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Pupil's and teachers' views about the nature of science

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Bacon's ideas have been modified and improved by some and contested by others over the centuries. *Logical positivism,* which evolved from empiricism, has two important tenets, namely, observation and deductive logic in reasoning. As with empiricism, knowledge is considered as objective and reliable (Chalmers, 1983).

Two main criticisms have been levelled against the inductivist account. Firstly, there can be no such thing as innocent, unbiased observation. What an observer sees depends in part on what is really there and in part on the observer's past experience, knowledge and expectations (Hodson, 1982). Secondly, an inductive argument is not logically valid. Popper (1980, 29) lends weight to this claim when he contends "...that a principle of induction is superfluous, and that it must lead to logical inconsistencies". In spite of such criticisms, inductivism has in the past had a very strong influence on science curricula in Britain and America (Hodson, 1982; Finley, 1983).

In response to these criticisms, Popper suggests that science does not start with stark observations but with a pre-conceived idea, hypothesis or with a "...problematic observation in the light of some theory" (Chalmers, 1983, 46). Although Popper has been identified with a philosophy known as *logical empiricism* (Richards, 1983), his views have been so overwhelming that its adherents have become known as *falsificationists* (Chalmers, 1983). Falsificationists believe that science proceeds by trial and error until it arrives at a theory which satisfactorily explains the evidence. To quote Popper (1963, 51),

> there is no more rational procedure than the method of trial and error - of conjecture and refutation; of boldly proposing theories; of trying our best to show that these are erroneous; and of accepting them tentatively if our critical efforts are unsuccessful.

Popper labels this attempt to disprove "falsifiable" theories falsification. He contends that scientific theories cannot be verified but can be shown to be false. When theories are not falsified, their confirmation should be accepted as tentative. The idea of tentativeness of scientific knowledge has its roots with the falsificationists (Popper, 1963).

Popper's ideas are not free from difficulties. If theories are to be falsified on the basis of new observations, such observations can also be shown to be fallible. In other words, statements which form the "basis for the falsification are themselves suspect" (Hodson, 1982, 113). In addition, evidence from history does not lend support to the methodologies advocated by falsificationists. This evidence suggests the need for a different, more complex account of science and its development (Chalmers, 1983).

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND TO THE PROBLEM

"Was the electron discovered or invented"? (STEP, 1974).

Providing a scientifically acceptable answer to the above poser may not come easily for many science students. Their answers will make demands on their conceptions of the nature of science. What then is meant by the nature of science?

Many definitions of the nature of science are found in scientific literature. According to Lederman and Zeidler (1987, 721), it may refer to the "values and assumptions inherent to the development of scientific knowledge"; values such as whether or not scientific knowledge is amoral, tentative, empirically based, a product of man's creativity, or parsimonious. The National Science Teachers Association of America (N.S.T.A) (1964, cited in Carey and Stauss, 1968) describes the nature of science as comprising three areas, namely, knowledge, modes of enquiry, and human endeavour. Herron (1977, 30) has referred to it as a learner's "value system" which is implicitly conveyed via the teacher's classroom behaviour.

The above views suggest that the nature of science incorporates the nature of scientific knowledge (including its generation, characteristics and limitations) as in science, and how science is practised. The various conceptions of the nature of science and their influence on science curricula are briefly considered.

1.1.1 Philosophy of science

The beliefs about the nature and philosophy of science have changed throughout history. Abimbola (1983) suggests that for science education, a relevant starting point in the history of the modern philosophy of science is with *classical empiricism* and the ideas of Francis Bacon (1561-1626). This philosophy suggests that the basic method of generating knowledge is by *inductivism*. According to the inductivist view, scientific knowledge starts with simple, unbiased observations. From these singular observations, generalizations and theories can be formed provided certain conditions are met.

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DECLARATION

I declare that this research report is my own unaided work, unless otherwise acknowledged. It is being submitted for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Ellis Koe Ayayee

23rd day of November, 1995

ABSTRACT

This study investigated pupils', student teachers' and teachers' views about the nature of science. The "nature of science" includes the nature and generation of scientific knowledge, its characteristics and limitations, values in science, and how science is practised.

A convenience sample of 47 Std 10 physical science pupils, 14 pre-service teachers, and 20 teachers from institutions in Johannesburg were involved in this descriptive study. An opinionnaire based on an existing instrument, "Views on Science-Technology-Society" (VOSTS) was developed and administered. It consisted of 13 multiple-choice items. Propositional knowledge statements which summarized current viewpoints held by scientists and philosophers of science were used to categorize the views of the respondents into various positions.

Generally, the positions selected by the majority of pupils were quite similar to positions chosen by practising teachers. Pupils and teachers defined science as consisting of facts and processes. The majority of them also believed 'a' scientific method existed. This position supports a positivistic view. The common but erroneous view among the three groups was that hypotheses mature into theories which later mature into laws. The student teachers generally had a better understanding than the practising teachers of some aspects of the nature of science. One possible reason for this is the positive influence of a newly introduced methodology course in the philosophy of science on the students' understanding of the nature of science.

The results of this study confirmed findings of research in other countries that pupils and teachers have inadequate conceptions about the nature of science.

The implications of these findings for curriculum development and teaching practice are also considered.

PUPILS' AND TEACHERS' VIEWS ABOUT THE NATURE OF SCIENCE

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consensus forms and it becomes unproductive to launch further challenges (Stanley and Brickhouse, 1994).

2.1.5 Multicultural perspectives on knowledge validation

According to Reiss (1993), science has been portrayed in textbooks and in the classroom as a product of western culture and not as a universal human activity. He finds this positivistic view problematic and suggests it should be corrected. Stanley and Brickhouse (1994) believe that if scientific knowledge is validated by a team of inquirers, it is important that such a group should represent people of diverse cultures. They propose such a group should have, among other things, the capacity to generate and consider various possibilities for understanding and determining knowledge. They contend that western scientific frameworks cannot provide a universal position, as it is only one perspective among many others. Multiple perspectives should be considered and seen as a rich resource for science and science education.

2.2 THE PHILOSOPHICAL BASIS OF CURRICULA

In a bid to maintain world supremacy in science and technology, new curricula were introduced in schools in the United States of America in the early 1960's (Yager, 1982). However, the curricula innovations did not fully achieve their desired purpose. A crisis in science education developed about twenty-five years after the national effort to upgrade the quality of science curricula and instruction. The crisis was characterized by a general discontent with science education, and with falling numbers of pupils enrolling into science (Yager, 1982). Duschl (1985) and Hodson (1988) contend that the science curricula were not satisfactorily developed by the National Science Foundation (NSF). The theme underpinning the NSF sponsored curricula was "to learn by doing" which eventually became known in science education as "science by enquiry" (Duschl, 1985, 548).

It has been observed that at a time when curricula innovations were being effected (1958-1966), equally rapid changes were occurring in the philosophy of science (Abimbola, 1983; Duschl, 1985). For example, according to Martin (1972, cited in Duschl, 1985) as the notion of enquiry as presented in the NSF curricula was being soundly rejected and replaced with new notions in

2.1.4 How does science progress?

Popper and Kuhn seem to have divergent opinions about how science progresses. Whilst Popper believes that scientists discover the truth about nature by approaching it closer and closer, Kuhn thinks the answers are not so simple. He believes that unless the approach to truth is defined as the result of what scientists do, we cannot recognise progress towards that goal (Kuhn, 1970). This view seems to have caused Kuhn to be regarded by Stove (1982) and others as irrationalist.

Popper, with his universalist view of science, claims that the ontological physical world itself judges the validity of a scientific account of that world, and that this account is unrelated to such things as human interest, culture, gender, race, class ethnicity or sexual orientation (Stanley and Brickhouse, 1994). Although falsificationism appears to support the idea that the acceptance or rejection of a theory depends at least in part on scientists' decisions, Popper (1980) denies that this process reflects the culture or interests of the decision makers. He claims such methods are universal, rational and independent of particular human interests or the cultural characteristics of scientists. Furthermore, he asserts that without universal standards for making such decisions, we will have no way to judge or determine if one description of reality is better than any other. To the "new" philosophers, there is nothing universal about such methods as they are subject to ongoing reconsideration and reconstructions as the group of scientific enquirers changes (Stanley and Brickhouse, 1994). To the "new" philosophers of science, the activity of modern science is rooted in the community of scientific inquirers and as a result we cannot have any unmediated access to reality. We can only establish scientific knowledge through the interpretative efforts of those engaged in scientific inquiry (Stanley and Brickhouse, 1994).

Social constructivism, an offshoot from the Kuhnian perspective, provide further insight as to how scientific knowledge is constructed. Stanley and Brickhouse (1994) cite Latour (1987) and Longino (1983) as the most representative of this position. They maintain that because science is done by human beings who are inevitably influenced by ethical, ideological and cultural values, the claims which are put forward as facts must have been previously affected by their contextual values. The social constructivists, according to Stanley and Brickhouse (1994), further argue that individual scientists do not produce facts but *construct claims*. Such scientists then work to sustain their claims in the face of challenges through judicious modification and the marshalling of appropriate technical, rhetorical and social resources. The claim becomes a fact when a

Two phases of science are postulated: normal science and revolutionary science. The normal science phase is considered a period of relative calm in which the fundamental assumptions of a discipline are accepted without question. The type of activity scientists engage in, and the techniques used, are considered fairly routine, much like "puzzle solving" (Kuhn, 1970a). The overthrow of the paradigm is *initiated* when it is unable to provide adequate answers to problems that arise. The final overthrow may take time but will occur when a rival paradigm is able to account for the discrepancies that beset the older paradigm. The new scientific thought coming into dominance may be based on quite different and even "incongruous principles and axioms" (Toulmin, 1970, cited in Abimbola, 1983) so as to make impossible scientific communication between periods (Kuhn, 1970a). This incommensurable nature of scientific paradigms, as it is called, also makes observational data taken from the two periods to be different. In summary, the stages involved between two successive periods of normal science are: normal science, crisis, revolution, and new normal science.

Even though criticism of the "new" philosophy of science has been made by its proponents, such criticisms have been levelled as a means of shedding further light on the philosophy (Abimbola, 1983). For example, Abimbola notes that Toulmin (1970) believes "revolution", as a political term, has long since worn out its value as an explanatory concept. From a historical perspective Toulmin has taken the "incommensurability of paradigms" to task and argued that political change has never involved absolute and outright breach of continuity. The term "paradigm" has also been criticized as having multiple, and therefore vague definitions (Masterman, 1970). In response to such criticisms, Kuhn (1970a, 1970c) has elaborated on his notion of paradigms and identified two very different usages of the term "paradigm": the conceptual level of individual scientists; and the social level of a scientific community. Kuhn (1970a) has also advocated the use of the term "disciplinary matrix" to connote group commitments of scientists.

Rubinstein et al. (1984) have explicated the various meanings of paradigms and their functions at the individual and community levels. To the individual scientist, a paradigm represents his conception of an aspect of science. At the social level, a paradigm or disciplinary matrix may be seen as the world view of a given scientific community that governs not a subject matter but rather a group of practitioners. Such a community may be defined in various ways: "...by discipline, by membership in a specialized area of work, or by explicit commitment to an approach to investigating a significant problem" (Rubinstein et al., 1984, 63).

Falsificationists consider it easy to obtain confirmations or verifications for nearly every theory; what is therefore important is to be able to refute a theory. According to Popper (1980), scientific statements do not *have* to be tested before they are accepted, but they must be *capable* of being tested or falsified. Although scientific statements are never in theory fully justifiable or verifiable, Popper (1980, 44) considers scientific statements objective if they can be "inter-subjectively tested". This will involve other investigators independently testing and understanding them. A statement which cannot be refuted by any conceivable event is considered non-scientific. The criterion for what counts therefore as a scientific theory is not its testability but its falsifiability or refutebility (Popper, 1980).

2.1.3 The "new" philosophy of science

Abimbola (1983) points out that the basic themes of the "new" philosophy of science are woven around the ideas of Kuhn (1970a). Some of the philosophers and scientists, who Abimbola (1983) suggests are identified with this new approach are Lakatos (1970), Toulmin (1970) Feyerabend (1970), and Brown (1977). Contrary to positivism, this "new" philosophy rejects formal logic as the primary tool of analysis of science. In its place it relies on the detailed study of the history of science for its analysis (Kuhn, 1970; Brown, 1977).

The objectivity in perception which has characterized positivism is no longer held in high esteem by supporters of the 'new' philosophy of science. Perception is seen to be influenced to a great extent by the knowledge, beliefs and theories we hold. Thus, science cannot be presumed to be free from unfounded speculation or the influences of tradition (Cawthron and Rowell, 1978). Science is essentially seen to represent a human activity with "no neutral observation language" in which scientists aim to invent theories that explain observed phenomenon (Kuhn, 1970b, 2).

The "new" philosophy rejects the view that science progresses by accretion, and instead proposes that science is organised around a paradigm (Kuhn, 1970a). (A paradigm may be considered in this context as an accepted world view of a scientific community that frames the scientific activity for some time) Scientific progress is seen to occur when one paradigm is relinquished and an incompatible alternative is accepted. The replacement of the older paradigm is usually because it is unable to meet challenges posed by logic, experiment or observation (Kuhn, 1970).

Even though researchers agree there is no unified conception of what positivism embodies, some of its major assumptions have continued to be the target of criticisms. Stanley and Brickhouse (1994) list some of the tenets as follows:

a) the assumption of a single, tangible reality that can be studied independently;
b) a correspondence theory of truth, in which 'truth' is defined as knowledge that matches reality;
c) the language of science is exact and literal, therefore meanings are universal;
d) the assumption that experience is taken to be objective, testable and not influenced by theoretical viewpoints;
e) the assumption of value free method and the separation of facts and meanings; and
f) a verificationist method of justification.

Kemeny and Oppenheim (1970, cited in Abimbola, 1983) complete the list of tenets with the following:

g) Scientific knowledge increases by accretion.
h) Observations remain the same during scientific revolutions. A new theory is only an improvement over the old, as it takes into account more observations.

The effects of some of these assumptions on science curricula development are discussed in section 2.2.2.

2.1.2 Falsificationism

Popperian philosophy or falsificationism (Chalmers, 1983) is regarded as a transitional doctrine between logical empiricism and the new philosophy of science (Abimbola, 1983). Some of the tenets of falsificationism are (Popper, 1970):

a) the reliance on the study of the history of science for an analysis of science;
b) the rejection of the view that science progresses by accretion (Kuhn, 1970a);
c) the assertion that for scientific statements to be valid and acceptable they must be testable;
d) the assumption that scientific knowledge is provisional;
e) the acceptance of falsification as the process of establishing scientific knowledge.

CHAPTER 2
LITERATURE REVIEW

The literature under review on the nature of science is considered under three broad sections: The first section deals with views about the nature and philosophy of science as held by scientists and philosophers of science. The second section examines the philosophical perspectives that underpin some of the existing science curricula. The final section deals with the literature on pupils' and teachers' conceptions of the nature of science, and curric developments which attempt to influence their conceptions about the nature of sci...

2.1 THE NATURE AND PHILOSOPHY OF SCIENCE

Throughout history, philosophers and scientists have tried to describe how science acquires and validates reliable knowledge and understanding of the world. Some of the major philosophies have been classical empiricism, positivism, logical positivism, logical empiricism and the "new" philosophy of science (Abimbola, 1983).

