teaching a Grade 10 Physical Science class resulting in easy access for qualitative data collection.

In accordance with mixed methods approach this study used both probability and non-probability sampling. For the quantitative component of this study cluster sampling (Cohen et al., 2000) was used to select respondents. This sampling technique was used since it economises on time and costs incurred given that the representative population was widely dispersed (Bloch, 2004). Simple random sampling was not used since all schools within Chatsworth would have to be visited which was not possible given the time constraints and limited resources of a masters' research study. Maree and Pietersen (2007a) assert that if the clusters chosen are heterogeneous as the population then the selected clusters will be representative of the population. The school classes chosen in this study were widely dispersed within the suburb of Chatsworth to ensure they were representative of the target population. Furthermore, schools within the suburb of Chatsworth are co-educational, multiracial and majority of the learners are Indian since the schools are located in a historically Indian area. Accordingly the schools chosen for this study reflected the same characteristics.

Initially my intention was to target five secondary school Physical Science classes for quantitative data collection. However my data collection was close to year-end examinations, during which many learners stay away from school to study. Consequently I decided to target seven schools, which included my own school, to increase the validity of generalizations within the sample population and to ensure an adequate response rate. This resulted in a sample size of 190 learners for quantitative data collection. Physical Science class sizes ranged from 20 to 35 learners among the sample schools, which is similar to the target population. Respondents were of mixed ability levels from either lower or middle socio-economic backgrounds. Furthermore, they included both male and female learners and Indian and Black learners. Their ages ranged from 15 – 17 years.

For the qualitative component of this study I used convenience sampling (Cohen et al., 2000). The participants were learners from a grade 10 physical science class taught by the researcher. There were a number of reasons why I chose participants I taught for the qualitative part of the study. Firstly, learners chose to attend additional Physical Science lessons subsequent to year-end examinations during which qualitative data was collected. During this period other learners were at home. Secondly, my own learners would be more comfortable in asking clarification questions with regards to the open-ended activities as compared to learners from another school. Thirdly, it was easy to get permission from my principal and head of department to use participants from my school. Fourthly, I wanted to engage learners in a discussion of nature of science, subsequent to them completing the activities, to obtain their understanding of this construct.

Participants were of mixed ability levels from either lower or middle socio-economic backgrounds. They could all communicate fairly well in English since this was the first language of all participants. It was not possible to sample an equal number of learners from both genders since my class did not have an equal number of male and female learners. Furthermore, my class consisted of only Indian learners. As a result qualitative analysis will not be used to analyse conceptions due to cultural differences. The sample size for the qualitative component was 24.

3.10 SUMMARY

A mixed methods approach was used to answer the research questions. Quantitative data was collected using a structured questionnaire. An open format questionnaire comprising a set of scenarios related to nature of science was used to collect qualitative data. A relatively large sample size was used for the qualitative component to provide a richer understanding of learners' conceptions of nature of science since only two instruments were used for data collection. Both the quantitative and qualitative data were analysed and this is presented in chapter four.

CHAPTER 4

DESCRIPTION AND ANALYSIS OF FINDINGS

In this chapter, the findings of the study are described and presented in detail. The data were analysed and grouped under the following three strands - nature of science knowledge (content of science), the nature of scientific inquiry (process of science) and the relationship between science and society (social institution of science). The reasons and process of grouping is described earlier in the literature review and research design chapters. For each strand the associated survey statements are given and the learners responses described. This is followed by description of responses to the open-ended scenario questions and findings in relation to differences between the different gender groups and cultural groups. The findings are then discussed in relation to other studies.

The table below provides a general description of the participants for both the Views about Science (survey questionnaire) and the Scenarios of Science (open format questionnaire) instruments.

Table 4.1 Sample composition for each instrument used.

Instrument	Schools	Number of learners	Male	Female	Indian	Black
Survey questionnaire	7	190	97	93	142	48
Scenarios in science	1	24	16	8	24	0

There were approximately 25 to 30 learners per school and only one class for the open format questionnaire. They were evenly divided between male and female but predominantly Indian learners.

As mentioned in the previous chapter the responses to the survey questionnaire were coded and captured in spreadsheet format before analysis. A likert scale was used for responses with categories from +3 to -3. These were recoded so that strong agreement was coded 7, undecided coded 4 and strong disagreement coded 1. High means e.g. 6.0 indicate that learners strongly agree and hold contemporary views. A low mean represents learners' disagreement with accepted views of the scientific community. Statements 1, 7, 8, 11, 13, 16 and 17 were negatively stated therefore these scores were reversed. Consequently all results represent positive statements that indicate agreement with scientific community. In other words for negative statements strong disagreement was coded 7 and strong agreement coded 1. As a result low means ($M < 4$) indicate agreement and high means ($M > 4$) indicate disagreement.

4.1 NATURE OF SCIENCE KNOWLEDGE

The following represent contemporary views of nature of science knowledge which learners are expected to possess and is also a requirement of C2005 (see p. 55):

> Scientific knowledge is supported by empirical evidence and is universal, general and grows slowly building on that which is known; much of the science knowledge taught at schools is well established, reliable and beyond reasonable doubt; this knowledge is subject to change in the future when current information is re-evaluated or new evidence becomes available; scientific knowledge is socially constructed and different cultures have contributed to it.

4.1.1 Learners' conceptions from the survey questionnaire

The questionnaire had seven item statements which were considered to be related to nature of science knowledge:

Statement 15: Important contributions to the advancement of science have been made by people from different cultures (e.g. African, Indian, Chinese, etc.).

Statement 17: Scientific facts can never change but scientific theories can change.

Statement 18: There are certain physical events in the universe that science can never explain.

Statement 19: Traditional medicine-making can be considered as genuine scientific research.

Statement 20: In science the testing, revising, and occasional discarding of theories, new and old, never ends.

Statement 22: Science is one of several ways of knowing about the world. We can also learn about the world through our indigenous knowledge from our culture.

Statement 26: Science knowledge usually grows slowly through contributions from many scientists.

The response categories for each statement in the survey questionnaire were collapsed to represent only agree, undecided and disagree. In other words responses 1 to 3 for positive statements were added to indicate agreement (score greater than 4) and responses -1 to -3 were added to represent disagreement (score less than 4). As mentioned earlier the scores were reversed for negative statements. Learners had contemporary views for six of the seven statements. From learners' responses (Table 4.2), it is evident that there were large numbers of learners who agreed (greater than 70% of learners) with most statements in this strand. However for statements 17 (67%) and statement 19 (45%) the percentage agreement was less compared to the rest of the statements in this strand.

Table 4.2 Summary of learner's aggregated responses in the Scientific Knowledge Strand.

Statement number	% Agree	% Disagree	% Undecided	Mean (max = 7)
15	73	8	18	5.54
17	67	17	16	2.97*
18	72	15	13	5.46
19	45	30	24	4.35
20	81	6	13	5.55
22	87	7	6	5.79
26	73	17	10	5.31

* reverse coded due to it being stated negatively

The graph (Fig. 4.1) below shows the mean responses for these statements (indicated as questions) where 4 corresponded with undecided, greater than 4 indicated agreement and less than 4 indicated disagreement for positive statements.

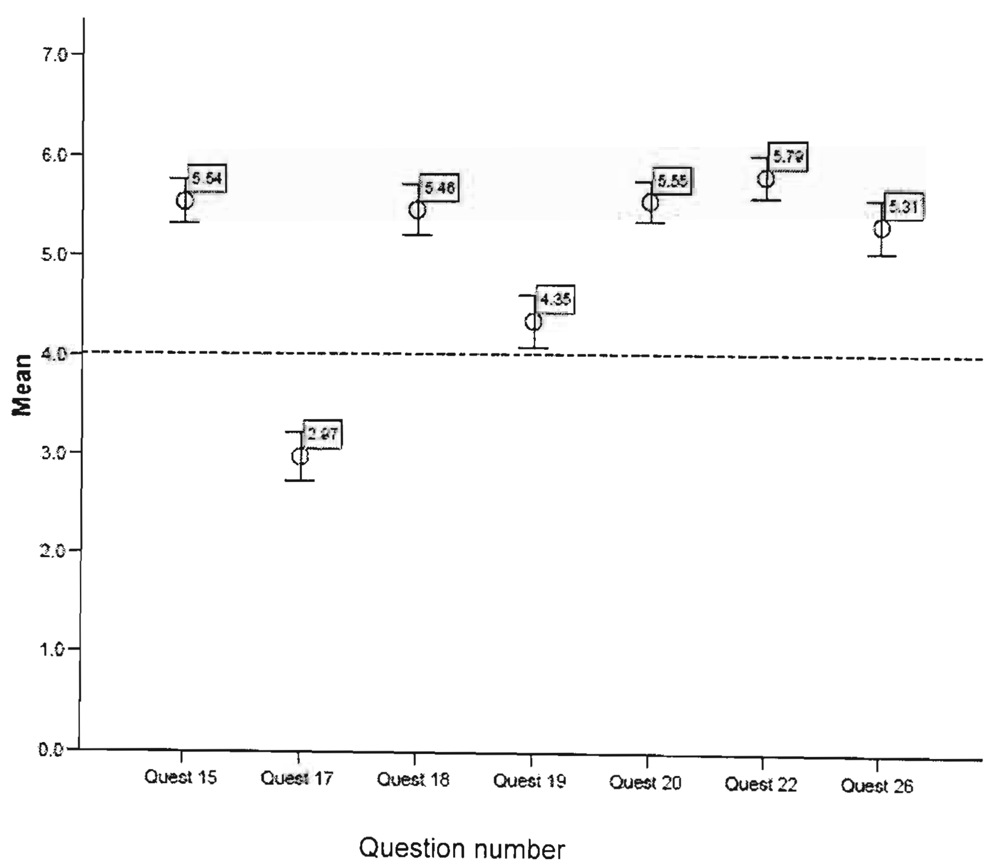

Figure 4.1 Graph illustrating the mean responses for Scientific Knowledge for all 190 learners

When examining the graph (Fig. 4.1) one can see that six statements had a mean response above four. However the mean response for statement 19 ($M = 4.35$) was close to four (undecided) implying weak agreement. A small percentage of learners (45% of responses) agreed that traditional medicine-making can be considered as genuine scientific research. The low mean may be attributed to 30% of learners who disagreed and 24% that were undecided for this statement. The graph also shows that the mean response ($M = 2.97$) for statement 17 was well below four. This was one of the statements where the score was reversed since it required a negative response. As a result the low mean indicates that 67% agreed that scientific facts do not change but scientific theories can change. This is contrary to the intentions of C2005 and the scientific community. The contemporary view is that both scientific facts and theories are subject to change. Upon reflection this statement should have been separated into two statements since it is ambivalent. Learners could be agreeing to either the scientific facts never changing or scientific theories can change. This was not picked up during the pilot stage.