Classical empiricism, associated with the ideas of Francis Bacon, recognises the importance of experimentation in order to reveal more about nature than would observation. Positivism is understood as a severe or austere form of empiricism (Lincoln and Guba, 1985). According to Hacking (1983), some of the philosophers with a positivistic frame of mind were Hume (1739), Comte (1830-1842), and Van Fraassen (1980).

The themes of three major philosophies that continue to influence science education namely, positivism, falsificationism and the "new" philosophy of science, are considered below.

2.1.1 Positivism

Positivism, as a family of philosophies with an extreme view of science and scientific method, has been the focus of critique for more than a century (Stanley and Brickhouse, 1994). One of the major criticisms levelled at it is its failure to provide an adequate conceptualization of what science is (Hesse, 1980, cited in Lincoln and Guba, 1985).

tools for thinking. Individuals with the anti-realist frame of mind who deny that theories are to be taken literally are said to have the *instrumentalist* perspective (Hacking, 1983).

1.8 ABBREVIATIONS

The following abbreviations are used in this study:
TED: Transvaal Education Department. This was one of 16 education departments in the "old" South Africa.

DET: Department of Education and Training. This department was responsible for black education in the "old" South Africa.

Std: Standard. The 12 years of schooling in South Africa consists of grades 1 and 2 and Stds 1-10. Primary schools usually include grade 1 to Std 5, and secondary schools Std 6 to Std 10. The matriculation examinations are taken at the end of Std 10.

1.9 DELINEATION OF THE STUDY

Clearly, South Africa at the time of this study in 1994 was in a state of transition, and this is reflected in the nature of schools. Pupils from a traditionally white, but currently multi-racial, government school in Johannesburg were sampled. Traditionally black schools under the Department of Education and Training (DET) were not used because such schools had been disrupted for a period of several years. It was therefore unlikely one would get views of pupils who had closely followed the science and biology curricula.

1.10 LIMITATIONS OF THE STUDY

As the samples were relatively small and not randomly selected, claims about the generalisability of the results cannot be made by the researcher. However, it is hoped that the details provided will allow the reader to determine the transferability of the information (Lincoln and Guba, 1985).

1.6 RESEARCH METHODS

A descriptive study was used to explore the views of pupils, student teachers and practising teachers in the greater Johannesburg area about the nature of science.

The sample consisted of the following: forty-seven Std 10 physical science and biology pupils from a government school in Johannesburg; fourteen BSc graduates who were studying biology and/or physical science methodology courses in preparation for their Higher Diploma in Education; twenty practising physical science and biology teachers from five government schools in the greater Johannesburg area.

An opinionnaire based on an existing instrument, "Views on Science-Technology-Society" (VOSTS) (Aikenhead and Ryan, 1992) was developed and administered.

Propositional knowledge statements which summarized current viewpoints held by philosophers of science and scientists were formulated and used to categorize the views of the respondents into various positions. The results were recorded in tables and graphs, and quotations were used to convey answers to the free-response questions.

Details of these methods are included in Chapter 3.

1.7 EXPLANATION OF TERMS

Epistemology of science according to Bullock and Stallybrass (1977), is the philosophical study of scientific knowledge, which seeks to define and distinguish its principal varieties. Scientific realism is a movement within the epistemology of science. According to Hacking (1983), advocates of *realism* believe that the entities, states and processes described by correct theories really do exist (e.g. protons, photons, field of force). Such advocates are described as realists or are said to hold the *ontological* perspective (Ryan and Aikenhead, 1992).

Opposed to this viewpoint is anti-realism. Advocates believe there is no such things as electrons, etc. Such entities, they maintain, are socially constructed fictions, and theories about them are

According to Hurd (1960, ited in Lederman, 1992), its earliest occurrence in the American syllabus was in 1920. It was regarded then as necessary to better train the mental faculties of students (Lederman, 1992). More recently it was advocated that an adequate conception of the nature of science was necessary if scientific literacy was to be achieved in the population (AAAS, 1989, cited in Lederman, 1992).

Science, including physical science and biology, is being taught to pupils in South Africa and yet the curricula do not attempt to develop pupils' conceptions about the nature of the discipline. It is likely that any views pupils currently hold about the nature of science have been developed implicitly in class, and through media and everyday experience. As efforts are now underway to develop a national science curriculum for a new democratic South Africa, it is appropriate to assess the views of pupils and teachers about the nature of science. This will facilitate the development of a more relevant and philosophically valid curriculum and allow any problematic ideas about science that may emerge during this study to be addressed in the new curriculum.

The knowledge gained from this study will hopefully guide teachers and educators in the design of science lessons and syllabi which will facilitate the development of authentic conceptions of the nature of science.

1.5 RESEARCH QUESTIONS

a) What views do Std 10 physical science and biology pupils at a government school in Johannesburg have about the nature of science?

b) What views do physical science and biology student teachers at the University of the Witwatersrand have about the nature of science?

c) What views do practising teachers in selected government schools in the greater Johannesburg area have about the nature of science?

of pupils from all racial groups, and reduced interest and disengagement by most girls in the sciences (SAATPS, 1978; HRSC, 1981; Levy, 1989) These problems have led to the persistent technical manpower shortages in industries (Cooper, 1993).

While many countries are experiencing a renaissance in terms of the philosophy of science in education (Matthews, 1990), it appears that the South African situation is not as promising. Two problems exist: Firstly, the current school physical science and biology curricula do not explicitly address the nature of science. Secondly, as far as the researcher is aware, no research has explored teachers' views about the nature of science in South Africa and little has been done in this field involving pupils. Notable exceptions are research by Parker and Rochford (1995) and Laugksch and Spargo (1995).

1.3 PURPOSE OF THE STUDY

The purpose of the study was to describe the views held by the following selected pupils and teachers in Johannesburg about the nature of science:

a) Std 10 physical science and biology pupils who had been exposed to the current curricula;
b) pre-service physical science and biology teachers who had completed a BSc degree and were nearing completion of their Higher Diploma in Education. It was expected that all lectures linked to the nature of science would have been completed by the time the instrument was administered;
c) physical science and biology teachers with one or more years of teaching experience. This would hopefully reveal whether teaching experience influences or modifies the views of teachers about the nature of science.

1.4 IMPORTANCE OF THE STUDY

The development of adequate conceptions of the nature of science has been an important objective of science curricula in several overseas countries for many years (Lederman, 1992).

Matthews (1990) has also highlighted the problems of science education in the 1980's in many western European countries such as Britain, Germany, France, Italy and Denmark. The problems include: the "alarming flight" from science education by pupils, failure of science education to develop scientific understanding with science illiteracy rated at 90 per cent of the general population, the existence of "massive" misconceptions, and poor understanding of science among science pupils (Matthews, 1990, 227). The school science curricula in these countries were blamed to a large degree for these inadequate conceptions held by pupils and teachers (Abimbola, 1983; Hodson, 1988). The curricula were alleged to be outmoded in terms of the philosophy of science underpinning them and thus they presented a distorted image of science (Hodson, 1988).

Clearly something had to be done to address the problems and there was good reason to believe that research could provide the needed answers. The search for solutions led to a re-awakening in the late 1980's across Europe and U.S.A to the importance of studies in the nature and history of science as a contributory solution (Matthews, 1990). Consequently, many lines of research emerged with some science educators focusing attention on students' and teachers' conceptions of the nature of science. Others sought for relationships between teachers' beliefs, classroom practices, and students' conceptions of the nature of science (e.g. Lederman and Druger, 1985; Lederman and Zeidler, 1987; Brickhouse, 1990). Another line of research has been to develop new curricula and use them to improve pupils' conceptions (e.g. Hodson, 1988). Abimbola (1983), Hodson (1988), and Solomon et al. (1992) have called for a more contemporary approach to the teaching of science. Such an approach should incorporate the historical and philosophical dimensions in the development of scientific knowledge.

Based on the research findings of the late 1980's, various countries including America, Britain and Denmark have included history and philosophy of science topics in their science curricula (Matthews, 1990; Solomon, 1991).

1.2 STATEMENT OF THE PROBLEM

Science education in South Africa faces similar problems at the secondary school level to those cited above. Research findings indicate there is the avoidance of physical science by a majority

The "new" philosophy of science is the most contemporary view of science and a number of philosophers and scientists, including Kuhn, Lakatos and Feyeraband are identified with this viewpoint. According to Abimbola (1983), their main claims are as follows:

a) The knowledge, beliefs and theories we already hold determine to a great extent what we perceive; hence, observations are theory-laden.
b) Scientists operate within accepted paradigms (Kuhn, 1970a), presuppositions (Brown, 1977) or research programmes (Lakatos, 1970). Paradigms determine what problems to solve, the instruments to use, and the inferring techniques and models to employ.
c) Formal logic is rejected as the primary tool for a science and replaced by a reliance on the detailed study of the history of science. The ultimate decision on scientific value rests with the scientific community.
d) Continuing research coupled with continuing criticism, rather than accepted results, are the core of science. Science has two phases, namely, normal and revolutionary science.
e) Observed data do not remain the same from one revolution to another. This is because scientific paradigms are incommensurable (Kuhn, 1970a).

The literature cited shows the major developments within the philosophy of science. What has been the influence of these philosophies of science on curricula?

1.1.2 The nature of science and the curriculum

The 1960's in America witnessed a period of rapid changes in the philosophy of science. This period was also coincident with equally rapid changes in the science curricula (Hodson, 1988). The main goal of the scientists was to encourage interest in science, and catch up with the Soviet Union in terms of science and technology (Yager, 1982). However many of the curricular innovations did not reflect the developments in the philosophy of science (Abimbola, 1983; Hodson, 1988). Martin (1979, cited in Hodson, 1988, 22) claims that "...the views of science methodology contained within the curriculum proposals were confused, frequently contradictory, and 'based on dubious or discarded philosophies of science'". The aftermath of such curricula implementation in the U.S.A. was the continued decline in enrolment in science coupled with poor attitudes and interest in science (Yager, 1982; Yager and Penick, 1986).

3.3 NATURE OF THE SAMPLES

3.3.1 Pupils

One school was selected based on convenience. The school, established in 1967, was until recently a traditionally white government school. It is now a multi-racial, co-educational government school with an enrollment of 1100 pupils. The performance of pupils in the matriculation examination ranks above the national average (Headmaster, pers. comm). Streaming is practised in this school with pupils put into different subject groups according to their abilities. There were four Std 10 physical science classes. Pupils from the higher ability classes were selected in order to minimize the effect of low ability on answers to the questions (McCarthy, 1994).

The sample which was drawn from two Std 10 classes consisted of 47 pupils (31 males and 16 females) of average age of 17 years 10 months. They all took physical science and mathematics. The other science subjects taken by the pupils were biology (20 pupils) and geography (13 pupils).

3.3.2 Student teachers

The reason for selecting student teachers at the University of the Witwatersrand was one of convenience. Fourteen student teachers who were registered for a Higher Diploma in Education (HDE) at the university were involved in the study. Eight of them took the physical science methodology course while six took biology methodology. Ten of the student teachers had graduated the previous year with a BSc degree. Two of the remaining four students (who had graduated two to three years earlier) had two years teaching experience. The other two students had no teaching experience. It is therefore safe to assume that except for the 10 weeks teaching practice completed during the HDE, most of the student teachers had no practical teaching experience.

Teaching experience has also been cited as one of the possible factors that influences teachers' conceptions about the nature of science (Brickhouse, 1990). The inclusion in this study of student teachers with little or no teaching experience was regarded as important to investigate this proposition.

CHAPTER 3
RESEARCH METHODS

3.1 INTRODUCTION

The broad goal of this study was to describe the views held by a selected group of pupils and teachers about the nature of science, and to determine the extent to which these views converged on contemporary viewpoints about the nature of science. In order to achieve this goal, a descriptive study was conducted. A survey was carried out which used an opinionnaire to determine respondents' beliefs about the nature of science.

As the most essential components of designing good descriptive research are subject selection and instrumentation (Schumacher and McMillan, 1993), these will be considered in detail.

3.2 SAMPLING TECHNIQUES

Three populations were sampled:

Pupils: Std 10 physical science and biology pupils from "model C" schools in Johannesburg.
Student teachers: recently qualified BSc graduates who are completing a Higher Diploma in Education.
Teachers: practising science (including biology) teachers in "model C" schools in the greater Johannesburg area.

Non-probability sampling (Schumacher and McMillan, 1993) was used in selecting each sample. As the researcher does not know how representative each sample is of the population, generalizations about the population can not be made. However it is expected that meaningful information and trends will be revealed about the samples.

took 16 weeks of observation. Duschl and Wright found that teachers never gave consideration to the nature of science in their decision-making about what content to teach and how to teach it. It seemed that teachers rather took into consideration student development, syllabus objectives and pressures of accountability to guide their decisions in selecting instructional tasks.

A refocussing of researchers' attention on the presumed relationship between teachers' and pupils' conceptions has demonstrated that the influencing variables involved are complex (Lederman, 1992). Lederman has hypothesized that the most important variables that influence students' beliefs about the nature of science could be a combination of "...those specific instructional behaviours, activities, and decisions implemented within the context of the lesson" and a balanced treatment of the history and nature of science (Lederman, 1992, 351).

It seems that for adequate conceptions of the nature of science to be developed in pupils, appropriate understandings must be translated into classroom practice. In South Africa there appears to be no data base to determine if pupils and teachers have the necessary understanding of the nature of science. Such a data base is necessary before an attempt is made to develop instructional strategies to promote adequate understandings.

and decisions are significantly influenced by their conceptions of the nature of science. Various researchers have explored these assumptions.

Brickhouse (1990), using a purposive sample in a qualitative study, explored these assumptions when she investigated three science teachers' understanding of the nature of science, and the influence of such views on their classroom practice. The two experienced teachers in the sample exhibited classroom practices that were consistent with their personal views and philosophy of science. The other teacher, a novice, had no well defined conceptions and so demonstrated no definite pattern of classroom behaviour. Brickhouse (1990) concluded that teachers' conceptions influenced classroom practice.

Three other studies provided no clear cut answers to the assumptions. Lederman and Zeidler (1987) used a blend of qualitative and quantitative research methods to test the assumption that teachers' conceptions of the nature of science directly influenced their classroom behaviour. They used a non-random sample of 18 teachers with average teaching experience of 15.8 years, and one randomly selected grade 10 biology class taught by each teacher. A questionnaire, the Nature of Scientific Knowledge Scale, was used to place teachers along a continuum graded as 'high conceptions' to 'low conceptions' of the nature of science. Classroom observations of pupils' and teachers' verbalizations, chalkboard notes, handouts, mannerisms, non-verbal cues, etc. provided 44 classroom variables. Although these variables were specifically related to various aspects of the nature of scientific knowledge, they could not statistically be used to differentiate between teachers with 'high conceptions' and 'low conceptions' of the nature of science. Lederman and Zeidler (1987) concluded that teachers' classroom behaviour does not vary as a direct result of their conceptions.

Lederman and Druger (1985) also tested the assumption that teachers' understanding of the nature of science is positively related to the changes in the conceptions of their pupils. Using a case study approach and pupils and teachers from 18 senior high schools, the data showed that the teachers possessed more adequate conceptions than the mean of the students in their classes. However, the teachers' conceptions were not found to be related to changes in their students' conceptions of science over the instructional period.