There appeared to be mixed responses to statements that related to culture. Whilst there was strong agreement ($M = 5.54$ with 73% responses showing agreement) that different cultures have contributed to the generation of scientific knowledge and that one can learn about the world through different cultures ($M = 5.79$ with 87% responses showing agreement) only 45% of learners agreed that traditional medicine-making can be considered within the realm of science knowledge (a view which teachers are asked to encourage).

4.1.2 Comparison of male and female conceptions from the survey questionnaire

If one looks at the means in Table 4.3 it seems as if both males and females have responded similarly for each statement in the scientific knowledge strand. Both groups appear to share similar views for this strand as required in Curriculum 2005 and as expressed by the scientific community.

Table 4.3 Comparison between male and female responses within the Scientific Knowledge Strand.

Statement number	Gender	N	Mean	Std. Dev.	Std. Error Mean
15	Male	96	5.25	1.711	0.175
	Female	92	5.77	1.310	0.137
17	Male	96	3.08*	1.923	0.196
	Female	92	2.84*	1.499	0.156
18	Male	97	5.62	1.692	0.172
	Female	92	5.30	1.784	0.186
19	Male	97	4.34	1.814	0.184
	Female	92	4.32	1.670	0.174
20	Male	96	5.26	1.530	0.156
	Female	93	5.88	1.187	0.123
22	Male	96	5.66	1.521	0.155
	Female	92	5.90	1.267	0.132
26	Male	95	5.41	1.795	0.184
	Female	93	5.24	1.820	0.189

* reverse coded due to it being stated negatively

To find out if there is a statistically significant difference between male and female responses a t-test (Independent Samples test) was carried out. The sample of learners consisted of two independent groups viz. boys and girls. On closer inspection a statistically significant difference was found between male and female responses for statement 15 ($t = -2.341$, $df = 186$, $p = 0.02$) where the female responses ($M = 5.77$, $SD = 1.31$) were more positive than those of the males ($M = 5.25$, $SD = 1.711$). This implied that there was stronger agreement among females than males that many cultures have contributed to the advancement of science. A significant difference was also found for statement 20 ($t = -3.112$, $df = 187$, $p = 0.02$). Again the responses from females were more positive ($M = 5.88$, $SD = 1.187$) than those from males ($M = 5.26$, $SD = 1.53$). It appears that the females showed stronger agreement that in science the testing, revising, and occasional discarding of theories, new and old, never ends. As mentioned earlier responses to statement 17 indicate that learner conceptions on scientific theories and laws appear to be contrary to the accepted views of the scientific community. There was no significant difference ($t = 0.977$, $df = 186$, $p = 0.33$) between males and females for this statement.

4.1.3 Comparison of different cultural groups' conceptions from the survey questionnaire

As mentioned in the previous chapter there were more Indian learners than Black learners in this study since it was undertaken in a historically Indian area. Nevertheless, an attempt is made to determine if the two cultural groups have different conceptions of science.

Table 4.4 Statistics for different cultures within the Scientific Knowledge Strand.

Statement number	Race	N	Mean	Std. Dev.	Std. Error Mean
15	Indian	141	5.50	1.538	0.130
	Black	47	5.51	1.586	0.231
17	Indian	141	2.98*	1.826	0.154
	Black	47	2.91*	1.412	0.206
18	Indian	142	5.73	1.658	0.139
	Black	47	4.66	1.748	0.255
19	Indian	142	4.12	1.744	0.146
	Black	47	4.96	1.587	0.232
20	Indian	142	5.61	1.434	0.120
	Black	47	5.45	1.316	0.192
22	Indian	140	5.79	1.418	0.120
	Black	48	5.75	1.376	0.199
26	Indian	141	5.38	1.751	0.417
	Black	47	5.17	1.971	0.287

* reverse coded due to it being stated negatively

Black and Indian learners had similar means (Table 4.4) for five of the seven statements. Both cultural groups had contemporary views and shared agreement with the scientific community for statements 15, 20, 22 and 26. However both groups disagreed with the scientific community for statement 17. They are of the view that scientific facts do not change but scientific theories do.

A t-test has revealed a statistically significant difference in the responses between the two cultural groups for statement 18 ($t = 3.793$, $df = 187$, $p < 0.000$ two-tailed) and statement 19 ($t = -2.916$, $df = 187$, $p = 0.004$ two-tailed). It appears that Indian learners' responses to the statement that science cannot explain certain physical events in the universe (Statement 18) were more positive (Table 4.4) compared to Black learners. It is interesting that 23% of Black learners were undecided for this statement compared to 9% of Indian learners. Black learners' responses to the statement that traditional medicine-making can be considered as genuine scientific research (statement 19) were more positive than Indian learners. This is to be expected since African culture is embedded in traditional therapies that have been passed on from generation to generation. It is a culture that encourages its people to seek remedies from traditional healers in addition to western doctors.

4.1.4 Learners' conceptions from the open format science scenarios

What follows is the presentation of the results from the Scenarios of Science (Appendix B) given to one class of learners. Scenarios two and four pertained to the nature of science knowledge. The results from scenario two will be presented first followed by scenario four.

Scenario two made reference to a 'scientifically proven' washing powder named Nu-clean and a 'proven' washing powder named Brighter. An overwhelming majority (23 out of 24) chose the washing powder that was 'scientifically proven' to the one that was 'proven'. All females (eight) chose the scientifically proven washing powder whilst 14 out of 16 males made a similar choice. Learners used words like 'tested by scientists', 'tested in a laboratory' and 'many tests' in order to explain why they chose the scientifically proven powder. Most learners used similar words to explain what proven and scientifically proven meant to them as typified by the following response, "Scientifically proven is when it is researched and tested several times to see the results. Scientists in laboratories could test it. Proven: It could be anyone that could say it works. There is no real guarantee that it works" (learner 22).

The confidence in a scientifically proven product is indicated by the following response:

> The simple reason as to why I had chosen Nu-clean is because it was tested scientifically, while on the other hand the other product was not. The scientifically proven tells me that this product has been put through comprehensive tests which thereafter showed good results telling me this product is better as compared to the product which was tested by regular and normal individuals. (learner 11)

The above response alludes to both critical testing which the scientific community describe as a characteristic of scientific knowledge and confidence in scientists. In examining all responses three main reasons for their confidence were offered by learners. It appears that the learners have confidence in the scientifically proven product due to rigour of experimentation, participation of scientists and the use of laboratories, which are equipped with specialised equipment.

A learner who provided a negative response gave the following reasons as to why the proven powder and not the scientifically proven powder was chosen:

> Scientifically proven means in a laboratory and not practically proven.The comment is based on what scientists believe and by not washing clothes to see for sure. Proven means to practically wash clothes and witness the stain removal. It may be based on fact because people or someone witnessed the stain disappear. (learner 12)

It appears that this learner considers scientists as philosophers (theorists) rather than individuals who physically see the results of their experiments. As a result this learner believes that scientists proposals are unsuitable for real-life applications.

Scenario four mentioned the hoodia plant and its association with the San people. Majority of learners (17) indicated that the medicinal properties of the hoodia plant discovered by the San people cannot be considered as scientific knowledge. There were 12 out of 16 males and five out of eight females that were of this view. The theme identified from their responses is scepticism. This is evident from the words 'not scientifically proven', 'no scientific evidence', 'traditional myth', 'common knowledge' and 'ancient beliefs and knowledge', which appeared in learners' responses. Typical responses provided by learners were:

> Because it has not been tested by scientists in labs. Ancestors passed it on to them. It is traditional medicine and has not been tested in labs to look for side effects andwhether it may in the long-term cause complications in the human body.
> (learner 14)

> These people have no scientific evidence to prove their theory although they do have the result concluded from the way their body reacted to the hoodia plant, they only know it eases stomach pains, fatigue etc. They don't know what is in the plant e.g. vitamins what it contains and how it is able to do what it does for us.
> (learner 23)

The responses above indicate some of the reasons for learners' scepticism. The reasons offered by the learners included that scientists did not test it, the San do not understand how and why it works and what the possible side effects are. As a result they believed that indigenous knowledge does not form part of established scientific knowledge since they held strong beliefs in empiricism. This corresponded to similar findings for statement 19 from the survey questionnaire where only 45% of learners agreed that traditional medicine-making is true scientific research.

Seven learners indicated that the knowledge of the hoodia plant could be considered scientific knowledge. A typical reason for this response is given below.

> The San life may seem primitive but all science started at some point. We can suggest that the knowledge of the hoodia plant is scientific, it is medicine and medicine is closely linked to science. Even Hypocrites used primitive ingredients to invent medicine so we cannot say that what the San are using is non-scientific. (learner 2)

These learners commented on the plant being a medicine and that some form of testing had occurred when San people initially tried it. Although they have displayed a limited understanding they appeared to acknowledge the contribution of indigenous knowledge to science.

When asked whether the knowledge of the San could be viewed as scientific knowledge if it appeared in science textbooks 17 learners chose yes. There were six out of eight females and 11 out of 16 males that answered in the affirmative. It appears that this group of learners consider the knowledge of the San as scientific knowledge for the reason that scientists were involved in testing this knowledge since it appears in science text books and that whatever is learned at school is scientifically factual. This is supported by the following typical responses:

> If it appeared in science textbooks then it means the plant has been tested by scientist to see whether the San people's knowledge of the plant was right. Science textbooks will give us detailed explanations of the plants and its effects because of the number of experiments it goes through. (learner 18)

> Because I'm sure this knowledge has been tested and tested to get a correct answer. Whatever we learn in school is most of the time all facts and we'll remember it even out of school. The school would not let us learn something that is not tested or something that does not have solid proof that it is true. (learner 7)

The responses above allude to critical testing which according to scientific community underpins the generation of scientific knowledge. Furthermore learners had confidence in what was taught at schools and it appears that they considered school science beyond reasonable doubt.

There were seven learners (five males and two females) who indicated that they would not consider the knowledge of the San scientific knowledge despite it appearing in science textbooks. There were two common reasons provided for their choice namely that it is oral knowledge and that there was no experimentation or tests undertaken. This indicates that some learners feel that scientific knowledge should be written down as opposed to orally transmitted and that it has a basis in empirical tests.

When considering the value of the knowledge, only one learner indicated that she would not consider the knowledge of the San as valuable knowledge. She provided the following reason, "Because in modern times which is presently now, people don't focus on traditional methods of healing and treatment. With the simple mode of transport a chemist is found easily and medication can be purchased quite fast and easily" (learner 5). It appears that this learner considers traditional medicines outdated and difficult to obtain. There was general consensus among rest of the learners who considered this knowledge valuable. There were two reasons generally provided. One being an alternative treatment to ailments as indicated by learner 4 who answered that, "Maybe it can be used today by doctors as an additional treatment for stomach aches, fatigue, etc. If other treatments don't work maybe this one can help". The other reason was is to initiate scientific research as exemplified by the following response:

> Scientists can now investigate this plant and experiment with it to see if it really works. Scientists can find practical evidence to prove that the plant can cure illnesses. The San people have given the scientists an idea of discovering and an idea to study it. (learner 21)

What is apparent from the responses is that learners considered traditional knowledge valuable but not necessarily scientific.

4.1.5 Summary and discussion of scientific knowledge strand

Learners' conceptions in this strand were generally consistent with contemporary views. In this study learners' conceptions on scientific knowledge for six of the seven statements in the survey questionnaire were in accordance with the scientific community (Collins et al., 2001) and C2005. Chelin (2003) conducted research to explore learners' perceptions of nature of science with a sample of 120 learners from grade 8 to grade 11 in a South African school. She found that majority of learners agreed that many cultures have contributed to science knowledge, which concurs with this study. This is expected since many outcomes-based textbooks contain examples of scientific technologies and scientific practices of different cultures. A large percentage agreed that science is not the only way we can know about our world. A significant number agreed that science knowledge changes gradually due to testing and revising of new and old knowledge and that there are certain physical events that science can never explain. Chelin (2003) also reported similar results.

Curriculum 2005 recognises that multiple knowledge exists in understanding the world and it allows for different world-views to be integrated into the science curriculum. However learners in this study did not show contemporary understandings of this construct. A small percentage in this sample agreed that traditional medicine-making could be considered scientific research which is a contemporary view. Furthermore in the open format questionnaire learners regarded African traditional medicines to be "common knowledge" and "a traditional myth" and considered it unscientific since there was "no scientific evidence" because it was not "tested by scientists". Learners in this study do not place the same value on African science and western science. A study conducted by Liu and Lederman (2002) among 'gifted' Taiwanese Grade 7 learners found that, like the learners in this study, they believed that western medicine was based on scientific evidence and therefore different from traditional medicine. Nevertheless, all learners except one learner considered traditional knowledge to be valuable since it can "help scientists discover new medicines" (learner 14) and it could be an alternative form of treatment. Majority of learners in this sample answered in the affirmative that they would consider indigenous knowledge to be scientific knowledge if it appeared in science textbooks since it would be "tested" and be scientifically "factual". They trust that what is done at school is scientific. Unlike the findings by Dekkers and Mnisi, (2003) where teachers see no distinction between the practical effectiveness, the status and the nature of the knowledge system behind traditional medicines, learners in this study see the status of indigenous knowledge as different from science.

Learners believed that certain types of scientific knowledge are not tentative, a view not shared by the scientific community. The empiricist oriented view seemed to prevail when learners held the common misconception that scientific facts represent absolute knowledge. Similar findings were reported by, Bady (1979), Bell et al. (2003), Ryan and Aikenhead (1992) and, Ayayee and McCarthy. (1996). According to McComas (1996) a possible reason for this could be the false hierarchical relationship that learners attribute to facts, hypotheses, theories and laws. It appears that learners do not understand the "conceptual change of scientific progression" (Tsai, 1999), which could be grounds for further research.

There were differences between the groups (gender and culture) for certain conceptions of nature of science knowledge. There were statistically significant differences between males and females for two statements in this strand. Interestingly there was stronger agreement among females than males that many cultures have contributed to the advancement of science. However this was contrary to the findings Tsai (1999) who found that Taiwanese female students in their first interview (prior to explicit nature of science instruction) had a stereotype image that science was a product of western society. In this study females showed stronger agreement that scientific theories are continuously being revised and changed, than males. There does not appear to be any reason why this difference exists. Indian and Black learners also had statistically significant differences for two statements in this strand. Indian learners showed greater agreement than Black learners that science cannot explain certain physical events. Perhaps it is the language difficulties in the statement itself that resulted in the difference since a significant percentage of black learners were undecided for this statement. English is the spoken language of Indian learners whilst for many Black learners it is not. Rollnick (1998) found that second language speakers (learners not taught in their spoken language) experience difficulty in interpreting words due to language difficulties, conceptual difficulties or cultural differences where the word may have different meanings. Black learners appeared to show greater confidence than Indian learners that traditional medicine-making can be considered scientific research.

4.2 NATURE OF SCIENTIFIC INQUIRY

Both C2005 and the scientific community propose that learners develop the following conceptions of nature of scientific inquiry (see p. 55):

> Scientific inquiry is a cyclic process that entails questioning, formulating hypotheses or predictions and conducting investigations to test hypotheses; there is no single scientific method; while the core activities of scientists are disciplined observation and critical testing, science uses a range of methods or approaches that involve precision and rigour, careful analysis and the use of logical reasoning; the outcome of a single experiment is insufficient to establish a knowledge claim; scientific knowledge claims do not emerge simply from the data but through a process of data analysis, interpretation and theory building; scientists use intelligence, hard work, imagination and

even chance to invent models and theories and to explain empirical observations; scientific inquiry is a human activity that is not exempt from personal, social and ethical values; it is possible for scientists to legitimately interpret the same data differently and therefore, disagree.

4.2.1 Learners' conceptions from the survey questionnaire

The questionnaire had eight item statements that were considered to be associated with the nature of scientific inquiry:

Statement 1: There is a fixed set of steps that scientists follow in scientific investigations.

Statement 2: Results can change each time you do the same scientific investigation because of different methods, different materials used and sometimes because the thing being studied actually varies.

Statement 5: It is important to do the same scientific investigation many times before accepting the results as correct.

Statement 8: Scientists have no idea of what will happen in an experiment before they actually do the experiment.

Statement 9: Scientists use creativity and imagination when doing scientific investigations.

Statement 10: Scientific discoveries usually result from a logical series of investigations but science is not completely logical. There is an element of trial and error, hit and miss, in the process.

Statement 21: Scientists' explanations about what happens in the world come partly from experimental evidence and partly from creativity and imagination (ie. from what they think).

Statement 23: Scientific models (e.g. the model of DNA or the atom) are not real (ie. not directly observable) but are created by scientists to explain what they think may be happening and to predict observations.

From the graph (Fig. 4.2) below it appears that a large percentage of learners have agreed with most statements in this strand. The scoring was reversed for statement 1 and statement 8 therefore mean values less than four indicate agreement.

Thus for statement one 76% of learners (Table 4.5) agreed ($M = 2.5$) with this statement. They seemed to hold the view that there is a single scientific method which is contrary to what the scientific community and C2005 have proposed. Learners appeared to be equally divided for statement 8.

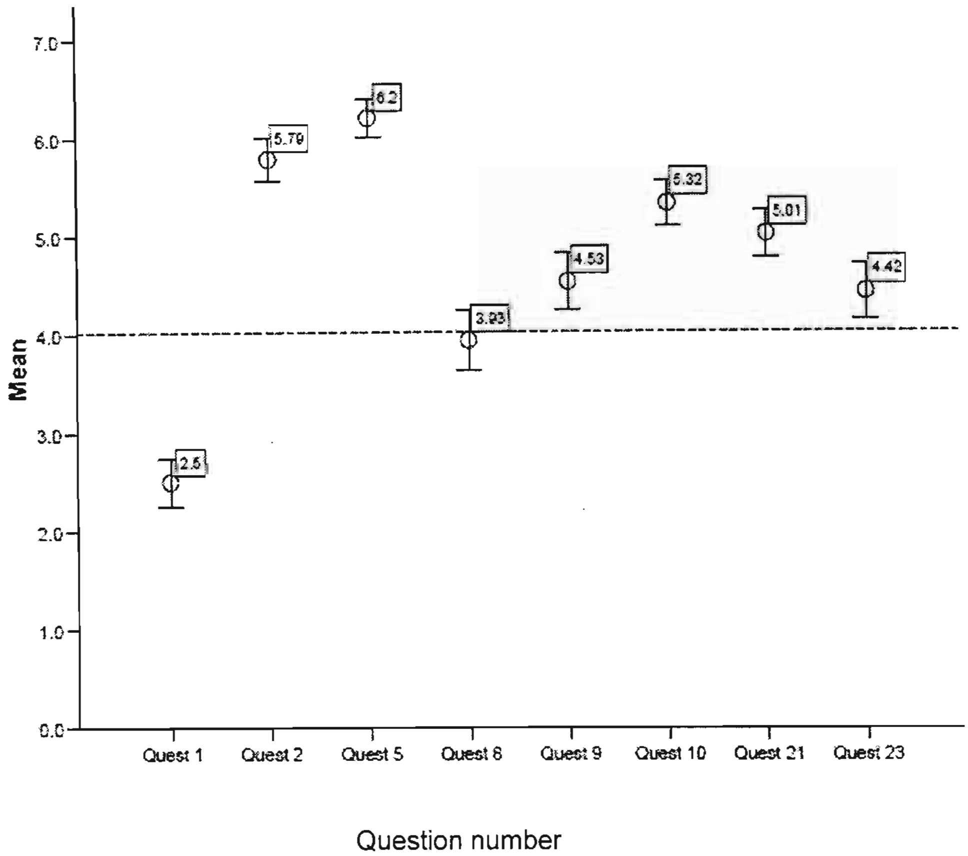

Figure 4.2 Graph illustrating the mean responses for Scientific Inquiry for all 190 learners

Forty-four percent of learners have disagreed whilst 43% agreed that scientists have no idea of what will happen in an experiment prior to carrying out the experiment. However, the low mean ($M = 3.93$) indicates weak agreement since it lies very close to 4 (undecided). The low mean could be the result of 13% of learners being undecided and the 1% difference between learners that agreed and disagreed. Nevertheless, the contemporary view is that scientists do make predictions and have some idea of what will happen in experiments.

Table 4.5 Summary of learner's aggregated responses in the Scientific Inquiry Strand.

Statement number	% Agree	% Disagree	% Undecided	Mean(M) (max = 7)
1	76	14	10	2.50*
2	86	9	5	5.79
5	90	5	5	6.20
8	43	44	13	3.93*
9	59	31	10	4.53
10	72	13	15	5.32
21	67	18	15	5.01
23	50	30	20	4.42

* reverse coded

If one looks at the means (Table 4.5) for the rest of the statements (positive statements) in this strand they indicate that learners have agreed (M > 4) with the statements which are contemporary views. A large majority (90% of responses) agreed with statement 5. This is expected since learners at schools are required to repeat investigations in order to verify results even in the conventional curriculum. However there were fewer learners that agreed with statement 9 (59% of responses) and mean response was close to 4 implying learners did not strongly agree that scientists use creativity and imagination in investigations. Statement 23, which also pertained to the theme creativity and imagination, had a low mean ($M = 4.42$) indicating that learners seem to be undecided. They appear to be ambivalent for this statement since 50% agreed but a significant percentage (20% of responses) were undecided. It seems that learners are not convinced or not aware that intuition and inspiration are an integral part of the scientific enterprise.

4.2.2 Comparison of male and female conceptions from the survey Questionnaire

When examining the means from Table 4.6 it appears as if male and female learners had similar conceptions for the scientific inquiry strand.