Duschl and Wright (1989) conducted a study in an American high school which involved 13 teachers and their pupils. The study which included both qualitative and quantitative techniques

definition of science. The 11 pre-service teachers without courses in history or philosophy produced typical textbook definitions of science e.g. "Science is the study of fundamental laws which govern the universe". However, most were aware that due to the social construction of scientific knowledge, science could not be neutral or objective. This finding was surprising to the authors who were aware of the "scientistic" and positivistic views that experienced teachers had expressed in other studies (Nadeau and Desautels, 1984; Hodson, 1988).

In trying to account for this seemingly unusual view of pre-service teachers when compared to practising teachers, King (1991) hypothesized that something happens to the new teachers after they begin teaching. The possibility of textbooks being accepted as dogmas, class size constraints, and exams which stress fact acquisition were cited as influences that reverted their ideas to "scientistic" ways of thinking. King proposed that teachers needed much longer courses in the history and philosophy of science for them to maintain adequate conceptions over the years.

Lederman (1992) summarised the main research findings regarding teachers' understanding of the nature of science as follows:

a) Science teachers do not possess adequate conceptions of the nature of science irrespective of the instruments used to assess understanding.
b) Academic background variables do not significantly improve teachers' conceptions of the nature of science.
c) Techniques to improve teachers' conceptions have been successful to some extent where they include either history or philosophy of science.

2.3.3 The relationships between teachers' and pupils' conceptions of the nature of science

According to Lederman (1992), two assumptions are implicit in the research into pupils' and teachers' conceptions of the nature of science. Firstly, pupils' understanding of the nature of science is related to their teachers' conceptions; and secondly, teachers' instructional behaviour

2.3.2 Teachers' conceptions of the nature of science

Herron (1969) noted that science teachers' preparation programmes were being blamed for the apparent inadequate conceptions of science held by science teachers. Kimball (1968) used the Nature of Science Scale (NOSS) to compare the understanding of the nature of science of 712 professional scientists and qualified science teachers in America. The year and school of graduation of the two groups were taken into account. However, no significant differences were found between the two groups. The author concluded that there was no difference in the concept of the nature of science held by scientists and science teachers when there academic backgrounds were similar. In the same study, the philosophy majors were found to display significantly better understanding of the nature of science than the science majors (including both teachers and scientists). The results served to discredit public criticisms of science education programmes for that period and also served to justify the call for the inclusion of philosophy of science in the undergraduate courses.

Carey and Stauss (1968) attempted to identify variables that might contribute significantly to a teachers' understanding of the nature of science. Thirty-five secondary school teachers in America completed the Wisconsin Inventory of Science Processes (WISP) instrument. Their scores were then correlated with variables such as teaching experience, total college science grade average, and total college science hours. No relationship was found between the teachers' conceptions of science as measured by WISP, and any of the academic background variables. It was concluded that none of the academic variables investigated could be used to improve science teachers conceptions of the nature of science. This finding seemed to confirm previous research that teaching experience did not contribute to a teachers understanding of the nature of science (Carey and Stauss, 1968; Kimball, 1968).

In a recent study, King (1991) investigated beginning teachers' knowledge of the history and philosophy of science. Thirteen Canadian pre-service teachers who had graduated with a bachelors degree in their subject areas completed a questionnaire on the first day of their introductory course in curriculum and instruction in science. Eleven of the 13 teachers were interviewed at the end of their course, after at least a week of student teaching. Background information from the questionnaire indicated that three of the 13 pre-service teachers had taken one course in either history or philosophy of science. These three students were found to be more articulate and with better reasoned responses on the philosophical questions and their

included the meaning of science, conceptual inventions in science, scientific method, and values in science. They found that pupils had not acquired a uniform view of the definition of science. Pupils' responses were divided between the content and process perspectives and they were all unaware of the social aspect of science. It was found that pupils misunderstood the concepts hypotheses, theories and laws. The majority of pupils expressed a simplistic hierarchical relationship in which hypotheses with enough proof became theories which also "matured" into laws - a view that has been termed "laws-are-mature-theories fable" (Horner and Rubba, 1979).

Two assumptions in the epistemology of science, namely, the absence of an interfering deity in natural phenomenon, and the inventive nature of knowledge were also investigated by Ryan and Aikenhead (1992). About half of the pupils believed the possibility of a supernatural being altering the natural world. On the inventive character of scientific knowledge, only 17 per cent of the sample were certain about scientists inventing theories to explain reality.

A majority of pupils also seemed to believe there was a definite pattern of doing science called "the" scientific method. Only nine per cent held the pragmatic view that maintained there was no "one" scientific method, and that scientists used any mode of enquiry suitable for their investigations. Another viewpoint investigated by this study was whether scientific knowledge changes with time. Even though most pupils accepted that scientific knowledge changes, they gave three different and conflicting reasons for the changes. Ryan and Aikenhead (1992) identified:

a) the constructivist perspective which held that scientific knowledge can change with time when new conceptual schemes are used to reinterpret the facts differently (Kuhn, 1970a);
b) falsificationist view which held that scientific knowledge could be disproved; and
c) a realist view which believed facts were true.

The researchers concluded that Canadian pupils were not well informed about the nature of science. They did not find this surprising as no consistent instruction took place across Canada to provide pupils with a more realistic image of the nature of science (Ryan and Aikenhead, 1992).

The review of the literature so far indicates that there are problems with pupils'understanding of the nature of science.

naively absolutist view of the nature of scientific hypotheses. Body believes the current acceptable position is that scientific theories cannot be proven but only disproven. Perhaps this too is a rather simplistic view which appears to bear the marks of falsificationism.

In a survey of a mid-western American school using Nature of Scientific Knowledge Scale, Rubba and Andersen (1978) found that 30 per cent of the high school pupils monitored believed that scientific research revealed indisputable facts. In addition, most were of the view that scientific theories, after a number of testings and confirmations, could eventually mature into laws. These misconceptions about the nature of scientific knowledge have since been categorized as the "myth of absolute truth" and "laws-are-mature-theories fable" (Horner and Rubba, 1979).

Rubba, Horner and Smith (1981) attempted to assess pupils adherence to the "myth of absolute truth" and "fable" positions with a convenience sample of 102 high ability grade 7 and 8 pupils. An instrument with a . ve-scale Likert-type format was used. The researchers concluded that pupils were not knowledgeable with respect to the "myth of absolute truth" and "fable" issues. In fact, the results neither confirmed nor disputed the pupils belief in the "myth of absolute truth" and "fable".

Tentativeness of scientific knowledge has been accepted by some researchers as the primary attribute of scientific knowledge, and that an understanding of this characteristic is achievable by all pupils of all age levels (Cotham and Smith, 1981; Lederman and O'Malley, 1990). Lederman and O'Malley (1990) investigated this assumption using a paper and pencil questionnaire followed by an interview. Their sample consisted of 69 American pupils enrolled in physical science, biology, chemistry and physics in grades 9-12. It was found that while the paper and pencil test seemed to show that pupils had an absolutist view of scientific knowledge, the interview indicated that pupils held a tentative view. Further investigation revealed a mismatch between the language used in the questionnaire by the pupils and the researchers, which gave a wrong impression of the conceptions pupils held. In this particular instance, the pupils understood the tentative and revisionary nature of scientific knowledge.

Ryan and Aikenhead (1992) used their empirically developed instrument, Views on Science-Technology-Society (VOSTS), to survey the conceptions of 2000 grades 11 and 12 Canadian students. As discussed in detail in the methods chapter on page 31, a modified version of this instrument was used in the present study. Some of the topics Ryan and Aikenhead investigated

Hodson is aware of the problems associated with establishing a relation between the nature of science and the nature of learning. The relationship would require further scrutiny (as demanded by Kuhnian philosophy), in order to make progress towards achieving valid and appropriate science curricula.

2.3 THE TEACHING AND LEARNING OF THE NATURE OF SCIENCE

The development of adequate conceptions of the nature of science by pupils has been an important objective of science education in the USA (Hurd, 1960, cited in Lederman, 1992). Hurd noted that its earliest occurrence in the syllabus in 1920 was to facilitate the training of pupils' mental faculties. Subsequently, it has continued to be part of the curricula objectives although with different emphases year after year (Lederman, 1992).

The main lines of research into the teaching and learning of the nature of science have included pupils' and teachers' conceptions of the nature of science, and the relationships between the two. In addition, other researchers have focused attention on the philosophies underlying various curricula, and have sought for ways of improving pupils' conceptions by developing new curricula. Lederman (1992) has produced a very comprehensive summary of the literature on pupils' and teachers' conceptions of the nature of science and many of the papers that he reviewed are cited in the following section. As the literature on pupils' and teachers' conceptions is so vast, an attempt will be made to follow in a chronological fashion samples of the various lines of research that deal with contemporary conceptions about the nature of science.

2.3.1 Pupils' conceptions of the nature of science

Research has revealed various dimensions of pupils' conceptions of the nature of science. Bady (1979) investigated samples of pupils in grades 9, 11, and 12 from both private and public schools in the USA on their understanding of the logic of hypothesis testing. He found that most pupils, regardless of age or school, believed that hypotheses could be adequately tested and proven by verification. He concluded that such students were likely to have a simplistic and

dynamic aspects of science as a way of finding out. Millar and Driver (1987) find this portrayal naive and reflecting a view of scientific knowledge as absolute and unproblematic in which facts are revealed to us if an appropriate method is followed.

2.2.3 Towards a philosophically valid curriculum

Hodson (1988) believes that for any science curriculum to achieve all its goals, an appropriate philosophy of science which also corresponds with the nature of learning must undergird it. For successful teaching and learning to be achieved, the philosophy and methodology of practising science teachers also needs to correspond with the philosophy of science underpinning the science curricula. Thus, the basic requirements for the curriculum are a valid philosophy and pedagogy.

Hodson believes the inductivist-empiricist philosophy of science does not provide the necessary relationship between scientific knowledge, scientific methods and the methods of learning science. He suggests that the Kuhnian philosophy does and it is therefore philosophically valid. The pedagogical validity of the Kuhnian model of science is established as a result of it having a direct equivalent in psychology in the constructivist theory of learning. It is therefore justifiable that the curriculum should be constructed along Kuhnian lines (Hodson, 1988). He envisages three stages of education: pre-paradigmic, within-paradigmic, and revolutionary science education. The pre-paradigmic science education would occur in the elementary and secondary school. According to Hodson (1988), this stage would be concerned with the establishment of what is and what is not science. Pupils would also be expected to acquire the 'language' of science at this stage. The within-paradigm stage would focus on the substantive structure of the subject and would lead pupils to practise the skills of normal science, such as acquiring new concepts and investigating the adequacy of theories. The essential goals of revolutionary science education would be the creation of new theoretical ideas and the investigation of theory choice by the community of scientists.

Hodson (1988) maintains that for philosophically valid curricula to be attained, curriculum designers must address the issue of whether the major emphasis should be science content or science processes. In addition, the issues of what constitutes the scientific method, the role and status of scientific theory, and the dissemination and validation of scientific knowledge by the scientific community, must also be resolved. In short, the nature of science must be addressed.

contends that without teaching how knowledge claims come about pupils tend to form authoritarian views about science in opposition to what science really is.

2.2.2 Content or process approach

Science education literature also distinguishes between science as a process and science as a body of knowledge or content. Millar and Driver (1987) give three meanings associated with the term "processes":

a) the processes scientists use in investigating the natural world;
b) the cognitive processes involved in learning science; and
c) the pedagogical processes taking place in classrooms.

According to Screen (1986, cited in Millar and Driver, 1987), the main thrust in Britain during the 1950's was to produce a *process led* science curriculum as distinct from one that was *knowledge led*. Similarly, Robert Gagné's advocation of the process view in America in the 1960's also had a substantial influence on curriculum instruction and research in science education (Hodson, 1988). Finley (1983) has observed that Gagné's views of 'science processes' (which are based on empiricism and inductivism), if subjected to philosophical criticism, would be unsupported for two reasons: Firstly, enquiry viewed as an inductive process is not tenable because there is no frame of reference for judging what facts should be collected or how they should be organised. Secondly, the idea that all meaningful information or knowledge is derived directly from experience is also untenable.

Finley (1983) agrees with contemporary views which suggest that our perceptions are partly determined and selected according to the prior knowledge we possess about the nature of the objects and events. Finley also foresees the likelihood of uninformed curriculum developers producing curricula based on simplistic and erroneous views about science. An example of such simplistic view, Finley noted, would be teaching that the methods and processes used by the various disciplines in science were the same.

From a pedagogical point of view, Black (1986) and Millar and Driver (1987) have argued that the content-process dichotomy is an artificial one. The process approach as a means of pedagogy has been seen to place less emphasis on science as a body of knowledge, focusing instead on the

education circles, so also was scientific knowledge as proven knowledge being rejected by philosophers of science.

However, according to Duschl (1985), the developments in the philosophy of science were not incorporated into the many curricular innovations. Duschl cites two reasons why the scientific community in control of the curriculum development did not incorporate the ideas of the philosophers. Firstly, the rate of development in both fields was different: The philosophers worked rather more cautiously whereas the scientists, under political pressure to turn out an appropriate curriculum, worked at a faster rate. Secondly, the ideas of the philosophers were not held in high credibility by the scientists, who as the writers, were not prepared to include such views in subsequent versions of the curricula.

Some of the philosophies underpinning secondary school science curricula are discussed below. This is necessary in order to expose the weaknesses of curricula and to provide grounds for proposing a more philosophically valid curriculum.

2.2.1 Two contexts of science

It has been suggested that two characterizations about the nature of science exist: the characterization of science as a process of justifying knowledge, often referred to as the context of justification, and the characterization of science as a process of discovering knowledge, also referred to as the context of discovery (Lincoln and Guba, 1985; D...l, 1988). John Herschel (1792-1871) is attributed with first making the distinction between the two contexts (Losee, 1981, cited in Duschl, 1988). With the advent of logical empiricism around the first half of the twentieth century, justification took precedence over discovery. So much was the concern of the empiricists for the justification and testing of knowledge claims that the issue of how the knowledge claims came to exist was "...treated as non-cognitive or non-rational" (Lincoln and Guba, 1985, 25). Hesse (1980, cited in Lincoln and Guba, 1985) lends weight to this assertion when she noted that positivism, by focusing on the testing of theories to the neglect of the discovery of theories, confused the two aspects of scientific enquiry.

Duschl (1988) seems to suggest that science as a process of justifying knowledge continues to dominate contemporary science education. It is his view that pre-college science education curricula should equally address how scientific knowledge has come about. Duschl (1988)

Science is often discussed in contemporary science literature in terms of science content, science processes and the social context of science (Ryan and Aikenhead, 1992). A content-oriented view of science is identified with a positivist approach (Nadeau and Desautels, 1984), a process approach is identified with vestiges of positivism, while a social context image is seen as consistent with contemporary views of science (Ryan and Aikenhead, 1992). These three perspectives are included in the options to Item 4.1 (Table 2). Option B represents a content-oriented position; options C and F may be considered as representing a process approach; option G relates to a social context image, while options D and E see science as a means to improving the world - a technological approach (Ryan and Aikenhead, 1992). This broad scheme was used in the analysis of the responses and in their placement in one of the four categories which are shown in Fig. 1.