Table 4.6 Comparison between male and female responses within the Scientific Inquiry Strand.

Statement number	Gender	N	Mean	Std. Dev.	Std. Error Mean
1	Male	97	2.71*	1.904	0.193
	Female	92	2.34*	1.361	0.142
2	Male	95	5.65	1.681	0.172
	Female	93	5.83	1.291	0.134
5	Male	96	5.85	1.569	0.160
	Female	91	6.52	0.835	0.088
8	Male	96	4.07*	2.099	0.214
	Female	93	3.89*	1.986	0.206
9	Male	95	4.58	2.056	0.211
	Female	93	4.53	1.931	0.200
10	Male	96	5.32	1.670	0.170
	Female	92	5.23	1.498	0.156
21	Male	96	4.93	1.767	0.180
	Female	93	5.09	1.479	0.153
23	Male	94	4.37	1.945	0.201
	Female	92	4.41	1.894	0.197

* reverse coded

However, a t-test has shown that there are statistically significant differences in responses for statement 5 ($t = -3.575$, $df = 185$, $p = 0.000$ two-tailed). Females ($M = 6.52$, $SD = 0.835$) were more positive than males ($M = 5.85$, $SD = 1.569$). This implied that females showed stronger agreement than males that it is important to repeat investigations before accepting the results as correct.

Both genders had contemporary views for most statements in this strand except statement 1 and statement 8. Both groups shared strong agreement (Table 4.6) that there is a fixed set of steps scientists follow in investigations (statement 1) although this is not what the scientific community and C2005 are proposing. It seems that the males have disagreed (*M* = 4.07*, *SD* = 2.099) whilst the females (*M* = 3.89*, *SD* = 1.986) have agreed with statement 8. In other words males have indicated that scientists have an idea of what will happen in experiments, which is what is being advocated by the scientific community, however females feel that scientists have no idea of what will happen prior to conducting an investigation. However these differences were not statistically significant ($t = 0.607$, $df = 187$, $p = 0.545$).

4.2.3 Comparison of different cultural groups' conceptions from the survey questionnaire

When examining the mean responses from Table 4.7 it looks as if both Black and Indian learners have responded similarly for statements in this strand.

Table 4.7 Statistics for different cultures within the Scientific Inquiry Strand.

Statement number	Race	N	Mean	Std. Dev.	Std. Error Mean
1	Indian	141	2.62*	1.783	0.150
	Black	48	2.27*	1.250	0.180
2	Indian	142	5.82	1.442	0.121
	Black	46	5.50	1.657	0.244
5	Indian	140	6.25	1.309	0.111
	Black	47	5.96	1.285	0.187
8	Indian	142	3.97*	2.038	0.171
	Black	47	4.02*	2.069	0.302
9	Indian	141	4.49	2.002	0.169
	Black	47	4.74	1.961	0.286
10	Indian	142	5.42	1.568	0.132
	Black	46	4.83	1.568	0.231
21	Indian	141	5.13	1.567	0.132
	Black	48	4.65	1.768	0.255
23	Indian	140	4.57	1.867	0.158
	Black	46	3.85	1.977	0.292

* reverse coded

A t-test has denoted that there are statistically significant differences between the two cultures for three statements within this strand. A statistically significant difference was found between Indian and Black learners' responses for statement 10 (t = 2.242, df = 186, p = 0.026) where Indian learners' responses (M = 5.42, SD = 1.568) were more positive than Black learners (M = 4.83, SD = 1.568). This meant that there was stronger agreement among Indian learners that science is not completely logical since it also entails trial and error. Nevertheless both groups' responses represent a contemporary view. Significant differences were also found for statement 21 (t = 1.780, df = 187, p = 0.077) and statement 23 (t = 2.248, df = 184, p = 0.026). Indian learners' responses were more positive (Table 4.7) that scientific explanations about the world come partly from experimental evidence and partly form creativity and imagination (statement 21). Indian learners agreed (M = 4.57, SD = 1.867) with statement 23 that scientific models are not real but are created by scientists whilst Black learners disagreed (M = 3.85, SD = 1.977) with this. It appears that Black learners have a view that is associated with a traditional more positivistic view of nature of science. Black learners seemed to believe that creativity and imagination is limited to the carrying out and planning of scientific investigations since their means (Table 4.7) for statement 9 (M = 4.74) is higher than statements 21 (M = 4.65) and 23 (M = 3.85) which all refer to creativity.

4.2.4 Learners' conceptions from the open format science scenarios

In the open format questionnaire scenario five related to the scientific inquiry strand. Scenario five made reference to the reasons provided by scientists for the dinosaur extinction. The purpose of this task was to obtain learners' views on scientists' interpretations of data. The first question in this scenario required learners to decide whether the reasons provided by scientists could be wrong. Most learners (21) indicated that the explanations provided by both groups of scientists could be wrong.

All females (eight) and 13 males indicated that the scientists could be wrong. Although the learners chose the correct response they provided superficial answers for their choice. Many responses alluded to scientists not being present during the dinosaur extinction and or that these are 'opinions', 'suggestions' or 'theories' proposed by scientists. The reasons provided are characterised by the following response, "Because no one really knows how the dinosaurs become extinct. They were just suggestions made by the scientists of how they became extinct" (learner 15). Another typical response was:

> Many suggestions had been put forward. The scientists unfortunately don't have solid hard evidence on how the dinosaurs became extinct. They have made deductions, which is fine, but don't have proof to back it up. They weren't alive at that time to see how they died. (learner 20)

Learners who offered these responses wrote about 'solid proof', 'practical evidence' or 'solid hard evidence' thereby inferring that scientists can only provide the correct answers through experimentation. Support for this is provided by the following response, "Most of these assumptions are logical but thorough investigating should be done to really find out how the dinosaurs disappeared"(learner 5). Evidently these learners have functioned within an empirical paradigm and ignored other rational and analytical activities that are characteristic of scientific inquiry. This concurs with the responses learners provided for statement 1 in the survey questionnaire. However two learners alluded to the diversity of scientific thinking as espoused by the scientific community when they responded, "Each scientist have their own way and methods of carrying out their experiment" (learner10) and, "...there are different methods or ways one can use to solve the problem" (learner 21). Nevertheless none of the learners mentioned scientists' theoretical background or personal values, which could affect interpretation of data.

A minority (3) who responded that the scientists could be right also subscribed to a positivist view of science. This is evident where one learner indicated that, "Scientists are highly intelligent and know what they're doing" (learner 12) and another mentioned that, "...whatever facts they come up with is true" (learner 9). These learners believe that scientists are objective, rational and unbiased people.

This scenario also required learners to provide reasons as to why scientists provide different conclusions from the same data. Most responses were very obvious and mentioned general characteristics like, 'different beliefs', 'different opinions', and 'different views'. This type of explanation is exemplified by the response, "Everyone is different and have their own point of view so their conclusions might be different or similar" (learner 16). Others were more specific and used words like, 'different knowledge', 'own knowledge', 'different experiments', 'different research' and 'different experiences' as typified by the following response:

> They each have different opinions because of the way they see things. Their knowledge and experience with these types of findings are different resulting in different conclusions. Their interpretation of certain data could be different because of their personal values, etc. (learner 22)

These learners had a vague idea that different training, different experiences and different theoretical background can shape the conclusions inferred from data. However learners did not mention these ideas earlier when questioned whether scientists could be wrong in their interpretation of the dinosaur extinction.

4.2.5 Summary and discussion of scientific inquiry strand

Overall it appeared that learners held contemporary views of scientific inquiry but with some specific areas of non-agreement with contemporary views. Learners in this study had a better understanding of empirical methods than the inventive nature of scientific inquiry. A large number of learners displayed strong agreement that repeating investigations was important. Support for this view was provided when learners referred to "several tests", "comprehensive tests" and "many experiments" in the open format questionnaire. Perhaps this is expected since teachers generally emphasise repetition of experiments to verify results even in the traditional curriculum. Learners were also very positive that results of similar scientific investigations seldom turn out exactly the same due to differences in methods, or materials used, or unexpected differences in the things being investigated.

A small percentage agreed to statements that were associated with imagination and creativity in scientific inquiry. Learners appeared to have mixed beliefs on the role of creativity and imagination in scientific investigations, interpretation of evidence and in the invention of explanations and models. Like the findings of Bell et al. (2003) the learners in this study may have failed "to recognise creativity as inherent and necessary throughout all stages of investigations" (p. 493). In his study involving 79 learners and 22 science teachers in Limpopo Province, Dekkers (2006) found that while many learners indicated that imagination and creativity play a role in science their explanations offered made reference only to the planning and conduction of experiments. This study concurs with the findings of Dekkers.

Generally learners subscribed to a positivist view of scientific inquiry for the open format questionnaire. Many learners were unaware of the inventive nature of explanations in scientific inquiry since they were more concerned about "proof" and "evidence" for the dinosaur scenario. This was consistent with the view expressed in the questionnaire. However there were some learners who expressed ideas about "different knowledge" (theoretical background) and "different experiences" affecting the interpretation of data. Although a contemporary view, a small percentage of learners in this study agreed that scientists have an idea of what happens in an experiment prior to carrying out the experiment. This is reflective of the findings by Chelin (2003). Perhaps this is so since the learners in this sample experienced the traditional grade 10 Physical Science curriculum where experiments are conducted to verify laws. Interestingly in Chelin's study and in this study a significant percentage of learners were undecided for this statement. It indicates an area which teachers should focus on.

Learners in this sample held strong beliefs in a single scientific method, which is not a contemporary view. A significant percentage of learners strongly agreed that scientists follow a rigid set of steps in experiments thereby implying a single scientific method. These findings support those of Chelin (2003) who also found that a significant number of learners believed that there are fixed steps to follow in an investigation. Both Ryan and Aikenhead (1992) and Ayayee and McCarthy (1996) also found that a very small percentage of learners held the view that there is no such thing as a scientific method. Learners in this study may have confused the experimental method, which McComas (1996) points out is one of several methods used in science, as the scientific method which is typically taught in schools. Bell et al. (2003) reported that the misconception of a single scientific method among learners is pervasive. Generally learners supported a similar view for the open format questionnaire where they were unaware of other analytic activities in science and presented the view that experimentation is the only means in providing scientific explanations.

There were few differences in conceptions between the groups for nature of scientific inquiry. There was a statistically significant difference between the genders where females seemed more convincing than males that systematic testing and replication of results, a characteristic of scientific methods and critical testing, is an essential feature of scientific inquiry. Although not statistically significant, male learners agreed that scientists have an idea of what will happen prior to conducting an investigation (hypothesis and predictions) but female learners disagreed. There were statistically significant differences between the two cultural groups for three statements in this strand. Firstly, there was stronger agreement among Indian learners than Black learners that science is not completely logical since there is an element of trial and error. Perhaps Black learners have "a more absolute view of science as an objective endeavour" (Bell et al., 2003, p. 493). Secondly, Indian learners displayed stronger agreement than Black learners that scientific explanations are the product of both experimental evidence and creativity. Thirdly, Indian learners agreed but Black learners disagreed that scientific models are not real but are invented by scientists. Indian learners in this study seemed to possess stronger beliefs in the inventive nature of scientific inquiry and the diversity of scientific thinking compared to Black learners.