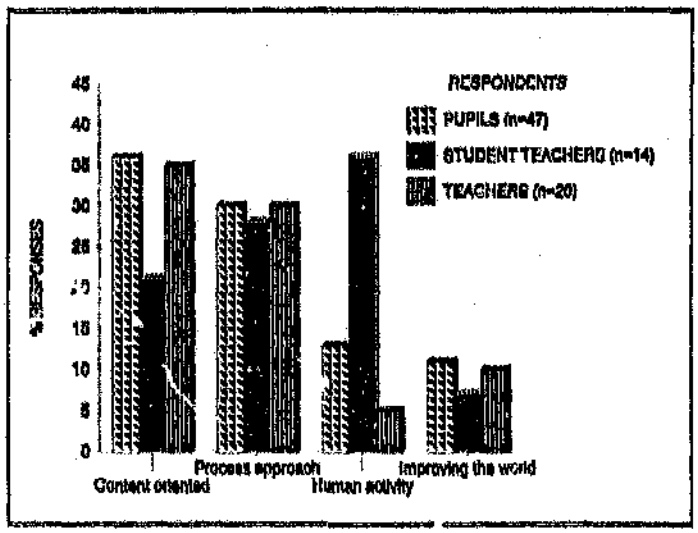


Figure 1: Pupils' and teachers' definitions of science

The general trend evident in Fig. 1 is that the content and process perspectives of science were most strongly favoured. The exception to this trend is that 36 per cent of the student teachers selected the more contemporary view of science as a human activity. It is interesting to note that less than 12 per cent of all the samples saw science as a means of improving the world, or saw it in terms of the traditional science subjects. Responses to the free response option H suggest that certain pupils and teachers have a very broad or poorly defined view of science. For

CHAPTER 4
RESULTS AND DISCUSSION

This chapter outlines and discusses the main findings of the study in order to answer the research questions which were formulated in Chapter 1. The conclusions and their implications for science education are considered in the next chapter.

The responses from the opinionnaire of pupils (P), student teachers (ST) and teachers (T) about the nature of science are presented in a series of tables. Each table displays an item in the opinionnaire including the various options. Adjacent to each option in the table is the percentage of respondents holding that position. The percentage calculation is based on the total number of Std 10 pupils (47), student teachers (14) and teachers (20) who completed the opinionnaire. The percentages are rounded off to the nearest whole number. The opinionnaires are included in Appendices 2 and 3.

This discussion of the results was greatly influenced by that of Ryan and Aikenhead (1992). In the discussion, the most common current views held by philosophers of science on each item are outlined first. This is followed by a discussion of the general trends of respondents' views. A comparison of the responses of the three samples is made.

4.1 DEFINING SCIENCE

Table 2: Respondents' definitions of science

P	ST	T	Defining science is difficult because science is complex and does many things. But science is mainly:
6	0	10	A. a study of fields such as biology, chemistry and physics.
36	21	35	B. a body of knowledge, such as principles, laws and theories, which explains the world around us (matter, energy and life).
4	0	5	C. carrying out experiments to solve problems of interest about the world around us.
0	0	0	D. inventing or designing things (for example, artificial hearts, computers, space vehicles).
11	7	10	E. finding and using knowledge to make the world a better place to live in (for example, curing diseases, solving pollution problems and improving agriculture).
26	29	25	F. a way of exploring the unknown and discovering new things about our world and universe and how they work.
13	36	5	G. a human activity oriented towards explaining and understanding the world.
4	7	10	H. None of these choices fits my basic viewpoint which is .....

not seem that these teachers spent more time on the opinionnaire than the first group. Nevertheless, this latter administrative procedure could have influenced the validity and reliability of the results. This is discussed in the critique of the study on page 72.

3.8 ANALYSIS AND PRESENTATION OF DATA

The nature and size of the samples, coupled with the type of information generated by the instrument, made a detailed statistical analysis of the findings inappropriate. As a descriptive study, the representation of views of respondents using frequency tables and graphs to summarize the data is considered more appropriate. Quotations are used to convey responses to the free-response questions.

they completed the opinionnaire. The researcher was available throughout the period to give further assistance to pupils when necessary. No major difficulties were experienced.

The instruction page was completed first, and this was checked to see if all necessary data were supplied. There was no break between the two periods during which the opinionnaire was administered to the two classes, and pupils were confined to their various classrooms. It can therefore be assumed that there was no discussion about the instrument among the pupils prior to it being answered.

3.7.2 Students teachers' opinionnaire

The opinionnaire was administered to the student teachers in two groups on two days.

Six out of seven biology methodology students were present for the lectures on the day selected for the administration of the opinionnaire and therefore participated in the study. The students had no prior knowledge about answering the opinionnaire and therefore their attendance was not influenced by their knowledge of the research. They were accommodated in a lecture hall. The purpose of the study was explained to them and their frank responses solicited. The researcher was present throughout the 20-minute session and no discussion between students was allowed. On completion of the opinionnaire, the group of student teachers were questioned in order determine their general impressions of the opinionnaire, and any problems they might have experienced.

This administrative procedure was also used for the physical science methodology students. Eight students were present at the lecture to answer the opinionnaire.

3.7.3 Teachers' opinionnaire

The instrument was administered to 20 teachers at 5 schools. Two main administrative procedures were followed. Firstly, ten of the teachers completed the opinionnaire in the presence of the researcher. This included teachers of the Std 10 pupils. Secondly, in two schools involving ten teachers, the respondents were allowed to complete the opinionnaire during their spare time. Completed opinionnaires were collected after two or three days. Each teacher was made aware of the need for personal and frank answers. Judging by the few free-responses provided, it does

3.6 PILOT STUDY

A pilot study was conducted at a "model C" high school in Johannesburg. Thirty Std 9 pupils and their physical science teacher completed the opinionnaire. It took the pupils about twenty minutes to complete the opinionnaire. Six pupils were randomly selected for an interview after they had completed the opinionnaire. The aim of the interview was to get feedback about the difficulty, clarity and phrasing of the questions.

The interview with the pupils showed the language level was appropriate (all being English first-language speakers), and pupils' verbal explanations supported their choice of options in the written instrument. The subject teacher confirmed in an interview that the language used was appropriate for the pupils, but hinted that the format of some of the questions was not clear.

An analysis of the responses showed that three questions were not properly structured and as a result, pupils selected more than one option. These options were restructured and each question was provided with a separate instruction requiring respondents to choose only one option.

The restructured questions were then administered to six teachers. No significant problems were detected in the format or content of the opinionnaire.

3.7 ADMINISTRATION OF THE INSTRUMENT

The opinionnaire was administered to the pupils, student teachers, and teachers close to the end of the academic year.

3.7.1 Pupils' opinionnaire

The following procedure was used to administer the opinionnaire to the pupils in the two Std 10 classes. Pupils completed the opinionnaire in their classrooms during the physical science period with their teacher and the researcher in attendance. Each session began with the researcher introducing himself and explaining the purpose of the study. This was intended to allay any fears and promote mutual trust and friendliness. No communication between pupils was allowed while

or more viewpoints. The free-response option was intended to reduce the amount of guessing of answers (Aikenhead, 1988).

All pupils, student teachers and teachers in the study completed the same opinionnaire. (See Appendix 2). The first page of the instrument stated the aims of the study and also encouraged respondents to answer questions in a frank manner. It was made clear to respondents that each item began with a stem sentence which usually expressed an extreme view on the topic with which they may or may not agree. Instructions were provided which detailed how the options to the statements were arranged, and how the questions were to be answered. Pupils were also required to fill in the following personal details: date of birth, present standard, and the science subjects being taken. Teachers and student teachers were required to provide details concerning their academic and professional qualifications and teaching experience. This covering page is included in Appendix 3.

3.5 FACE VALIDATION

The propositional knowledge statements and instruments were submitted to a panel of four educators at the University of the Witwatersrand to check for face validity. The panel included two specialists in education theory, one physics education expert and one expert in biology education. Modifications suggested by the validators included reducing further the number of options in some items, and interviewing pupils during the pilot phase to obtain feedback on their reactions to the instrument. Some of the issues raised in the propositional knowledge statements are subjects of ongoing debate among scientists and philosophers. One of the education theory experts on the panel would have preferred such debates to be described in the propositional knowledge statements. However, it was not a stated aim of this research to debate the opposing philosophical viewpoints about the nature of science. Rather, the goal was to explore the views of pupils, student teachers and teachers in this area. To facilitate meaningful discussions of these views, it was necessary to state the most common current views held by scientists and philosophers of science. While these views were used in this study as a basis for comparison with the views of the respondents, it is acknowledged that many of these views can be, and are, hotly debated within the scientific community.

or more viewpoints. The free-response option was intended to reduce the amount of guessing of answers (Aikenhead, 1988).

All pupils, student teachers and teachers in the study completed the same opinionnaire. (See Appendix 2). The first page of the instrument stated the aims of the study and also encouraged respondents to answer questions in a frank manner. It was made clear to respondents that each item began with a stem sentence which usually expressed an extreme view on the topic with which they may or may not agree. Instructions were provided which detailed how the options to the statements were arranged, and how the questions were to be answered. Pupils were also required to fill in the following personal details: date of birth, present standard, and the science subjects being taken. Teachers and student teachers were required to provide details concerning their academic and professional qualifications and teaching experience. This covering page is included in Appendix 3.

3.5 FACE VALIDATION

The propositional knowledge statements and instruments were submitted to a panel of four educators at the University of the Witwatersrand to check for face validity. The panel included two specialists in education theory, one physics education expert and one expert in biology education. Modifications suggested by the validators included reducing further the number of options in some items, and interviewing pupils during the pilot phase to obtain feedback on their reactions to the instrument. Some of the issues raised in the propositional knowledge statements are subjects of ongoing debate among scientists and philosophers. One of the education theory experts on the panel would have preferred such debates to be described in the propositional knowledge statements. However, it was not a stated aim of this research to debate the opposing philosophical viewpoints about the nature of science. Rather, the goal was to explore the views of pupils, student teachers and teachers in this area. To facilitate meaningful discussions of these views, it was necessary to state the most common current views held by scientists and philosophers of science. While these views were used in this study as a basis for comparison with the views of the respondents, it is acknowledged that many of these views can be, and are, hotly debated within the scientific community.

Holton (1978), Ziman (1980, 1984), Gauld (1982), and Fleming (1989). These contemporary viewpoints of philosophers of science were also favoured by science educators such as Abimbola (1983), and Ryan and Aikenhead (1992) as representing modern views about the nature of science.

Five key issues within the nature of science were selected for this study. These were defining science, knowledge generation, nature of scientific knowledge, conceptual inventions, and values in science. An understanding of these areas was considered necessary in order for pupils and teachers to have an adequate conception of the nature of science.

The following functions were served by the propositional knowledge statements: Given the vast area of knowledge covered by philosophy of science, the propositional knowledge statements were used to delimit the scope and depth of knowledge to be explored, and to select appropriate items from the VOSTS instrument. Finally, they were used by the researcher to address the content validity of the instrument.

3.4.5 Modification of the VOSTS Instrument

The 114 VOSTS items were examined and individual items which related to the five topics mentioned above were selected. The selected items numbering 35 were critically examined for clarity of expression. Finally, 13 questions covering the selected content area, and which could be answered within about 25 minutes were chosen to constitute the instrument.

Some items had several options with similar meanings. The number of options varied between 8 and 13, which is quite unusual in tests used in South African schools. An attempt was made to modify the instrument so that it conformed to the pattern of multiple choice questions familiar to South African pupils. The language used was 'South-Africanised' in some items. Similar options were deleted which reduced the number of options in each item to an average of about six. Rather than including the response formats "I do not understand" and "I don't know enough about this subject to make a choice", the following free-response option was provided: "None of these choices fits my basic viewpoint which is...". This option was to be used when respondents felt their views were not expressed adequately in the item, or when they wanted to combine two

a) Two statements were composed for each of the eight VOSTS topics with each statement portraying the opposite point of view. Empirical data on pupils' views about the statements were gathered by making them write argumentative paragraphs in response to the statements. Over 2000 pupils from diverse backgrounds responded. About seventy of these written argumentative paragraphs were sampled to ensure a rich diversity of opinions.

b) The paragraphs were analyzed and grouped into categories to represent pupils' common viewpoints. The viewpoints were then rephrased using pupils' vernacular, and cast into the traditional multiple choice format without altering the original student paraphrases. One of the two initial statements became the stem sentence of the item.

c) The clarity of each VOSTS statement was revised with a batch of 10 new pupils. These pupils were made to write new paragraphs to the original test statements and then select a "pupil position". This was then followed by an interview to determine how well the wording of the multiple choice item corresponded with the pupils viewpoints. It was also a means of determining the reliability of pupils' responses.

d) About 10 students per VOSTS item, worked through several VOSTS items verbally in the presence of an evaluator and researcher to check if the pupils' meaning corresponded with that of the researchers'. This technique ensured that the test questions would evoke responses properly related to pupils' understanding of the topic. It was also a means of improving the validity or trustworthiness of the items (Marshall and Rossman, 1989).

e) A total of 5000 pupils were made to respond to the VOSTS items. Pupil positions that received little or no response were eliminated, thus trimming down the number of options in each question to about 8 to 11.

3.4.4 Propositional knowledge statements

Before the VOSTS instrument was adapted for this study, propositional knowledge statements were formulated by the researcher. These were written descriptions which summarized contemporary viewpoints on key issues about the nature of science. (See appendix 1). The viewpoints selected were those of more recent philosophers of science such as Kuhn (1970a),

In response to the problems related to existing instruments, Aikenhead and Ryan (1992) developed the Views on Science-Technology-Society (VOSTS) instrument. Aikenhead (1988) estimated the ambiguity level of an empirically derived instrument's response format to be between 15-20 per cent compared to other response formats such as Likert, 50-80 per cent; paragraph, 35-50 per cent; and semi-structured interview, 5 per cent. Although research suggest that the semi-structured interview provides the best way to probe the viewpoints of the samples, McCarthy (1994) claims that the technique is very time-consuming. As a result, the VOSTS instrument was selected as a compromise. The tremendous rigour involved in the development of the VOSTS instrument (discussed in section 3.4.3) was the main attribute that influenced its selection. Some special features of the VOSTS instrument are explained in the following section before describing how it was modified and used in this study.

3.4.2 Special characteristics of VOSTS

The VOSTS items are based on science-technology-society (STS) content appropriate for high school students and on recent literature concerning the epistemological, social, and technological aspects of science. The VOSTS instrument consists of 114 multiple-choice items that fall under eight broad topics. These broad topics are: i) science and technology, ii) influence of society on science\technology, iii) influence of science\technology on society, iv) influence of school science on society, v) characteristics of scientists, vi) social construction of scientific knowledge, vii) social construction of technology, and viii) nature of scientific knowledge.

The developers of VOSTS have claimed it to be a "new generation instrument" with distinct "psychometric perspectives over conventional instruments" (Aikenhead and Ryan, 1992, 479). They note that whereas conventional instruments laid emphasis on test scores obtained from pupil responses, VOSTS presented pupils' ideas, not numerical scores. In addition, the distractors in VOSTS multiple choice items were empirically determined and not written from a researchers' viewpoint. As noted by Aikenhead and Ryan (1992, 480), "...this shift in emphasis of the responses has implications when the issue of the instrument's validity is addressed".

The details of how VOSTS items were developed are summarized in order to explain the processes and conceptual issues that were involved in the development phase.