4.3 THE RELATIONSHIP BETWEEN SCIENCE AND SOCIETY

This strand represents the effect social, political and religious aspects as well as personal and discipline-centred values have on the scientific enterprise. Learners are expected to develop the following contemporary conceptions for the relationship between science and society (see p. 56):

> Scientific knowledge is constructed from a particular cultural and gender perspective; science is located within an historical context and is influenced by the expectations of society; the application of scientific and technical knowledge is not value-neutral and thus may conflict with moral and ethical values held by groups within society; cooperation and collaboration among scientists and critical peer review are fundamental to the development of new scientific knowledge.

4.3.1 Learners' conceptions from the survey questionnaire

The questionnaire had11 item statements which were considered to be related to the relationship between science and society:

Statement 3: Community or government agencies should tell scientists what to investigate.

Statement 4: Scientists try to identify possible bias (unfairness) by checking each other's results and explanations but there is no guarantee against bias.

Statement 6: Two scientists can have different explanations and interpretations for the same set of observations because of their background, personal beliefs and values.

Statement 7: Religious views of scientists do not influence scientific research because scientists will research topics which are of importance to science and scientists, regardless of religious views.

Statement 11: Scientists are open-minded, logical, unbiased, objective and honest in their work.

Statement 12: Scientists should consult the well-versed public when making decisions which affect our society (e.g. producing a chemical which make it impossible for police detecting alcohol on your breath).

Statement 13: When a research team makes a discovery, it is all right for them to announce it to the press before other scientists have discussed it.

Statement 14: Scientific discoveries made by women will tend to be different to those made by men because, by nature or by upbringing, females have different values, viewpoints, perspectives, or characteristics (such as sensitivity toward consequences).

Statement 16: It is not necessary for scientists to communicate with other scientists about their work.

Statement 24: New ideas in science are often rejected by the scientific community.

Statement 25: Scientific evidence can be biased (distorted) by the way that data are interpreted, recorded, reported or selected.

From the graph (Fig. 4.3) it can be seen that learners held contemporary views ($M > 4$) for six statements in this strand namely statements 4, 6, 12, 13, 16 and 25. However learners did not possess contemporary views for statements 3, 7, 11, 14 and

24. A significant percentage of learners (57% of responses) seemed to disagree (M = 3.42) that community and government agencies have an influence on what scientists investigate (statement 3). In contrast, a high percentage of learners (71% of responses) have agreed (M = 5.34) that scientists should consult the public when making decisions that affect society (statement 12).

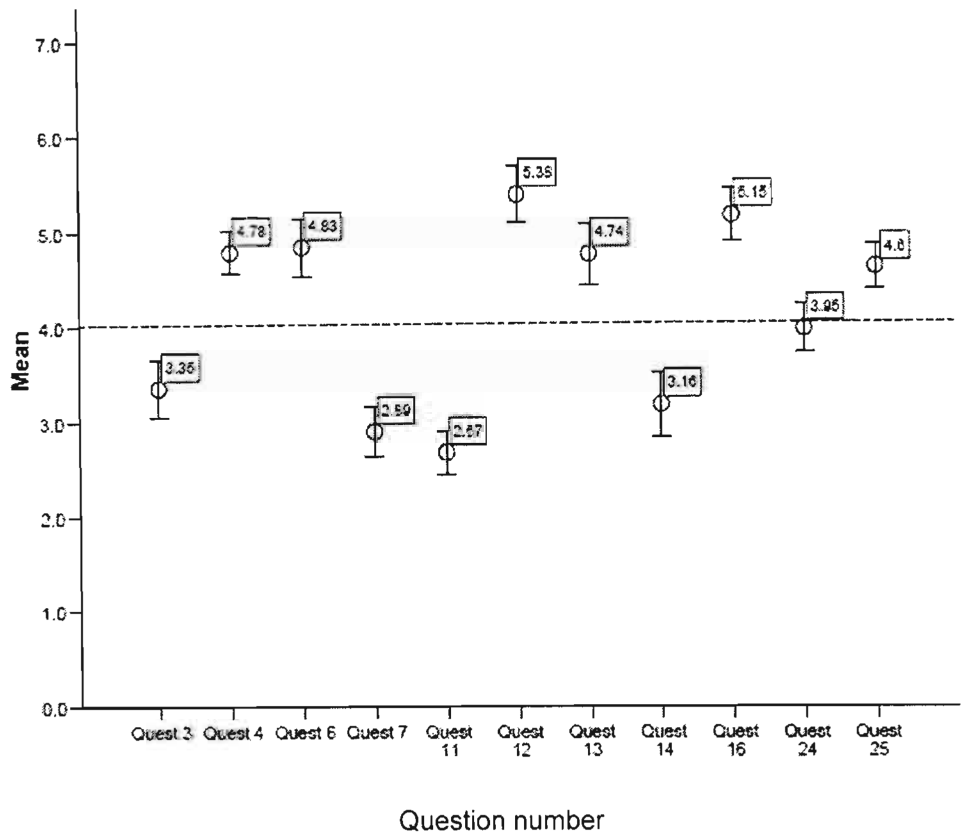

Figure 4.3 Graph illustrating the mean responses for the relationship between Science and Society for all 190 learners

Learners also appeared to disagree that women can make different discoveries compared to men (statement 14). Both the scientific community and C2005 advocate the study of the historical development of science, which illustrates how social, political, cultural, and gender factors have a bearing on science. Although a greater percentage (36% of responses) disagreed that new ideas are often rejected by the scientific community (statement 24) the difference between those that agreed and disagreed was only two percent. Furthermore there were 30% of the learners who were undecided for this statement. This could have contributed to the very low mean (M = 3.93).

Table 4.8 Summary of learner's aggregated responses in the Science-Society Strand.

Statement number	% Agree	% Disagree	% Undecided	Mean(M) (max = 7)
3	33	57	10	3.42
4	58	15	27	4.76
6	64	27	9	4.78
7	62	19	19	2.84*
11	71	14	15	2.75*
12	71	16	13	5.34
13	29	60	11	4.77*
14	29	60	11	3.20
16	19	71	10	5.20*
24	34	36	30	3.93
25	54	20	26	4.62

* reverse coded

The scoring for statements 7, 11, 13 and 16 were reversed since they were negative statements therefore means that are less than four imply agreement with these statements. Learners' conceptions with respect to cooperation, collaboration and critical peer review (statement 13 and 16) corresponded with the accepted views of the scientific community (Table 4.8). There were mixed responses to statements that referred to personal and discipline centred values in science. Most learners (62% of responses) agreed (M = 2.84) that religious views of scientists do not influence scientific research (statement 7), which is not a contemporary view. Nevertheless learners also agreed (M = 4.78) that personal beliefs and values might result in different interpretations and explanations of observations (statement 6). It appears that learners in this study are unaware that religious beliefs are associated with personal beliefs. A sizable percentage of learners (71% of responses) agreed (Table 4.8) that scientists are objective, open-minded and unbiased in their work (statement 11).

However this is contradictory to the responses provided in statement 25 where 54% of learners have agreed (M = 4.62) that scientific evidence can be biased and also statement 4 where many learners (58% of responses) agreed (M = 4.76) that there is no guarantee against bias. Overall it appears as if they have a variety of views which are sometimes contradictory.

4.3.2 Comparison of male and female conceptions from the survey Questionnaire

If one looks at the means in Table 4.9 it appears as if both males and females have responded similarly in this strand.

Table 4.9 Comparison between male and female responses within the Science-Society Strand.

Statement number	Gender	N	Mean	Std. Dev.	Std. Error Mean
3	Male	97	3.27	2.104	0.214
	Female	93	3.57	2.024	0.210
4	Male	97	4.71	1.443	0.147
	Female	92	4.80	1.499	0.156
6	Male	94	4.86	1.976	0.204
	Female	93	4.70	2.031	0.211
7	Male	96	2.83*	1.808	0.184
	Female	93	2.85*	1.681	0.174
11	Male	97	2.79*	1.620	0.164
	Female	93	2.71*	1.536	0.159
12	Male	96	5.38	1.932	0.197
	Female	93	5.31	1.032	0.211
13	Male	97	4.67*	2.135	0.217
	Female	92	4.87*	1.974	0.206
14	Male	96	3.14	2.145	0.219
	Female	92	3.27	2.307	0.240
16	Male	95	4.89*	1.882	0.193
	Female	89	5.52*	1.617	0.171
24	Male	95	3.82	1.798	0.184
	Female	92	4.03	1.530	0.159
25	Male	92	4.63	1.642	0.171
	Female	90	4.60	1.389	0.146

* reverse coded

A t-test has revealed a statistically significant difference in responses between males and females for statement 16 (t = -2.397, df = 182, p = 0.018). As mentioned earlier the scores for this statement were reversed. Females (M = 5.52, SD = 1.617) agreed more strongly than males (M = 4.89, SD = 1.882) that scientists need to communicate with other scientists. Nevertheless both genders conceptions represent contemporary views.

It is interesting to note that females have agreed with males that women tend to make similar scientific discoveries as men. In contrast C2005 and the scientific community propose that women are capable of and make different scientific discoveries compared to men because of their differences in nature and upbringing.

4.3.3 Comparison of different cultural groups' conceptions from the survey questionnaire

Looking at the mean responses from table 4.10 it seems as if both groups have responded similarly for each statement in this strand. However a t-test has shown that there were statistically significant differences for statement 3 (t = -2.125, df = 188, p = 0.035) and statement 13 (t = 2.070, df = 187, p = 0.040) between the two cultural groups in this strand. Both groups did not match the contemporary view that scientific research is informed by community and government agencies (statement 3). It appears that Indian learners showed stronger disagreement (M = 3.23, SD = 2.079) than Black learners (M = 3.96, SD = 1.946). Both groups disagreed that press announcements should be made prior to discussion with other scientists (statement 13) which represents a contemporary view. However, it seems Indian learners showed stronger disagreement (M = 4.94, SD = 2.083) than Black learners (M = 4.23, SD = 1.891). For other statements in this strand the responses provided by both cultural groups mirrored those given by all learners.

Table 4.10 Statistics for different cultures within the Science-Society Strand.

Statement number	Race	N	Mean	Std. Dev.	Std. Error Mean
3	Indian	142	3.23	2.079	0.174
	Black	48	3.96	1.946	0.281
4	Indian	141	4.79	1.453	0.122
	Black	48	4.67	1.521	0.219
6	Indian	140	4.76	2.021	0.171
	Black	47	4.85	1.956	0.285
7	Indian	141	2.85*	1.781	0.150
	Black	48	2.81*	1.633	0.236
11	Indian	142	2.76*	1.575	0.132
	Black	48	2.73*	1.594	0.230
12	Indian	142	5.25	2.109	0.177
	Black	47	5.62	1.497	0.218
13	Indian	142	4.94*	2.083	0.175
	Black	47	4.23*	1.891	0.276
14	Indian	141	3.13	2.223	0.187
	Black	47	3.43	2.224	0.324
16	Indian	140	5.21*	1.729	0.146
	Black	44	5.14*	1.960	0.295
24	Indian	141	3.98	1.641	0.138
	Black	46	3.76	1.766	0.260
25	Indian	137	4.72	1.490	0.127
	Black	45	4.31	1.579	0.235

* reverse coded

4.3.4 Learners' conceptions from the open format science scenarios

There were three scenarios from the open format questionnaire that pertained to the Science-Society strand. The first scenario referred to genetic engineering research and who should make decisions as to whether this research should be pursued. Most learners (20) indicated that scientists together with the public should make the decisions as to whether genetic engineering research should be conducted. There were 12 males and all females (8) who made this choice. There were four male learners who responded that only scientists should make these decisions whilst there were none that selected the public only.

Learners who responded that both scientists and the public should be involved in the decisions wrote about sharing ideas to make an informed decision. They used the words, 'both discuss', 'debate the issue', 'sharing of ideas', 'take their views or ideas', 'discuss these ideas', and 'bring about ideas' to express this. However the reasons given by many learners as to why they should share ideas were vague. This is supported by the following response:

> I feel that the scientist and the public should work together so that we have on one side the public learning and giving their views, the other side we have scientist taking into account the public's view. So by this we'll get a better end result. (learner 10)

In retrospection interviews would have assisted in probing responses further however this was not used as a method of data collection. Nevertheless responses that could be interpreted indicated that decisions would be informed if the discussions took into account risks and benefits. Learners used words like, 'advantages and disadvantages', 'good or bad', 'benefit or harm', 'benefits and limitations', positive and negative points', and 'consequences' to refer to risks and benefits as exemplified by the following response:

> The public could help because they will consider all the facts and consequences of the scientific research. The scientists together with the public can predict what will happen and the outcome of it. The public will take the positive and negative points into consideration. The public will also put pressure on the scientists to ensure that the evidence is correct. (learner 21)

A few learners also wrote about moral issues as typified by the response, "Scientists know what they are doing but should also consult with the public to consider possible consequences. Scientists have greater understanding as to whether something will work. The public can decide if it is right or wrong" (learner 15).

The four learners who selected scientists should make the decisions held a more positivist view of science. This is supported by the following response:

> They have a better understanding on what to test and do research on. Scientists can distinguish whether their research is going to be useful to humanity. By them testing things they will know what the outcome is and be able to announce it to the public. Scientists are doing things to have better understanding of the effect on the environment. (learner 3)

They believe that scientists should merely inform society of their results and not involve them in any decisions. These learners also inferred that scientists are objective and unbiased people with expert knowledge.

The second scenario (scenario 1.3) in this strand referred to a team of genetic engineering researchers and the effect of scientists' religious beliefs on research. The purpose of this task was to acquire learners' views on whether scientists' personal values influenced decisions about scientific research. A large number of learners (18 out of 24) indicated that a scientist's religious beliefs should not influence the type of research undertaken. There were 7 females and 11 males who were of this opinion. This corresponded with the findings for statement 7 from the survey questionnaire. Learners used phrases like 'should be fair', 'should not be narrow-minded', 'should not be ruled by emotions' and 'cannot contain biasness' in their responses. They presented scientific inquiry as being value free as typified by the following response, "Science is something that cannot contain biasness. Everything has to be based on fact and not people's personal issues. Religious beliefs may come in the way of what's right or wrong" (learner 12). This view is associated with statement 11 in the survey questionnaire where 71% of learners agreed that scientists are objective and unbiased. Also learners were of the view that personal values prevented the progress of science. This is evident form the phrases, 'hold back scientific research', 'stop a lot of research', and ' get in the way' which appeared in learners responses. This group of learners clearly held a more positivist view as typified by the following response:

> Science is about research and knowledge with practical applications. One can't bring his/her personal beliefs into it. Every scientist is entitled to his or her opinion and ideas but it is based on science only and not religious beliefs. In some

> cases religious beliefs hold back scientific research and give the public the wrong impression. Science is here to improve our living or life, not to hold it back.
> (learner 20)

According to these learners scientists are considered to be objective, neutral and value-free if not it hampers the quest for scientific knowledge.

A few learners (6 out of 24) who responded that religious beliefs should influence research seemed to have misunderstood the question. They supported their choice in terms of the right to practise religion rather than how it influences research as indicated by the following response:

> Religious beliefs play a key role in one's life and so too in the lives of scientists. Religion should be protected at all costs. If science is so great then it should cater for the beliefs of every religion. Religious beliefs must be protected and respected no matter how much help the research and findings will give. Science must never go against religious beliefs. (learner 2)

Upon reflection I believe that I should have modified this question to get a more focussed answer. Although these learners have acknowledged that science is a human activity they have failed to see the influence religious beliefs have on scientific inquiry.

The third scenario in this strand (scenario three) pertained to the development of a chemical to prevent smoking. Learners had to respond to two parts. The first part was whether the chemical should have been developed. The second part was whether residents should have been notified about the release of this chemical into their drinking water which is an application of science Most learners (21), all females (8) and 13 males, indicated that this chemical should be developed. The general reasons offered for their choice were reducing air pollution and improving personal health as exemplified by the following response:

> It is the best for the environment, as our environment would be polluted with smoke, our air would be cleaner. The chemical also benefits the person as an individual, it could save him from being infected with cancer or lung disease. It is a win, win situation. Everybody gains from it. (learner 8)

A few learners (3 out of 24) who responded that the chemical should not be developed explained their choice with respect to distribution of the chemical rather than why the chemical should not be developed. In other words they provided responses for the second part.

There were 19 learners (8 females and 11 males), for the second part, who responded that the residents should be notified about the chemical being released into their drinking water. This concurred with the findings for statement 12 in the survey questionnaire. In examining all responses three themes emerged namely freedom of choice, safety and, the right to access of information. Learners felt strongly that one is entitled to freedom of information as indicated by the following response:

> The residents have a right to know about what they consume. This will make residents aware of the chemical. Some could be allergic to the substances and it could cause ill- effects to them. If they consume this unknowingly they could be in danger. (learner 21)

They also raised concerns with regard to safety and side effects as typified by the following response:

> The residents probably pay for water to use for domestic activities. They will certainly not appreciate people adding substances to that water without informing them. It is basically unethical and sly. Most residents will be sceptical about this idea since you cannot be 100% sure that there will be no after effects in terms of consuming this water. They would fear for their family's safety and health. (learner 24)

Many learners wrote that it infringed on ones right to choose whether to quit smoking or not as supported by the following response:

> They don't have a right just to put a chemical in water connected to peoples' homes and it is up to the smoker as to whether he/she wants to stop not some scientist who thinks they should stop. These residents deserve to know what is happening and it should be their choice to stop or carry on smoking. (learner 1)

The answers offered showed that learners have confidence in science and are aware of ethical practices required by scientists and the respect for societal constitutional rights in the application of science.

4.3.5 Summary and discussion of the relationship between science and society strand

It seems that learners were divided in that they agreed with some statements and disagreed with other statements in this strand. They agreed with six out of 11 statements in the survey questionnaire. It is apparent that learners in this study held contemporary conceptions of critical peer review and collaboration among scientists. There were a significant percentage of learners that agreed scientists needed to communicate with other scientists and not make press announcements until they have discussed findings with other scientists. This concurs with the findings of Ayayee and McCarthy (1996), Chelin (2003) and Ryan and Aikenhead (1992).

Some responses regarding external factors that affect science were contradictory. While learners agreed that scientists should consult the public they disagreed that community and government agencies should inform scientists what to investigate. In the open format questionnaire learners acknowledged that scientists have a social responsibility. They answered that scientists should "debate" issues and "share" ideas with citizens and respect ones "choice" and ones "right to know".

Learners in this study held a positivist view concerning the effect of scientists' personal beliefs and values on research. Despite a reasonable percentage of learners having agreed that scientific evidence can be biased and that there is no guarantee against bias a significant percentage also agreed of that scientists are unbiased and objective. In their study Ryan and Aikenhead (1992) also reported that a significant percentage of learners discounted the role of private science values. Although a reasonable percentage of learners agreed that personal beliefs and values could result in different interpretations and explanations a similar percentage disagreed that religious views of scientists influence research. Bell et al. (2003) also found all learners in their study ignored personal bias or beliefs of scientists when discussing different interpretations by scientists. A significant number of learners in this study also responded in the open format questionnaire that religious beliefs should not affect scientific research. They believed that scientists are "narrow-minded", biased and subjective if their religious beliefs influenced research. It is apparent that learners in this study did not possess contemporary conceptions of biasness and the influence of scientists' personal beliefs and values in science. Like the findings of Ryan and Aikenhead (1992) learners in this study disagreed that women scientists tend to make different discoveries due to different values, viewpoints, upbringing, etc. Perhaps this is so since teachers and science textbooks still portray the stereotypic image of science as a masculine preserve (Scantlebury, 1998).

There were a few conceptions in this strand where differences existed between groups. A significant difference was that females agreed more strongly than males that scientists need to communicate with other scientists about their work. There were significant differences between Indian and Black learners. Indian learners showed stronger disagreement than Black learners that it is ok for scientists to make press announcements prior to discussing findings with other scientists. Indian learners disagreed more strongly than Black learners that government and community agencies should tell scientists what to investigate. Both cultural groups did not possess a contemporary view on the influence of social and political forces on the scientific enterprise.

This chapter presented and discussed the overall findings of the two instruments namely the Views about Science and the Scenarios of Science used in this study. In the following chapter the limitations and the implications of this study will be discussed.

CHAPTER 5

IMPLICATIONS AND CONCLUSIONS

The purpose of this study was to ascertain what conceptions of nature of science learners have at the beginning of the FET phase. This was achieved by attempting to answer the primary research question, "What are grade 10 Physical Science learners' conceptions of nature of science?" In order to answer the primary research question the study focussed on answering two secondary questions. These questions were:

1. To what extent, if any, are the learners' nature of science views consistent with contemporary views and with those of Curriculum 2005?
2. Do different gender and cultural groups possess different views on nature of science?

A mixed methods approach was used in this study. This entailed using both quantitative and qualitative modes of inquiry to answer the research questions. A descriptive survey was undertaken utilizing seven schools to obtain quantitative data. Learners from these schools were required to complete a structured questionnaire that used a Likert scale to probe their conceptions of nature of science. To map out more fully learners' conceptions of nature of science further qualitative data was collected from a class in one school. Learners in this class completed an open format questionnaire containing six science-based scenarios. What follows is a summary of the main findings with limitations and implications.