3.4.3 The development of VOSTS items

Five thousand Canadian pupils of average age of 17.3 years participated in the development of the instrument. The following steps were taken in the formulation of each item (Aikenhead and Ryan, 1992):

Table 1: Particulars of teachers who completed the opinionnaire (n=20)

TEACHER	QUALIFICATION							TEACHING EXPERIENCE	INSTITUTION ATTENDED	
	ACADEMIC					PROFESSIONAL		NUMBER OF YEARS	ACADEMIC	PROFESSIONAL
	B Sc	B Sc (HONS)	B A	B ED	B PRIM Ed	1 YEAR POSTGRAD	COLLEGE DIPLOMA			
1	*					*		3	WITS	WITS
2	*					*		4	WITS	WITS
3			*				*	14	UNISA	JCE
4	*					*		5	WITS	WITS
5					*			0	WITS	-
6							*	26	-	JCE
7							*	28	-	JCE
8			*				*	11	UNISA	FORDSBURG
9				*			*	6	UNISA	JCE
10	*					*		2	WITS	UNISA
11	*					*		3	WITS	WITS
12	*					*		8	UNISA	WITS
13		*				*		14	RHODES	RHODES
14	*						*	24	WITS	JCE
15			*			*		16	NATAL	NATAL
16	*					*		1	WITS	WITS
17	*					*		1	WITS	WITS
18	*					*		2	UCT	UNISA
19		*					*	26	WITS	JCE, UNISA
20			*			*		4	WITS	WITS

Key to institutions

WITS - University of the Witwatersrand
JCE - Johannesburg College of Education
UNISA - University of South Africa, Pretoria
NATAL - University of the Natal, Durban
UCT - University of Cape Town
RHODES - Rhodes University
FORDSBURG - Teachers' Training College

3.3.3 Teachers

Twenty teachers from five government schools in the greater Johannesburg area were conveniently sampled to complete the opinionnaire. Attempts were made to include in the sample teachers with a wide range of teaching experience and qualifications. Details regarding the particulars of the secondary school teachers are included in Table 1.

Of the 20 teachers, 18 had university academic degrees. These comprised 10 B.Sc. degrees, 2 B.Sc. (Hons), 4 B.A., 1 B.Ed., and 1 B.Prim.Ed. Twelve had a post-graduate teaching diploma, and 7 had an undergraduate teaching diploma from a teachers' training college. Of the seven teachers who graduated with undergraduate teaching diplomas, five had over the years obtained a university degree. The 18 degreed teachers were also noted to have graduated from five universities in the country, with 11 of them graduating from the University of the Witwatersrand. In terms of their teaching experience, 14 of the teachers had taught for five or more years, with 5 teachers teaching for more than 20 years. The subjects taught by the teachers included biology, physical science or mathematics and these were taught from Std 6 to Std 10. Physical science seemed to be the most common subject taught by these teachers. Five of the teachers had taught all three subjects in past years up to Std 10.

3.4 DESIGN OF THE INSTRUMENT

As this study aimed to establish what pupils and teachers know and believed about the nature of science, it was necessary for the most appropriate instrument to be used.

3.4.1 Instrument selection

Several standardized instruments used in the past to investigate respondents' understanding of the nature of science have had "ambiguity problems" (Aikenhead et al., 1987). Researchers had erroneously assumed that respondents perceived and interpreted test statements as they did, and that language was used in the same context by both parties (Aikenhead and Ryan, 1992). A mismatch in the language used by the respondents and researchers often as high as 80 per cent was documented by Aikenhead (1988).

Three positions are embraced by the options in this item:

a) Scientific knowledge changes (options A and B).

b) Scientific knowledge appears to change (options C and D).

c) Scientific knowledge does not change (option E).

What do respondents believe about the provisional nature of scientific knowledge? (See Fig. 4). A large majority (74 per cent of pupils; 86 per cent of student teachers; and 90 per cent of teachers) selected the position that acknowledges scientific knowledge changes. Twenty-four per cent of pupils, 7 per cent of student teachers and 5 per cent of teachers held the view that scientific knowledge appears to change. Only one pupil and one teacher chose the position asserting that scientific knowledge does not change because it consists of fact. (Fig 4).

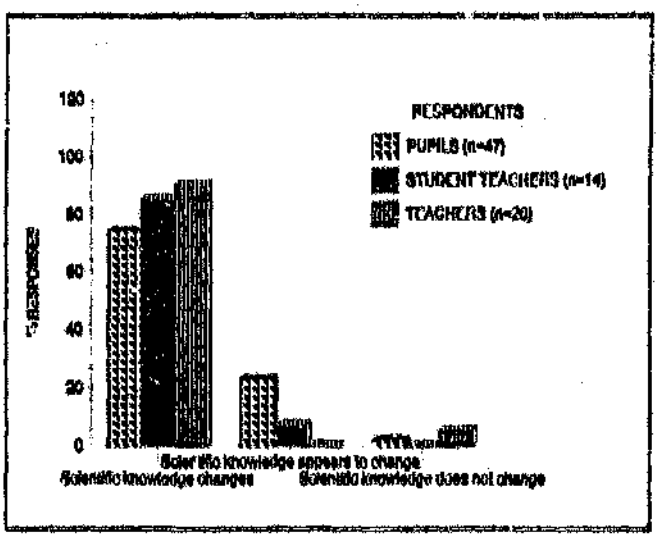


Figure 4: Pupils' and teachers' views on how scientific knowledge changes

However, a consideration of the specific options selected by the respondents sheds further light on their understanding of the changing nature of scientific knowledge. Option B is the contemporary "constructivist" view which accepts that scientific facts can change with time, when new concepts are used to interpret facts differently. This Kuhnian position was held by 14 per cent of pupils, 22 per cent of student teachers, and 45 per cent of teachers.

view of scientific theories. The dominant position of teachers' views however seem to have shifted from a content/process view to an epistemological view. This is a favourable shift. The strong social image of science expressed by student teachers' views seems to be consistent with the epistemological views most of them expressed in this item.

4.6 VIEWS ON HOW SCIENTIFIC KNOWLEDGE CHANGES

Table 7: Respondents' views on how scientific knowledge changes

				Even when scientific investigations are done correctly, the knowledge that scientists discover from those investigations may change in the future.
				What do you think?
				Scientific knowledge changes:
P	SE	T°s		
60	64	45	A.	because new scientists disprove the theories or discoveries of old scientists. Scientists do this by using new techniques or improved instruments, by finding new factors overlooked before, or detecting errors in the original "correct" investigation.
14	22	45	B.	because the old knowledge is reinterpreted in light of new discoveries. Scientific facts can change.
4	7	5	C.	Scientific knowledge APPEARS to change because the interpretation or the application of the old facts can change. Correctly done experiments yield unchangeable facts.
20	0	0	D.	Scientific knowledge APPEARS to change because new knowledge is added on to old knowledge; the old knowledge doesn't change.
2	0	5	E.	Scientific knowledge does not change because it consists of proven facts.
0	7	0	F.	None of these choices fits my viewpoint which is .....

Falsificationists and the 'new' philosophers both acknowledge the tentative nature of scientific knowledge. For the naive falsificationists, changes occur when scientific knowledge is disproved (Lakatos, 1970). The Kuhnian or 'new' philosophers' position maintains that old facts change and become different facts when new conceptions are developed and facts are interpreted differently.

The ontological position appears to be held by 47 per cent of pupils, 7 per cent of student teachers and 15 per cent of teachers. The epistemological position was supported by 23 per cent of pupils, 64 per cent of student teachers and 60 per cent of teachers. Positions between these two extremes were held by 23 per cent of pupils, 7 per cent of student teachers, and 20 per cent of teachers (Fig 3).

In support of the epistemological viewpoint, a student teacher noted: "Scientists invent theories to the extent that they put forward a theory based on evidence they have found". This point of view is consistent with Solomon et al. (1992) as to why scientists do experiments. Basically it is to try out their explanations for why things happen. Such explanations in the form of hypotheses or theories, are constructed by the scientists to explain observed facts.

What is the relationship between such theories and reality? In an open ended response, a student teacher felt a "...theory is both dependent on mind and reality and thus depends on both". Another student teacher, supporting the realist camp, believes that "...scientists follow a path of 'discovery' and make a conclusion based on the evidence in front of them". It is necessary to bring out the essential differences between the realist and the instrumentalist views in order to address the initial question posed. This is about how each group of scientists views the "conclusions based on their evidence". Are they considered the exact description of what is observed or an attempt at creatively describing what they think is observed? The realist or the ontological position suggests that the evidence is exact (Hacking, 1983).

In the other open ended responses, the two positions were described sometimes in rather ambiguous terms. One pupil stated "...scientists neither invent or discover theories but merely put into words the facts that are present." This response pinpoints the dilemma of pupils when faced with options which are not familiar to them. To achieve a scientifically literate citizenry, such distinctions must be taught at schools so that pupils are able later on to make informed decisions about social issues based on nature of scientific theories.

In summary, it seems that whilst the largest category of pupils' responses (47 per cent) favoured the ontological view, those of student teachers and teachers favoured the epistemological view. (See Fig 3). When the dominant positions selected in this item are compared with respondents' choices on the definitions of science, a rough correlation of the dominant views become obvious. Pupils who strongly favoured a content perspective of science seem to equally support a realist

to imaginative insights which are then developed by conscious thought (Popper, 1972, cited in Hodson, 1986).

Are scientific theories invented or discovered? This question delineates the two schools of thought within the philosophy of science concerning the status of scientific knowledge. The ontological or realist view believes that scientific knowledge tells us what is really out there. Or put in another way, there is a reality out there that can be objectively described. The metaphor of a miner discovering gold appropriately describes the ontological position of uncovering reality (Ryan and Aikenhead, 1992). This position is also consistent with the positivist view (Ryan and Aikenhead, 1992). The other school of thought, the epistemological position, maintains that scientific knowledge is created to explain what is out there. The explanation is actually a fiction to account for what exists. The metaphor used is the invention or creation of a sculpture, and this perspective agrees with currently held views (Ryan and Aikenhead, 1992). Hodson (1986) however advocates a compromise view for school science and this is outlined on page 60.

What do the respondents think about theories? Three positions are embraced by the options in this item. (See Table 6).

a) Options A, B and C delineates the ontological position.

b) Options E and F is the epistemological position.

c) Option D encompasses both positions.

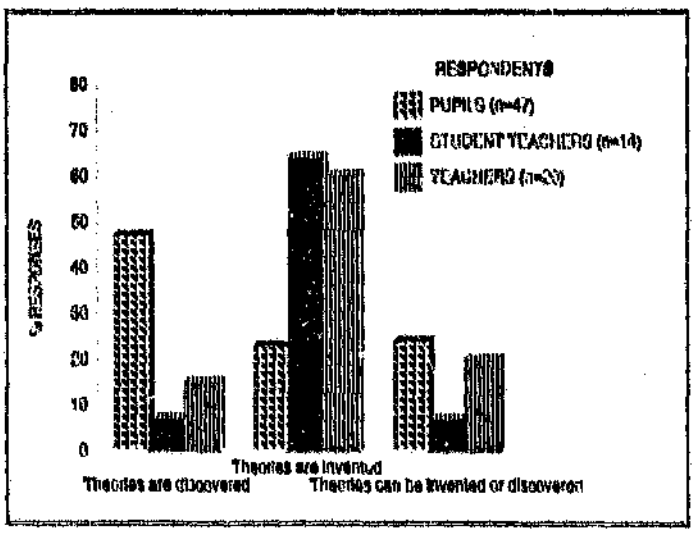


Figure 3: Pupils' and teachers' ideas on how theories are formed

discoveries in science would be a waste of time if we assumed that science was not logical. Many discoveries have been accidental and many have come about from a series of investigation building logically one upon the other.

Finally, although scientific work within a paradigmic period may be conceived as progressing in an orderly, step by step manner, scientific work between successive paradigms cannot be considered as such. Kuhn and Popper seem to agree that science does not progress by accretion between successive paradigms (Watkins, 1970).

4.5 VIEWS ON THE INVENTION OR DISCOVERY OF THEORIES

Table 6: Respondents' views about theories

P	ST	T %	
			For this statement, assume that a gold miner "discovers" gold, while an artist "invents" a sculpture. Some people think that scientists discover scientific THEORIES. Others think that scientists invent them.
			What do you think?
			Scientists **discover** a theory:
30	7	5	A. because an idea was there all the time, just needing to be uncovered.
13	0	10	B. because it is based on experimental facts.
4	0	0	C. but scientists invent the methods to find the theories
24	7	20	D. Some scientists may stumble onto a theory by chance, thus discovering it. But other scientists may invent the theory from facts they already know.
			Scientists **invent** a theory:
19	80	50	E. because a theory is an interpretation of experimental facts which scientists have discovered.
4	14	10	F. because inventions (theories) come from the mind • we create them.
6	22	8	G. None of these choices fits my basic viewpoint which is .....

Theories are propositions devised to explain observations, facts and laws, and to make predictions (Ryan and A'kenhead, 1992). Theories give a sense of understanding to the facts and laws they explain. To give better comprehension, models or other visual representations may be used (Ryan and Aikenhead, 1992). A theory is paradigm bound, and may enjoy a high degree of scientific confidence as long as no other theory supersedes it or no paradigm-change occurs. It used to be thought that theories were logically derived from laws. Today theories are attributed

The largest category of respondents (53 per cent of pupils, 64 per cent of student teachers, and 85 per cent of teachers), who selected option B, agreed with the view that scientific discoveries usually follow from a well-planned series of investigations although imagination and trial and error may play a role. Ryan and Aikenhead (1992) acknowledge the consistency of this option with currently held views .

The next most popular choice was option C which stresses the accidental nature of most discoveries. This option was selected by 34 per cent of pupils and 21 per cent of student teachers. Interestingly, no teacher selected this option. Clearly, some discoveries have been accidental; the unintended product of the scientist's research. Examples include the discovery of x-rays, radioactivity and electrons. The discovery of x-rays (Taylor 1941, cited in Kuhn, 1970a) occurred when the physicist, Roentgen, while investigating cathode rays, noticed a strange phenomenon. A barium platino cyanide screen at some distance glowed when the discharge was in progress. Further investigations led to the discovery of the x-rays.

The belief in accidental discoveries does not seem to be limited to pupils in this study. Solomon et al. (1992) invest[illegible] 14-year-old British pupils' responses to a question as to whether or not scientists know what they expected to happen before they did an experiment. Most of their responses seem to indicate scientists were thoughtless about the end-products of their investigations. The depiction of scientists in pupils' pictures with bandages on their faces was an additional confirmation to Solomon et al. that pupils have serendipitous notions of scientific investigations and discoveries. However, this serendipitous view did not persist after pupils were instructed in a course that dealt with the role of hypotheses and theories in past scientific discoveries (Solomon et al., 1992). Ryan and Aikenhead (1992), in a related study on 17-year-old American pupils, had similar findings. They believe pupils' views of most scientific discoveries being accidental may have been perpetuated by the media and popular writers of history of science (Ryan and Aikenhead, 1992).

The researcher concedes that while there are many accidental discoveries in science (see Roberts, 1989), there are many more cases of scientific discoveries occurring as a result of well [illegible]rmulated research programmes (Ryan and Aikenhead, 1992). The free response of a student te[illegible]her puts the accidental view of scientific discoveries into proper perspective. She noted that

4.4 PROGRESS IN SCIENCE

Table 5: Respondents' views about progress in science

P	ST	T	%	Progress in science occurs as a result of a series of investigations, each one building on an earlier one, and each one leading logically to the next one, until the discovery is made. What do you think?
9	0	10		A. All scientific discoveries result from a well-planned series of investigations. Experiments (for example, the experiments that led to the model of the atom, or discoveries about cancer) are like laying bricks onto a wall.
53	64	85		B. Usually scientific discoveries result from a logical series of investigations. But science is not completely logical. Discovery sometimes comes by a flash of imagination, or by trial and error.
34	21	0		C. Most scientific discoveries are accidental, or they are the unpredicted product of the actual intention of the scientist. Some discoveries result from a series of investigations building logically one upon the other.
4	0	0		D. Scientists do not know what to expect when they do experiments. Therefore scientific discoveries do not occur as a result of a logical series of investigations.
0	14	5		E. None of these choices fits my basic viewpoint which is .....

Contemporary opinion is that science processes which lead to progress in science do not simply involve experimentation and the systematic accumulation of facts. Kuhn (1970a) sees scientific development as a succession of paradigm-bound periods which are punctuated by non-cumulative breaks. The "normal science" practitioners engage in during the paradigm-bound periods do not produce major breakthroughs according to Kuhn, but are akin to puzzle solving. New theories are however thought of under situations when a phenomenon stubbornly refuses to be explained by existing ones. Each major advance in science alters previously established patterns of relationship. The decisive step leading to the development of a theory is often by a leap of imagination, intuition or a flash of inspiration (Kuhn, 1970a). Hence, option B is currently considered to be the most acceptable.

What are the views of respondents on the progress in science? (See Table 5). Although options A and B agree with the premise that scientific discoveries result from an orderly set of investigations, there are other differences between them. Option A suggests all scientific discoveries come from well planned investigations, while option B maintains that some aspects of science are illogical, with some discoveries coming through flashes of the imagination or by trial or error.

As in the above quotation, other respondents seem to express principles similar to mathematical or logical proof, where premises and rules of inference are used to strengthen arguments to prove a point (Kuhn, 1970a). A content-oriented, positivist view of science, it is suggested, portrays science in this way. Contemporary scientific views on theory choice suggest it is the values of the scientific community that are important - values such as accuracy, simplicity, fruitfulness. These values which are generally shared by the scientific community provide the basis for decision making. Kuhn (1970a) supports this view about the shared values of the scientific community influencing theory choice, and believes this is achieved through persuasion.

The most popular anti-consensus view selected by the teachers is that as long as a theory explains results and is useful, the opinions of other scientists are irrelevant. Clearly, this view does not acknowledge the important role played by the scientific community in knowledge generation.

It should also be noted that "radically new" theories are never accepted under an old paradigm. A radically new theory only gains prominence when the old paradigm is unable to explain important observations, and this happens during the "crisis" period (Kuhn, 1970a).

For some teachers, selecting one answer to this item was difficult as they agreed with two very different options. This clearly shows they were uninformed on how decisions are made in science: As one candidly wrote for option G: "...I would accept both of the above C and F". The student teachers, in general, seem to have a clearer view of the role and establishment of a theory than other respondents. A current and acceptable view was expressed as follows:

> Many theories have very little supporting evidence and are used because many scientists agree with the logic and apparent valuability of the theory.

Although this attitude towards "supporting evidence" is questionable, the view is generally realistic. The evidence supporting the Big Bang theory and the theory of Continental drift, for example, may not be considered convincing by others outside the research paradigm. However, since scientific knowledge is not fixed but provisional, there is the possibility of such theories being updated or discarded in the light of new evidence. Indeed, this is one of the processes that makes scientific knowledge dynamic.

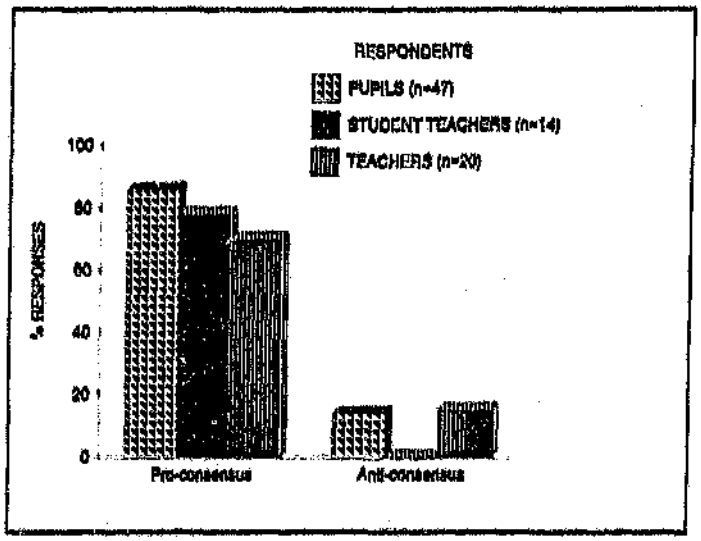


Figure 2: Pupils' and teachers' views about scientific knowledge generation

Clearly, the majority of respondents selected the consensus view. But a critical look at the options reveals that pupils and teachers were divided between options A and C. Option C, which is in line with current epistemology of science, was selected by 43 per cent of pupils, 35 per cent of teachers, and 64 per cent of student teachers. It is encouraging that the majority of the student teachers were aware of the importance of scientists convincing others before scientific knowledge is accepted as reliable.

The sizeable percentage of pupils and teachers who selected option A, it appears, do not understand how consensus is reached. To them, it entails providing conclusive evidence to prove a theory true. This is in line with the content-oriented view discussed in section 4.1 in which science is seen as a fixed body of facts which have been proven true. This viewpoint of conclusively proving a proposed theory (option A) was expressed strongly in the open responses (option (i). As one student teacher noted:

> once a theory is proposed it needs to be conclusively proved, a consensus needs to be reached and it needs to fit into the present paradigm and be workable unless of course it is radically new.

4.3 KNOWLEDGE GENERATION IN SCIENCE

Table 4: Respondents' views about knowledge generation

P	ST	C		When a new scientific theory is proposed, scientists must decide whether to accept it or not. Scientists make this decision by consensus; that is, proposers of the theory must convince a large majority of fellow scientists to believe the new theory. What do you think?
				Scientists who propose a theory must convince other scientists:
43	14	35	A.	by showing them conclusive evidence that proves the theory true.
0	0	0	B.	because a theory is useful to science only when most believe the theory.
43	64	35	C.	because when a number of scientists discuss a theory and its new ideas, scientists are likely to revise or update the theory. In short, by reaching a consensus, scientists make the theory more accurate.
				Scientists who propose a theory do not have to convince other scientists:
8	0	0	D.	because the supporting evidence speaks for itself.
2	0	0	E.	because individual scientists will decide for themselves whether to use a theory or not.
4	0	15	F.	because an individual scientist can apply a theory as long as the theory explains results and is useful, no matter what other scientists believe.
0	22	15	G.	None of these choices fits my basic viewpoint which is .....

When is a theory accepted to become part of the body of scientific knowledge? Ziman (1984) points out that the 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. Kuhn (1970a) believes it is these experts working within the same paradigm, who on examining the evidence, decide whether or not to uphold the theory. Where there are rival theories, Kuhn (1970b) contends that the superiority of one theory over another cannot be *proved* in a debate. Instead, each party to the debate tries to persuade the other of the merits of their theory. The end result is that one party is won over to the other side or "converted" (Kuhn, 1970b).

How do pupils and teachers view scientific knowledge generation? (See Table 4). Figure 2 conveys the opinions expressed by the respondents combined as either pro-consensus or anti-consensus views. The pro-consensus view (options A and C) recognise the importance of consensus within the scientific community in the generation of knowledge, whereas the anti-consensus view (options D, E and F) does not.

What are the respondents' views on "the" scientific method? (See Table 3). Options A to E represents various forms of the "enquiry" or "experimental" method. Option G portrays "the scientific method" as an attitude, while option I is the contemporary position on "the scientific method".

For a sizeable percentage of respondents (32 per cent of pupils, 43 per cent of student teachers and 60 per cent of teachers), the scientific method is a series of experimental steps (option E). Pupils and teachers but not student teachers also favoured some aspects of experimental procedure (options B, C and D). In trying to explain why respondents select the experimental steps as the scientific method, Gallagher (1991) believes they seem to confuse scientific method with the way one records and reports scientific experiments or structures scientific papers. It is apparent that the contention by recent philosophers and writers about the scientific method has not been explicitly discussed in most classrooms and lecture halls. Gallagher notes that even when a textbook carries a more enlightened view of the methods of science, most teachers stressed the "steps of the scientific method" as the major point when teaching it. The enlightened view that science has no one entirely rational method needs to be discussed in teacher training institutions, if pupils are to be encouraged to design and explore various modes of experimentation.

Student teachers were the only group to regard the scientific method as an attitude that guides scientists in their work. This point is further explored in section 4.12. Only about one-fifth of student teachers and a smaller proportion of pupils and teachers selected the position which says there is no one correct scientific method.

However, in retrospect, it is clear that there are problems with the phrasing of this question. These problems are discussed in the critique of the study on page 71.

example, one teacher noted "...all of the above could be science". A Std 10 pupil expressed clearly this lack of uniform view of science when he noted "...science is all around us, it is included in all these answers. You can't pinpoint science to one thing, everything is taken into". One could argue that many of the activities mentioned in the various options have a part in science. However, the question says "But science is *example*".

4.2 SCIENTIFIC METHOD

Table 3: Respondents' conceptions of "the scientific method"

P	ST	T	When scientists investigate, it is said that they follow the scientific method. The scientific method is:
4	0	5	A. the laboratory procedures or techniques, which are often written in a science book or journal by a scientist.
9	0	0	B. recording your results carefully.
10	0	5	C. controlling experimental variables carefully, leaving no room for interpretation.
34	0	15	D. testing and retesting - proving something true or false in a valid way.
32	43	60	E. the identification of a problem, offering a hypothesis, and conducting an experiment to prove it with a conclusion.
2	7	0	F. a logical and widely accepted approach to problem solving.
0	22	0	G. an attitude that guides scientists in their work.
11	21	15	I. Considering what scientists actually do, there is no such thing as "the scientific method".
2	7	0	J. None of these choices fits my basic viewpoint which is .....

In practical terms, science involves an organisation of people who have ideas and techniques for discovering new knowledge (Ryan and Aikenhead, 1992). Given the diverse forms of scientific knowledge which exists and the equally numerous techniques for arriving at such knowledge, contemporary views indicate that there is no such thing as "the" scientific method (Hodson, 1982). Scientists use any method that is appropriate for obtaining results including imagination and creativity (Chalmers, 1983). There is, however, a scientific attitude which may be used by scientists to guide them in their work (Gauld, 1982).

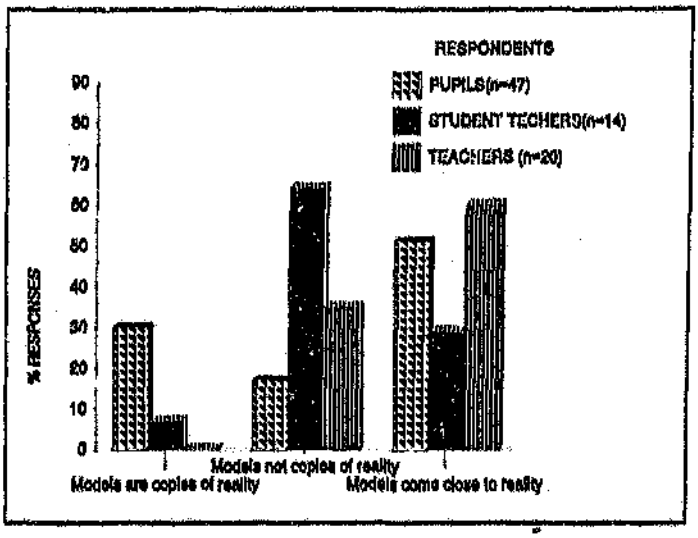


Figure 9: Pupils' and teachers' views about models

Although only about 17 per cent of pupils hold contemporary views of scientific models, an impressive opinion was given by a pupil when he noted:

> they are physical forms of what the scientist believes the structure will look like after many experiments, logical thinking and rationalizing. They are useful as a visual interpretation.

A teacher with a more ontological view wrote:

> Scientific models simulate reality and are attempts to explain reality. The better the model the closer it resembles reality.

Kuhn believes there is no way of knowing if we are getting closer to reality. He maintains that until we define the approach to truth as the result of what scientists do, we cannot recognise progress toward that goal. Hodson (1988) does not totally agree with this view. He sees some theories as true descriptions of the world and models as convenient devic s for manipulation and description.

The answers to this debate are not easily found without appealing to some philosophical debates about reality and truth. Stanley and Brickhouse (1994) attempt to resolve the controversy on what is real or true by arguing that even if we assume a material reality exists independently to the observer, our knowledge of reality will always be mediated, incomplete, and distorted. Thus,

played with. These were hold-in hand models of the inner constitution of nature. In recent times, a model is regarded as something you can hold in your head rather than your hands, or a mixture of both (Hacking, 1983). Where there are theories or phenomena which are too complex to discern, models are used as approximate representations of them - an instrumentalist position.

The debate among philosophers of science over the status of theoretical models (just like theories) has been polarised into two extreme positions: the naive realist who considers such devices to be true representations of reality, and the instrumentalist who regards them as fictions, logical constructions or intellectual instruments for reasoning about the world (Hodson, 1986). Hodson believes the two extreme positions have serious limitations when compared to the actual practise and history of science. The *critical realist position*, according to Hodson, presents the best account of theory from the point of view of the learner. It takes a realist view concerning theories which they believe are true, and takes an instrumentalist view of others they find as useful but not true. Hodson (1986) has further urged that the role and status of theories and models be defined quite early in the science classroom in order to forestall excessive instrumentalism and naive realism views developing in the classroom.

Three positions are embraced by the options in this item:
a) Scientific models are copies of reality (options A, B a
b) Scientific models come close to being copies of reality (option D).
c) Scientific models are not copies of reality (options E and F).

What do respondents see models to be? (See Fig. 9). Between 50 and 60 per cent of pupils and teachers regard models as close to copies of reality. Twenty-nine per cent of student teachers also chose this option. Sixty-four per cent of student teachers do not regard models as copies of reality. This puts the student teachers as the largest group who favoured the contemporary view.

Thirty per cent of pupils appear to hold a purely realist perspective in which models are seen as true copies of reality (options A, B and C). Student teachers and teachers do not seem to be committed to this perspective.

impurities dissolved in the glass. Ziman (1978, 75) summarising the main points of the argument notes:

> But our main point is to notice the uncertainties and errors that can accompany good experimental technique by highly competent research workers, and the necessity of independent replication and verification of the results of observation if we are to acquire reliable empirical knowledge concerning the external world.

This view of the pupils and teachers that competent scientists can observe and reach similar conclusions even when they believe in different theories underscores an ontological view of a reality being out there which can be observed in an unbiased way.

It is worth noting that between 5 per cent and 13 per cent of the respondents believe that observations are exact (Table 10). This position seems to be a positivist view termed "excessive rationalism" (Nadeau and Desautels, 1984).

4:10 SCIENTIFIC MODELS

Table 11: Respondents' conceptions of scientific models

P	ST	T %	Many scientific models used in research laboratories (such as the model of the wave, the neuron, DNA, or the atom) are copies of reality. What do you think?
			Scientific models ARE copies of reality:
2	0	0	A. because scientists say they are true, so they must be true.
11	0	0	B. because much scientific evidence has proven them true.
17	7	0	C. because they are true to life. Their purpose is to show us reality or teach us something about it.
51	29	60	D. Scientific models come close to being copies of reality, because they are based on scientific observations and research.
			Scientific models are NOT copies of reality:
17	64	35	E. rather they are simply helpful for learning and explaining, despite their limitations.
0	0	0	F. and therefore they have no use in science.
2	0	5	G. None of these choices fits my basic viewpoint which is .....