5.1 SUMMARY OF STUDY FINDINGS

In this section the findings of this study will be presented as answers to the research questions. It will conclude with answers to the main research question by providing nature of science beliefs of typical grade 10 learners.

To what extent, if any, are the learners' nature of science views consistent with contemporary views and with those of Curriculum 2005?

In general the learners held the following contemporary views of nature of science shared by the scientific community and present in curriculum 2005: Scientific knowledge grows slowly as new evidence challenges existing theories; science has limitations in that it can explain only certain aspects of reality; different cultures have contributed to our understanding of the world and the advancement of science; scientific inquiry is a continual and cyclic process of testing ideas by means of experiments since scientific knowledge has basis in empirical evidence; new science knowledge claims arise from social negotiations among scientists and must undergo critical peer scrutiny.

However closer probing using the open format questionnaire revealed that many learners had mixed or superficial beliefs about the value of African science, the use of creativity for the invention of explanations and models and, the role of society in science. These findings lend some support to the claims of Ayayee and McCarthy (1996), Bell et al. (2003), Dekkers (2006), Lederman (1992) and Ryan and Aikenhead (1992) that learners have few contemporary conceptions although sometimes misguided. Nevertheless the value of African science is not explicitly mentioned in nature of science studies and needs further research.

There were certain conceptions that were clearly not consistent with contemporary views. Firstly, most learners possessed the traditional conception of a single scientific method with experimentation as the only means of explaining observations. A review of the literature has revealed that this perception is pervasive among learners. Secondly, learners did not show clear understanding of the internal and external sociology of science. They exhibited a positivist image for this theme and did not exhibit the contemporary conception that scientists' personal values, discipline-centered values and the demands of society are part of the context of doing science. Similar results were reported in the literature. Thirdly, learners believe that only certain types of scientific knowledge are tentative. The literature shows that this is a common belief among learners. It appears as if our learners hold views very similar to those found throughout the world (Bady, 1979; Bell et al. 2003; Lederman, 1992; Liu & Lederman, 2002; Ryan & Aikenhead, 1992; Tsai, 1999).

Do different gender and cultural groups possess different views on nature of science?

There were differences in views between groups for certain conceptions of nature of science. There were a significant differences between the genders where females seemed to hold more contemporary views for the following aspects: the provisional nature of scientific theories; the multicultural nature of scientific knowledge; systematic testing and replication of results; co-operation and collaboration among scientists. There was a minor difference between the genders regarding hypothesis and predictions and the rejection of new ideas in science. There were also significant differences between Indian and Black learners for certain conceptions of nature of science. Indian learners seemed to have stronger beliefs in the diversity of scientific thinking and the inventive nature (creativity) of explanations and models; critical peer review; the limitations of science in that it cannot answer all questions and, the influence of political and social forces on research compared to Black learners. However Black learners appeared to have contemporary views pertaining to the value of non-western science knowledge compared to Indian learners. There were minor differences between the cultures for hypothesis and predictions in science.

Views of typical learners

Taking the above into consideration what can be said is believed by typical grade 10 physical science learners. They would agree with the scientific community that scientific knowledge grows by being corrected slowly when existing theories are re-evaluated; science cannot explain all observations; new knowledge claims in science arise out of cooperation and collaboration among scientists and are subject to critical peer review; scientific inquiry has an empirical base and involves cyclic critical testing of ideas which value precision, rigor, evidence, logic, and good arguments; different people from different cultures have contributed to scientific knowledge; imagination is used in the planning and conduction of scientific investigations.

They would disagree with the scientific community on the following: There are many methods or scientific approaches to generate reliable explanations for observations; empirical evidence is interpreted based on current scientific practices as well as personal subjectivity due to scientists' values, knowledge, and prior experiences which may result in different interpretations for the same event or observation; science is not value neutral and scientists are no less biased than others are; human creativity and imagination is used in the invention of explanations and theoretical models; African science has also contributed to scientific knowledge;

scientific facts, theories and laws are all tentative; political and social forces (the demands of society) have a strong influence on what scientists research.

When dealing with males and females there would be slight differences in their views. Females would have stronger beliefs with regard to: the tentative nature of scientific theories; the cross-cultural nature of scientific knowledge; repetition to validate results and, collaboration and cooperation among scientists. Indian and Black learners would also have slightly different views. Indian learners would have stronger beliefs about critical peer review of findings, government and societal influence on research, the use of creativity and imagination to invent scientific explanations and models, limitations of science and, the diversity of scientific thinking. Black learners would value both African science and western science while Indian learners would place a greater value on western science.

5.2 LIMITATIONS

This is a small-scale descriptive survey, undertaken in a particular school district that is a historically Indian area. This study was undertaken using only seven schools due to time and financial constraints. Furthermore it was not possible to obtain an equal number of learners from both cultural groups due to school demographics in this area. The contexts of the schools and the background of the learners are specific to this sample and might or might not be the case in other situations. They also have different teachers who might influence this learning outcome differently. It is a limitation that the findings of this study are specific to a particular sample of learners. This sample cannot be said to be representative of all schools and all grade 10 learners in South Africa.

As such the findings may not be generalizable to all science learners within South Africa. However the researcher believes that when teachers read this study it will assist them to plan explicit nature of science instruction to target specific nature of science constructs, be aware of differences between groups of learners and, to explore their learners' conceptions of nature of science.

5.3 IMPLICATIONS

The findings of this research may be relevant to many stakeholders in the education process especially in the secondary school. A literature search has revealed that while there is growing research on teachers' perceptions of nature of science in South Africa (Ayayee & McCarthy, 1996; Dekkers, 2004; Karup et al., 2004; Linneman et al., 2002; Meiring, 1995; Mnisi & Dekkers, 2003; Ogunniyi, 2006) there are limited studies on learners' perceptions (Ayayee & McCarthy, 1996; Chelin, 2003; Dekkers, 2006) of nature of science. This study provides baseline data on what conceptions or alternate conceptions learners have about nature of science. A number of implications arise from this study that needs to be addressed.

This study was undertaken when the second group of learners were experiencing C2005. The philosophy underpinning C2005 was outcomes-based education. The focus was on what learners can do with their knowledge and whether they can use what they know to meet specified outcomes. Furthermore teachers were also required to teach new content. Given that there were many changes from the traditional curriculum teachers were still grappling with how to deal with these areas in the new curriculum. One of the goals of the Natural Science curriculum for all learning outcomes, although not explicitly stated, is the development of informed conceptions of nature of science. It is apparent from the findings that learners in this study had some alternate conceptions of nature of science, which is consistent with many other research studies. Curriculum planners need to be aware that we have not reached all the goals of the new curriculum. Rogan (2004) points out that one of the reasons for not achieving outcomes is a huge gap between the intended and implemented curriculum. The implemented curriculum must be aligned with curriculum policy (Hattingh, Rogan, Aldous, Howie, & Venter, 2005).

Nature of science is a new focus in the South African science curriculum. The rationale for the inclusion of nature of science in the curriculum is that it will equip learners to debate socio-scientific issues so that they can make scientifically informed decisions (Bell et al., 2003; Collins et al., 2001; Lederman, 1999; Thomas, 1997). Moreover it provides a lens for understanding the process in generating science knowledge, how the scientific enterprise operates and, it assists learners in understanding science content (McComas et al., 1998). Teachers need to realise that developing an in-depth conceptual understanding of nature of science will "create a populace that can be considered scientifically literate" (Lederman, 1998, p. 2). However our learners are retaining more positivist viewpoints and many contemporary ideas about science are not present. Furthermore many textbooks still focus on content and either avoid aspects of nature of science or cover them very superficially.

Prior knowledge and experiences of the learner influence their conceptions about nature of science. We need to find out why learners have these alternate or traditional conceptions. Is it because teachers have these views, or is it due to the quality of teaching, or are teachers not focusing on specific aspects of nature of science? Research (Bell, 2001; Dekkers, 2006; Driver et al., 2004, Hammerich, 1998; Johnstone

& Southerland, 2002; Lederman, 1992; Smith & Sharmann, 2008) has shown that an explicit reflective approach to teaching enhances learners' nature of science views. Perhaps we need to change the way we teach and focus on areas where there are alternate conceptions. This will assist teachers to purposely plan instruction that enables learners to actively compare pre-existing conceptions with more informed conceptions of nature of science. McComas (2008) provides examples from various books that teachers may use to teach various aspects of nature of science.

In this study the researcher found that the scenarios gave more insight into learners' conceptions of nature of science than the closed questionnaire. These activities targeted specific aspects of nature of science that required learners to use their view to decide, that is knowledge in action, as opposed to a questionnaire which is more passive. Maybe teachers and researchers need to design instruments like the science scenarios so as to challenge learners' conceptions. Lederman (1992) has pointed out that qualitative instruments help to identify the variety and complexity of learners' perceptions.

5.4 CONCLUSIONS

Nature of science is a new focus in the South African curriculum. This study set out to find what conceptions learners have about nature of science. It is evident from this study that learners have some traditional (positivist views) and some contemporary conceptions. We are succeeding with some aspects of nature of science when learners state that "there is rivalry between the scientists and although one group is right, the other group will still say that it is wrong" but with some we are not, as indicated by a learner who stated that, "scientists should be open-minded in their thinking, religious beliefs and different forms of cultures should not affect science. If you were a scientist, you should not be narrow-minded". There is still scope for improving the quality of teaching and training of teachers so that they can successfully teach contemporary aspects of nature of science. Textbooks contain mainly historical vignettes of science. Textbooks and other curricular materials need to include nature of science activities that compel learners to reflect on their own conceptions of some aspect of nature of science. If these do not occur then understanding the scientific enterprise will remain complex and abstract and our learners will leave school without the contemporary view of nature of science.

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APPENDICES

A Views about Science

B Scenarios of Science

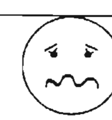
C Letter for Teachers and Learners

APPENDIX A QUESTIONNAIRE – VIEWS ABOUT SCIENCE

NAME:			
MALE/FEMALE:		GRADE:	
SCHOOL:			

VIEWS ABOUT SCIENCE

- The purpose of this questionnaire is to find out *your* views about science.
- Work on your *own*, in silence. There are no 'right' or wrong 'answers'.
- Consider each statement slowly and carefully. You may have to re-read some statements.
- Numbers from +3 to –3 will indicate your *agreement* or *disagreement* with each view about science.
- If you agree with *part* of a statement but disagree with the rest then you must select *disagree*.

						
Very strongly agree	Strongly agree	Agree	Undecided	Disagree	Strongly disagree	Very strongly disagree
+3	**+2**	**+1**	**0**	**-1**	**-2**	**-3**

- Please draw a **circle** around *one* of the numbers that indicate *your view* about the statement.