The word 'model' has taken different meanings in the sciences. According to Hacking (1983), in the early days models of molecules were like scale models of cars and aircraft that children

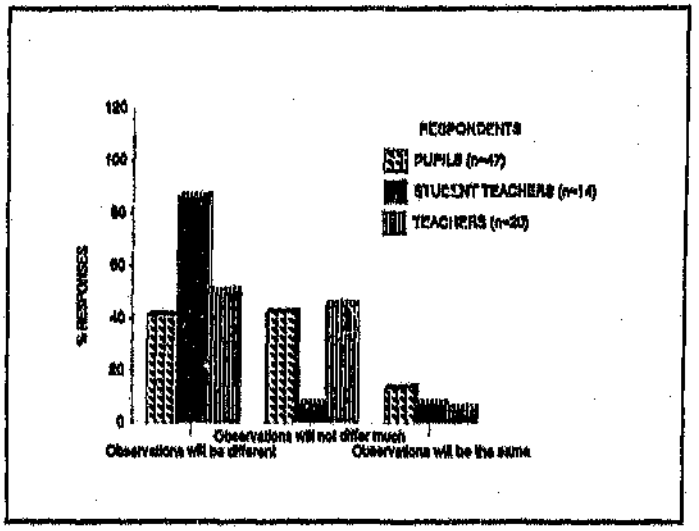


Figure 8: Pupils' and teachers' views about scientific observations

While option C is considered to be the most current view, sound arguments can be made for option B. The responses of student teachers are particularly favourable. Eighty-six per cent of these future teachers were aware that observations are theory-dependent.

The general trend of pupils' answers is similar to that of teachers (Fig 8). Fifty per cent of teachers and 41 per cent of pupils regard observations as theory-dependent. However, the reasons cited by these two groups for this view are quite different (Table 10). More teachers selected the accepted reason that observation is influenced by what the observer already knows.

Another similarity is that 42 per cent of pupils and 45 per cent of teachers hold the view that the observations of scientists who believe in different theories will be very similar. This view is quite mistaken as historical accounts do not seem to support it. An example is that of anomalous water described in Ziman (1978, 73). This water was condensed from the vapour in fine glass capillaries. Its strange properties, high viscosity, and strange behaviour on melting left competent scientists divided over its real nature. Some suggested it was a new phase of water, while others thought it was a polymer of ordinary water - polywater. However, after many observations and publications on the subject, it became clear that the anomalous properties were simply due to

4.9 SCIENTIFIC OBSERVATIONS

Table 10: Respondents' views about scientific observations

P	ST	T %	Scientific observations of the same thing made by two competent scientists will often be different if the scientists believe in different theo What do you think?
13	29	5	A. Yes, because scientists will experiment in different ways and will notice different things.
17	29	10	B. Yes, because scientists will think differently and this will alter their observations.
11	28	35	C. Yes, because what a scientist already knows will affect what he observes.
42	7	45	D. Scientific observations will not differ very much even though scientists believe different theories. If the scientists are indeed competent their observations will be similar.
9	0	5	E. No, because observations are as exact as possible. This is how science has been able to advance.
4	7	0	F. No, observations are exactly what we see and nothing more; they are facts.
4	0	0	G. None of these choices fits my basic viewpoint which is .....

Observation, as a primary source of data, has always been part of natural science. Scientific observations are made using the senses and perhaps instruments as aids. The current view of science maintains that what scientists observe is influenced by their past experience, existing knowledge and expectations (Chalmers, 1983). Furthermore, observations do not provide automatic access to secure factual information, but must be interpreted in the light of the theoretical beliefs of the individual (Hodson, 1986). Observations are therefore subjective, fallible and theory-laden. When confronting the same phenomenon, Hodson (1986) notes that competing theories may give rise to non-identical observations. In fact, Hacking (1983) believes observation is a skill, with some people better at it than others, but the skill can be improved by training and practise.

The views in this item can be grouped in three ways:

a) Observations made by different scientists will often be different because observations are theory-dependent (options A, B and C).

b) Observations made by different scientists will not differ very much because observations are not theory-dependent (option D).

c) Observations made by different scientists will be the same because they are not theory-dependant (options E and F).

> If the hypothesis is correct it can be repeated on other kinds of samples and then become a theory. Only become a law after further experimentation to make a law which will cover a general statement, eg. Any object thrown up will fall.

The distinction between hypothesis and theory is often unclear in the literature. Chalmers' (1983) falsificationist account sees theories as speculative and tentative conjectures or guesses freely created by the human intellect. Such a definition is more appropriate for "hypothesis". Popper (1963) is quite clear on what hypotheses are - conjectures. He argues that a form of hypothesis precedes every form of planned scientific investigation, and he takes pains to distinguish hypotheses from theories. Hypotheses can with supporting evidence become theories. If further supporting evidence is found for a theory, the same theory will enjoy greater articulation and confidence from the scientific community, but that does not make it a law (Ryan and Aikenhead, 1992).

The possible influence of everyday meanings of these terms is a factor that could have contributed to the misconception. Audesirk and Audesirk (1993, 12) support this view when they note that a "...scientific theory is similar to what we would call a "law" or "fact" in common English usage". The law of gravity, they noted in common English usage, is equivalent to the theory of gravitational attraction in physics. In addition, the misconceptions about hypotheses, theories and laws demonstrated by the respondents may have been the result of poor high school textbook writing or poorly taught science courses. This assertion is most probable when it is realised that certain elementary science textbooks portray this hierarchical relationship between the concepts. Ayerst et al. (1989, 6) for example note:

> Eventually scientists will publish a hypothesis that will be so successful at predicting what will happen that it becomes known as a theory. If the theory is shown to be always correct it may even become a law.

Options A and B, while maintaining that theories can't become laws, differ from each other in the following perspective: Option A sees laws as 100 per cent certain, and theories less than 100 per cent certain. Option B, which agrees with current views, sees laws as mainly descriptions and theories as explanations.

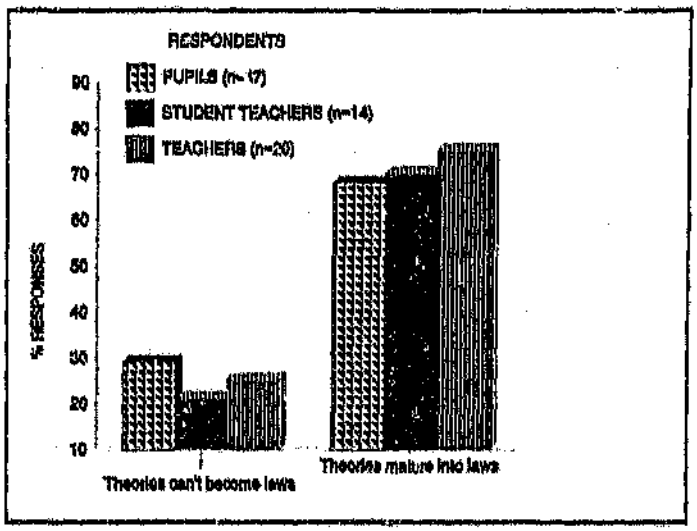


Figure 7: Pupils' and teachers' ideas about theories, hypotheses and laws

Options C and D are quite similar. Both agree with the viewpoint that with repeated testing, hypotheses can develop into theories and finally laws, but differ on how the stages are achieved. Option C supports the testing of an hypothesis to prove it correct (similar to the falsificationist position), while option D appeals to supporting evidence.

The results, as shown in Fig. 7, indicate that an overwhelming majority of respondents believe there to be an hierarchical relationship between hypotheses, theories and laws. They appear to believe that hypotheses mature to become theories and theories may eventually become laws. Option C, which stresses that it is the "amount of proof" sustained by an hypothesis and theory which allows it to become a law, was the choice of 47 per cent of the pupils and 35 per cent of teachers. This choice provides additional evidence that many pupils and teachers subscribe to the view that things can be proved conclusively in science. It is disturbing that the student teachers, despite having recently completed a short course in the philosophy of science, hold incorrect views regarding hypotheses, theories and laws. An example of one such view from a student teacher is as follows:

it, they are very tentative explanations or descriptions that guide investigations. Laws, on the other hand, are general statements that enjoy a high degree of scientific confidence. Finally, theories are propositions which are devised to explain observations, facts and laws, and to make predictions. Theories may also enjoy a high degree of confidence as laws do, but a theory cannot mature and become a law (Ryan and Aikenhead, 1992). Rather, it explains the law (Campbell, 1953). Laws and theories are therefore two different forms of statements, and both are distinguished from hypotheses by virtue of the degree to which they have been accepted by the scientific community (Ryan and Aikenhead, 1992). Figure 6 illustrates the relationships between these concepts. While these relationships are supported in the current literature, they are still hotly debated.

What are respondents' views about hypotheses, theories and laws. This item explored firstly, the assumption that theories and laws are different types of ideas (options A and B); and secondly, the hierarchical relationship in which hypotheses become theories which then become laws (options C, D and E).

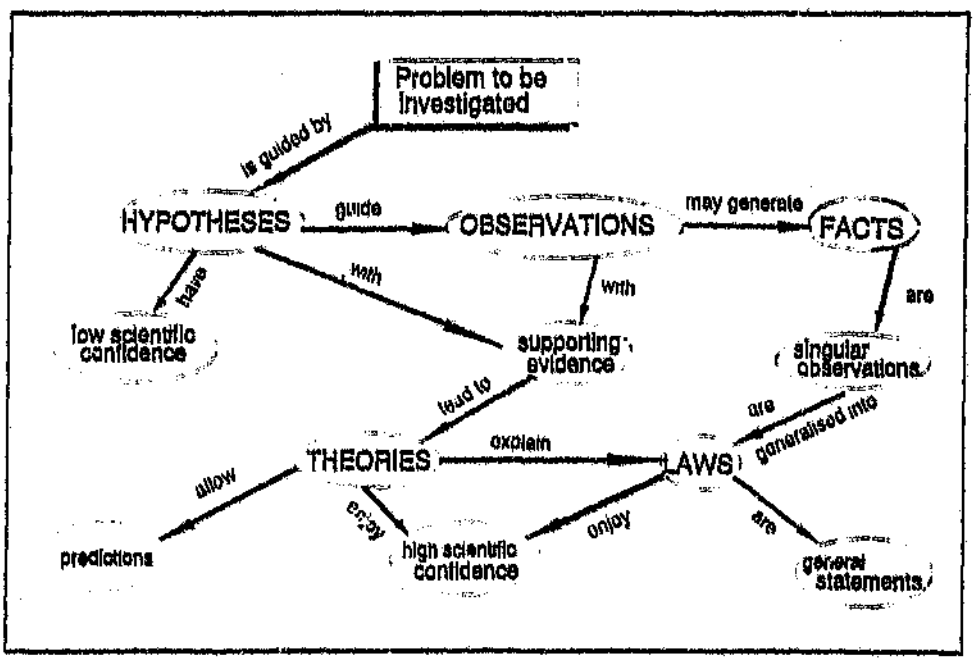


Figure 6: A concept map showing relationships between key scientific ideas

interesting to note that this particular student teacher is a physics and chemistry graduate. One wonders if the statement is a reflection of his observation about theories at the university level.

Another student teacher noted "...although a theory should be stated as simply as possible one must avoid over simplification which could lead to misconceptions". Even though the concern raised over the over simplification of theories is valid, it is clear the respondent is not fully informed of the criteria used in theory selection. As Lederman and Zeidler (1987) noted, accuracy and simplicity of explanations as opposed to complexity are of paramount importance when choosing a theory. It is the researchers' opinion that when the criterion of accuracy of a theory is satisfied, the "fear of over simplification" equally gets reddressed. For the accuracy of a theory would forestall its over simplification that would lead to misconceptions.

4.8 VIEWS ON HOW SCIENTIFIC IDEAS DEVELOP

Table 9: Respondents' views about scientific ideas.

P	ST	C %	**Scientific ideas develop from hypotheses to theories, and finally, if they are good enough, to being scientific laws. What do you think?**
15	7	15	A. Theories can't become laws because they are different types of ideas. Theories are based on scientific ideas which are less than 100% certain, and so theories can't be proven true. Laws, however are based on facts only and are 100% sure.
15	14	10	B. Theories can't become laws because they are different types of ideas. Laws describe things in general. Theories explain these laws. However, with supporting evidence, hypotheses may become theories (explanations) or laws (descriptions).
			Hypotheses can lead to theories which can lead to laws:
47	15	35	C. because an hypothesis is tested by experiments. If it proves correct, it becomes a theory. After a theory has been proven true many times by different people and has been around for a long time, it becomes a law.
17	50	20	D. because an hypothesis is tested by experiments. If there is supporting evidence, it's a theory. After a theory has been tested many times and seems to be essentially correct, it's good enough to become a law.
4	7	20	E. because it is a logical way for scientific ideas to develop.
2	7	0	F. None of these choices fits my basic viewpoint which is .....

The meanings of, and relationships between, the concepts of fact, theory, law and hypothesis are very important in science. Most scientists engage their investigations with some form of preconceptions or hypotheses (Popper, 1980). These hypotheses are the ideas or educated guesses of scientists about problems or issues in science. Or as Ryan and Aikenhead (1992) put

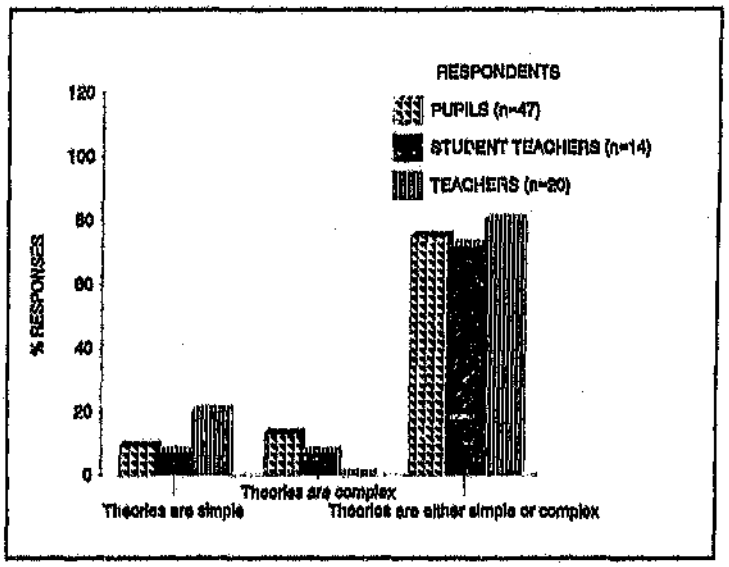


Figure 5: Pupils' and teachers' ideas about the structure of good theories

The most favoured opinion is that theories can either be simple or complex. (See Fig. 5). This position was selected by 75 per cent of pupils, 72 per cent of student teachers and 80 per cent of teachers. This is in contrast to the currently acceptable position which is more inclined towards the simplicity of theories. This option was selected by 9 per cent of pupils, 7 per cent of student teachers and 20 per cent of teachers. One student teacher, supporting the simplicity of theories viewpoint in the open response (option F), stated that theories should be simple but must "...not allow for misinterpretations - or enormous number of exceptions". This proposition is justified when it is noted that Rubba's Model of Scientific Knowledge prefers simplicity of theories (although not forbidding complex ones) (Rubba and Andersen, (1978). The criterion for choosing a theory, according to Rubba and Andersen, is that it would be able to explain the greatest number of observations with the minimum number of concepts.