	STATEMENT	RESPONSE Very strongly **agree** (+3) · undecided (0) · Very strongly **disagree** (-3)
	How do you view scientific investigations and scientific research?	
1	There is a ***fixed set*** of steps that scientists follow in scientific investigations.	+3 +2 +1 0 -1 -2 -3
2	Results can change each time you do the same scientific investigation because of different methods, different materials used and sometimes because the thing being studied actually varies.	+3 +2 +1 0 -1 -2 -3
3	Community or government agencies should tell scientists what to investigate.	+3 +2 +1 0 -1 -2 -3
4	Scientists try to identify possible bias (unfairness) by checking each other's results and explanations but there is no guarantee against bias.	+3 +2 +1 0 -1 -2 -3
5	It is important to do the *same* scientific investigation many times before accepting the results as correct.	+3 +2 +1 0 -1 -2 -3
6	Two scientists can have different explanations and interpretations for the same set of observations because of their background, personal beliefs and values.	+3 +2 +1 0 -1 -2 -3
7	Religious views of scientists DO NOT influence scientific research because scientists will research topics which are of importance to science and scientists, regardless of religious views.	+3 +2 +1 0 -1 -2 -3
8	Scientists have no idea of what will happen in an experiment before they actually do the experiment.	+3 +2 +1 0 -1 -2 -3
9	Scientists use creativity and imagination when doing scientific investigations.	+3 +2 +1 0 -1 -2 -3
10	Scientific discoveries usually result from a logical series of investigations but science is not completely logical. There is an element of trial and error, hit and miss, in the process.	+3 +2 +1 0 -1 -2 -3

	STATEMENT	RESPONSE Very strongly **agree** +3 — undecided 0 — Very strongly **disagree** -3
	How do you view the relationship between science, society and scientists?	
11	Scientists are open-minded, logical, unbiased, objective and honest in their work.	+3 +2 +1 0 -1 -2 -3
12	Scientists should consult the well-versed public when making decisions which affect our society (e.g. producing a chemical which make it impossible for police detecting alcohol on your breath).	+3 +2 +1 0 -1 -2 -3
13	When a research team makes a discovery, it is all right for them to announce it to the press before other scientists have discussed it.	+3 +2 +1 0 -1 -2 -3
14	Scientific discoveries made by women will tend to be different to those made by men because, by nature or by upbringing, females have different values, viewpoints, perspectives, or characteristics (such as sensitivity toward consequences).	+3 +2 +1 0 -1 -2 -3
15	Important contributions to the advancement of science have been made by people from *different cultures* (e.g. African, Indian, Chinese, etc.).	+3 +2 +1 0 -1 -2 -3
16	It is not necessary for scientists to communicate with other scientists about their work.	+3 +2 +1 0 -1 -2 -3
	How do you view science knowledge?	
17	Scientific facts can *never* change but scientific theories *can* change.	+3 +2 +1 0 -1 -2 -3
18	There are certain physical events in the universe that science can never explain.	+3 +2 +1 0 -1 -2 -3
19	Traditional medicine-making can be considered as genuine scientific research.	+3 +2 +1 0 -1 -2 -3
20	In science the testing, revising, and occasional discarding of theories, new and old, never ends.	+3 +2 +1 0 -1 -2 -3

	STATEMENT	RESPONSE						
		Very strongly **agree** +3			undecided 0			Very strongly **disagree** -3
	How do you view science knowledge?							
21	Scientists' explanations about what happens in the world come partly from experimental evidence and partly from creativity and imagination (ie. from what they think).	+3	+2	+1	0	-1	-2	-3
22	Science is one of several ways of knowing about the world. We can also learn about the world through our indigenous knowledge from our culture.	+3	+2	+1	0	-1	-2	-3
23	Scientific models (e.g. the model of DNA or the atom) are not real (ie. not directly observable) but are created by scientists to explain what they think may be happening and to predict observations.	+3	+2	+1	0	-1	-2	-3
24	New ideas in science are often rejected by the scientific community.	+3	+2	+1	0	-1	-2	-3
25	Scientific evidence can be biased (distorted) by the way that data are interpreted, recorded, reported or selected.	+3	+2	+1	0	-1	-2	-3
26	Science knowledge usually grows slowly through contributions from many scientists.	+3	+2	+1	0	-1	-2	-3

Thank you for taking the time to fill in this questionnaire

Any other comments you would like to make on your views about science?

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APPENDIX B **SCENARIOS OF SCIENCE**

NAME:			
MALE/FEMALE:		GRADE:	

- **Please answer each of the following questions after reading each extract.**
- **Some questions have more than one part. Please make sure you have answers for each part.**
- **This is not a test for marks. There are no 'right' or 'wrong' answers to the questions. I am only interested in your ideas relating to each question.**
- **If you require more space for answers write at the back of the page.**
  Remember to correctly number your answers.

1. Read the extract below on genetic engineering and answer the questions.

> Genetic engineering refers to the artificial changing or reshuffling of the genetic code (found in DNA) of a living organism. Scientists can take genes and segments of DNA from one species and put into another species e.g. a piece of fish DNA can be placed into the DNA of a tomato to make the tomato freeze resistant. Plants have been genetically engineered to be drought tolerant (e.g. sugar cane), cold tolerant (e.g. rice), herbicide resistant (e.g. wheat), etc. Human genes are placed in animals (e.g. pigs) as a source of organs for transplantation into humans. Many pharmaceutical drugs (e.g. insulin to treat diabetes) are being produced from g enetically engineered animals. Some people are opposed to the manipulation of genes, as they fear possible health and ecological repercussions in the future although there have been no ill effects as yet. Others are in favour of it since it also offers the treating, and maybe even curing of human genetic disorders such as muscular dystrophy (weakening and wasting of muscles), haemophilia (failure of blood to clot normally), etc.
>
> (Adapted from Root Yourself in Africa, No. 3, 2004)

1.1 Whom do you think should be involved in <u>making the decisions</u> as to whether scientists should carry out or not carry out genetic engineering research? (Scientists only, public only, scientists together with the public) NB. The <u>public</u> refers to all people who are <u>well informed</u> about scientific research.

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1.2 Provide reasons for your choice in (1.1).

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1.2 A team of genetic engineering researchers were involved in break-through research in Parkinson's disease (disease of the human nervous system). A key scientist in the research team claimed, "we are not here to play god, we must leave living things as they naturally are". As a result of her religious beliefs she convinced the other scientists on the team to stop their research on Parkinson's disease and pursue other research which was not in conflict with her religious beliefs.

1.3.1 Do you think a scientist's own religious beliefs should influence what type of scientific research is undertaken?

(*Yes / No*) ______________________

1.3.2 If yes why, if no why not?

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NAME:		
MALE/FEMALE:		GRADE:

2. Read the extract below and answer the questions that follow

> The manufacturers of a washing powder "Nu-clean" state that it is 'scientifically proven' to make clothes cleaner. Another brand of washing powder "Brighter" states on its packaging (box) that it is 'proven' to make clothes cleaner.

2.1 What does 'scientifically proven' mean to you as compared to 'proven'?

2.2 If you were to choose between the two brands of washing powder, which would you choose?

2.3 Give reasons as to why you would choose this brand of washing powder?

NAME:			
MALE/FEMALE:		GRADE:	

3. Read the extract below and answer the questions that follow

A group of scientists have developed a chemical (tasteless, odourless and with no side effects) that will stop people from smoking tobacco. They have decided, with permission from the relevant authorities but unknown to you, to put this chemical (undetected in water) into your suburbs drinking water.

3.1 Do you think they should have developed this chemical? (*Yes / No*)

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3.2 Provide reasons for your answer in (3.1).

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3.3 Should they have notified the residents in your suburb about their plans to put this chemical into your drinking water? (*Yes / No*)

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3.4 If yes, explain why they should have notified the residents and if no, give reasons as to why they should have not notified the residents.

NAME:			
MALE/FEMALE:		GRADE:	

4. Read the extract below and answer the questions that follow

> The spiny hoodia plant has for generations, been traditionally used by the Kalahari San people for its medicinal properties. The San chew slices of the bitter hoodia plant to ease stomach pains, fatigue, and hangovers. It is also used to stave of hunger and thirst on long hunting trips. The hoodia plant is believed to have appetite-suppressing compounds. This San knowledge is community owned and is handed down from generation to generation.

4.1 Do you consider this knowledge of the San as scientific knowledge?

(*Yes / No*) ____________________

4.2 Give reasons for your choice of answer in (4.1).

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4.3 If this knowledge appeared in school science textbooks, would you view this as scientific knowledge? (*Yes / No*)

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4.4 Provide reasons for your answer in (4.3).

4.5 Would you consider this San knowledge as valuable knowledge?
(*Yes / No*) ______________________

4.6 Why?

NAME:		
MALE/FEMALE:		GRADE:

5. Read the extract below and answer the questions that follow

> Approximately 65 million years ago the dinosaurs and all other large creatures on both land and in the seas became extinct. Many suggestions have been put forward to explain the cause for the extinction. In the early 1980's geologist Walter Alvarez, son of Nobel prize-winning physicist Luis Alvarez, discovered a layer of clay deposited during the period of the dinosaur extinction, in an Italian town. The clay contained strange concentrations of iridium. Extraterrestrial rocks (from outer space) such as meteorites were known to contain high concentrations of iridium. This led to the suggestion by Luis Alvarez that a huge meteorite hit the earth. Some scientists claim such an impact would have caused a dust cloud that blocked out sunlight for years, stopping plant growth and killing all large species of animal life including the dinosaurs. Other scientists have suggested that a series of volcanic eruptions could have caused the same effect while throwing iridium from deep within the earth into the atmosphere.
>
> (Adapted from The Nature of Science in Science Education, pg. 262, 1998)

5.1 Is it possible that these scientists are wrong? (*Yes / No*)

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5.2 Explain why? (Do not merely quote from the extract.)

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5.3 Often scientists reach different conclusions when they are looking at the same information and data (as in the dinosaur extinction). Why do you think scientists make these different conclusions?

APPENDIX C LETTER FOR TEACHERS AND LEARNERS

To the Physical Science Teacher

Thank you for participating in this research project. Your time and effort is well appreciated. Learners will take about 35 to 40 minutes to complete the questionnaire. Please hand all completed/incomplete/partially completed questionnaires to the Head of the Science Department (HOD). If learners wish not to participate please allow them to do so. Before commencing with handing out the questionnaires please read the following to the learners.

Dear learners

- The purpose of this research is to collect your views on science and by participating in this study you would be contributing to a collection of data on South African learners' views on science.
- Although the findings of this study would be made public your names would not be used when reporting the results.
- Your participation is voluntary. If you decide to participate you can at any time withdraw from the study if you chose to do so.
- Please direct questions to your teacher if you are unsure about the procedures.
- Read the instructions carefully before you start.
- Your efforts are well appreciated.

Regards

Anand Moodley