It is surprising and encouraging to note that only 12 per cent of pupils, 7 per cent of student teachers and no teachers regard theories as complex. What are the views of some respondents who see theories in science as complex? One pupil believes "...science is simple, but the theories (although stated simply) are actually complex". This certainly raises concern if pupils begin to see the form of theories as complex. A student teacher who doubted the simplicity of all theories wrote "...some theories are simple, others are more difficult". He certainly has a point. It is

4.7 THE COMPLEXITY OF THEORIES

Table 8: Respondents' opinions about the structure of good theories

P	ST	T %	Good scientific theories explain observations well. But good theories are also simple rather than complex. What do you think?
9	7	20	A. Good theories are simple. The best language to use is simple, short, direct language.
34	57	50	B. It depends on how deeply you want to get into the explanation. A good theory can explain something either in a simple way or in a complex way.
41	15	30	C. Good theories can be complex, but they must be translated into simple language if they are going to be used.
6	7	0	D. Theories are usually complex. Some things cannot be simplified if a lot of details are involved.
6	0	0	E. Most good theories are complex. This is because science is complex and difficult to understand.
4	14	0	F. None of these choices fits my basic viewpoint which is .....

Scientific knowledge is a product of human imagination and expresses the creativity of scientists. According to Rubba and Andersen (1978), although scientific knowledge tends towards simplicity, it can at times be complex. It is also comprehensive instead of being specific with effort being made to develop a minimum number of concepts to explain the greatest number of observations. Where there are two theories that equally explain an observation, the current practice of scientists is to choose the simpler of the two (Rubba and A. [illegible], 1978). As Lederman and Zeidler (1987) noted in support, scientific knowledge attempts to achieve accuracy and simplicity of explanation as opposed to complexity.

What do respondents think about the structure of theories? Three positions are embraced by the options in this item:

a) Theories are simple (option A).

b) Theories are complex (options D and E).

c) Theories can be either simple or complex (options B and C).

Option A is a falsificationist position, in which science is seen to progress by disproving the scientific theories of the past. This position was held by 60 per cent of the pupils, 64 per cent of student teachers, and 45 per cent of teachers. Even though a large percentage of student teachers selected the falsificationist position, some were aware of the difficulties inherent in the falsificationist process as discussed by Lakatos (1970). For example, a student teacher wrote, "I would combine A and B and include the fact that theories might not be disproved but rather modified in the light of new research".

Options C and D maintain scientific knowledge may appear to change for a variety of reasons: Option C suggests changes in interpretation or application of old facts, while option D suggests new information is added to the old knowledge as reasons for the changes. (See Table 7). Position D is an out-dated view which sees knowledge accumulation as the essence of the scientific process, while option C runs counter to the view that observation is theory-laden (Ryan and Aikenhead, 1992). Both positions seem to have received little support from teachers and student teachers. However, about a quarter of the pupils seem to share the view that although scientific knowledge does not change, it may appear to change due to new knowledge being added to it or to different interpretation. It is disturbing that so many pupils believe that knowledge from scientific investigations does not change with time.

An adequate conception of the tentative nature of scientific knowledge has been regarded by some researchers as the "primary attribute of scientific knowledge" (Lederman and O'Malley, 1990), and also as an important goal of science education (Cotham and Smith, 1981). Clearly, while the vast majority of respondents held acceptable views about scientific knowledge being provisional, these results seem to suggest that only the minority have ideas corresponding to current views about how scientific knowledge changes.

5.1.3 Opinionnaire administration

As explained on page 34, two procedures were used to administer the opinionnaire. In retrospect, the procedure should have been more rigorous. All teachers should have completed the opinionnaire in the presence of the researcher, thus ensuring uniformity in the administration procedure. Whilst it is strongly believed that there was no collusion in the answering of the opinionnaire, this cannot be guaranteed. As a result, the validity of the results may have been compromised.

5.2 SUMMARY OF THE MAIN FINDINGS

Five key areas within the nature of science were explored in this research. These were: defining science, knowledge generation, assumptions underlying scientific knowledge, conceptual inventions, and values in the practice of science.

In addition to a summary of the main views of respondents on items in these five areas, an attempt will be made to evaluate the adequacy of such views when compared to those expressed by supporters of the "new" philosophy of science. The criteria for measuring adequacy presents some inherent problems. Various criteria have been used in measuring respondents' views of the nature of science. Cotham and Smith (1981) used the tentative nature of science as the basis for assessing adequacy. Ryan and Aikenhead (1992) determined adequacy of conceptions in terms of how respondents fared on each item. Similarly, in this study the adequacy of respondents' views is determined in terms of how respondents fared in each of the five key areas. Views are judged as adequate if contemporary perspectives are selected by a large majority of each sample.

5.2.1 Definitions of science

It is evident that respondents do not have a well defined meaning of science. The content-oriented and process approaches were selected by more than two-thirds of pupils and teachers. This puts their viewpoints in line with positivistic thinking which sees science as a body of facts. About one-third of student teachers seem to have acceptable perceptions of what science is: a socially constructed human activity oriented towards understanding and explaining the world.

them was subtle. It was felt that in such cases, the options should have combined and reworded to give respondents a smaller range of options which were clearly different.

The instrument, as noted by Aikenhead, Ryan and Desautels (1989), was based on the empirical data of students, rather than on the philosophical stances of science educators. Thus, although a wide sample of student views were obtained, the contemporary perspectives were often missing from the options. For example, the definitions of science from a multicultural viewpoint and an option linking the three aspects of science were not included in item 4.1. In retrospect it is believed that the current views about the nature of science should have been included in the options of each item.

Two other issues which relate to the content of the items were also found to be problematic. The first problem is that of having a stem sentence with a viewpoint with which respondents could strongly agree or vigorously disagree. Although respondents were instructed that they might agree or disagree with the stated views in the stem sentence, it is natural for respondents to be biased by a stem sentence which may be correct or incorrect. A reasonable alternative would have been to reword all the stem sentences so that they were neutral. A specific example of this problem is found in item 4.2, the stem sentence of which affirms there is one scientific method and requests respondents to identify the scientific method from the options. Although scientific literature indicates there is no such thing as "the" scientific method, the nature of the stem statement is quite misleading and is likely to bias or confuse respondents into believing there is one scientific method - "the" scientific method.

The researcher believes that in relation to the above problems, a rewording of the items would have improved the quality and reliability of the instrument. In addition, these problems could have been addressed by piloting the instrument a few more times with different samples, and interviewing selected respondents in more depth before the final administration of the instrument. Initially the researcher was swayed by the tremendous time and rigour put into the development of the instrument (Aikenhead and Ryan, 1992), and the need to maintain the validity of the instrument. In retrospect, it might have been appropriate not to modify the existing instrument but rather to design a new instrument loosely linked to VOSTS but tailored to the specific needs of the participants in this research.

CHAPTER 5
CONCLUSION

This concluding chapter includes a critique of the study, and a summary and discussion of the major findings. Finally, the implications of the study and recommendations for science education in South Africa are considered.

5.1 CRITIQUE OF THE STUDY

5.1.1 Research design

The research design adopted in this study seems to be the most appropriate given the time constraints within which the research was to be completed. The study attempted to explore the views of a small sample of pupils and teachers on the subject. It is believed that a large randomly selected sample was inappropriate for such an initial study. However, the nature of the sample does limit the generalisability of the results. It is hoped that the data provided will allow the reader to determine the transferability of the information (Lincoln and Guba, 1985).

5.1.2 Instrument

The administration of the instrument and the analysis of the data revealed several problems with the structure and content of the instrument. These problems occurred despite the tremendous effort put into the rigorous development of the instrument by Aikenhead and Ryan (1992) and the subsequent modification by the researcher.

The problems that were associated with the structure of the opinionnaire had to do mainly with the stem statements and the options provided. The structure of some items was complex and may have confused or intimidated the respondents. For example, item 4.3 has a stem statement plus three options followed by another statement and four more options. Closely related to this problem is that certain items had too many options or options which were sometimes too similar. For example, options C and D in item 4.8 were so similar that the distinction between

a scientist will think in his scientific manner no matter where he is, and despite the political situation and environment.

The appreciation by the majority of pupils, student teachers and teachers that scientists are influenced by politics is a favourable recognition of scientists as members of the community, and whose activity can be influenced by the social and political milieu.

Options A to D clearly represent acceptable views of how politics affect scientists. A greater percentage of student teachers and teachers than pupils seem to be aware of how politics affect scientists in South Africa (Fig 11). Certainly, they were much more aware of how government funding determined and directed research. As one teacher noted: "... if a scientist is employed by a governmental department, funding directs his/her work".

On the political level, respondents were aware that government policies could affect the values of the scientist and cause negative reactions. A student teacher noted,

> negative political activity can cause a 'brain drain' of good scientists, consequently robbing the scientific community of significant contributors to scientific development.

A pupil noted the politically sensitive nature of certain scientists work and felt that government censorship could restrain their freedom to disseminate information freely. He said that

> scientists are affected by politics, perhaps because politics may or may not allow certain facts out due to political implications.

The opposing viewpoint that scientists are not affected by South African politics (options E and F) elicited responses from pupils and teachers but not from student teachers. A small percentage of pupils and teachers (9 per cent and 10 per cent respectively) felt the nature of scientists' work prevented them from taking to politics and therefore becoming affected. This view possibly supports the discarded stereotyped image of the scientist who is seen as a "workaholic" tied to the laboratory. Option F, selected by 19 per cent of pupils, is equally a mistaken image of the scientist which would have been appropriate for a different period in history (Gauld, 1982).

Generally, the student teachers and teachers seem to have a better understanding of the influence of politics on scientists than the pupils. This is not surprising since as adults they probably have a better appreciation of the historical situation in South Africa and its effects on the social and political life. A minority of pupils feel scientists are not affected by politics. As one pupil erroneously noted,

Fig. 11 conveys the answers selected by the respondents categorized into these two positions. Clearly, the majority of respondents sided with the view that politics affects scientists (options A to D) which fits the contemporary views of science.

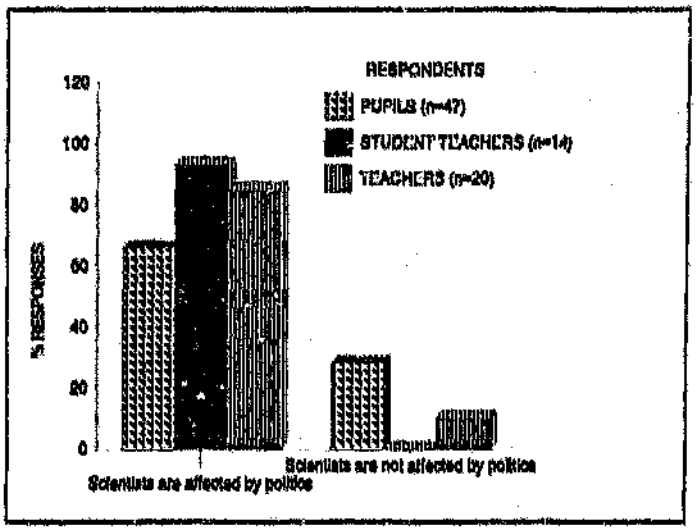


Figure 11: Pupils' and teachers' views on how politics affects scientists

However, different reasons were selected for that viewpoint. A fairly large percentage of respondents (36 per cent of pupils; 65 per cent of student teachers and 60 per cent of teachers) selected option B, which saw the influence occurring through both government funding and its research policy. This viewpoint is supported by Reiss (1993). He believes that in a society with limited financial resources, the choice of what to work on is not determined solely by scientific criteria, but to a large extent by the policies of the government of the day and the priorities of funding bodies.

Option A, which contends that the influence is exerted through government funding, was the choice of between 7 per cent and 15 per cent of pupils and student teachers. Options C and D focus on the human aspects of scientists, their links with society and their responsibility toward society. These two positions were favoured by a total of 13 per cent of pupils, 28 per cent of student teachers, and 25 per cent of teachers.

methods were employed, scientists were committed to principles that ensured that falsehood was not substituted for truth. Some of these principles constituted the scientific attitude (Gauld, 1982).

4.13: POLITICS AND SCIENCE

Table 14: Respondents' views on the effects of politics on scientists

P	Sf	Tch	Politics in South Africa affects South African scientists, because scientists are very much a part of the society (that is, scientists are not isolated from society). What do you think?
			Scientists ARE affected by South African politics:
15	7	0	A. because funding for science comes mainly from the government which controls the way the money is spent. Scientists sometimes have to lobby for funds.
36	65	60	B. because governments not only give money for research, they also set policy regarding new developments. This policy directly affects the type of projects scientists will work on.
9	14	25	C. because scientists are part of society and are affected like everyone else.
6	14	0	D. because scientists try to help society and thus they are closely tied to society.
			Scientists are NOT affected by South African politics:
9	0	10	E. because the nature of a scientist's work prevents the scientist from becoming involved politically.
19	0	0	F. because scientists are isolated from society; their work receives no public media attention unless they make spectacular discovery
6	0	5	G. None of these choices fits my basic viewpoint which is .....

Characterizations of scientists in the past have often provided stereotyped images of them as being deeply involved in their work, and with no other social concerns (Gauld, 1982). Contemporary views of science acknowledge its human dimensions and see scientists as people who are equally affected by the social and political life around them (Schibeci, 1986).

Does politics affect South African scientists? Two opposing viewpoints were embraced by the options:

a) Scientists are affected by politics (options A to D).
b) Scientists are not affected by politics (options E and F).

in Ryan and Aikenhead, 1992) reported that most credible scientists operated with values associated with private science, while "mediocre scientists" rather exhibit the scientific attitude.

Is the scientific attitude needed for doing the best science? What are the views of pupils, student teachers and teachers? Three perspectives were considered in this item:

a) The best scientists display certain characteristics (options A, B and C).
b) The best scientists do not necessarily display these characteristics (options D and E).
c) The best scientists do not display these characteristics (option F).

Research evidence seems to support many of the options that are in Table 13. The best scientists do display these characteristics in public science, (option A and C) but the view expressed in option B may be seen as naive. The abundance of such characteristics do not make you a better scientist. The views in the other options, while generally acceptable, can be debated.

The general indication among the three samples is in affirming the necessity of scientific attitude for doing "best science". A large percentage of student teachers and teachers seem to believe that additional personal traits are necessary to become good scientist (option C). The student teachers in this item seem to portray consistent views about the scientific attitude as they expressed for the scientific method.

The display of the scientific attitude is considered to make scientific knowledge objective (Ziman, 1978). Popper (1980) considers scientific knowledge objective if it can be tested against accepted observations and be understood by anybody. By selecting option C, a majority of respondents seem to hint at the notion of objectivity in scientific behaviour. Current views about scientific knowledge suggest it is socially constructed and therefore relies on the "subjective hunches" of individual scientists in their closets to provide the needed breakthrough. However, consistency only makes the observations objective but not valid (Ziman, 1978).

The option that the best scientists do not display these characteristics or that they are not important for doing good science was selected by a small percentage of pupils and teachers and no student teachers. Scientists generally do display these characteristics especially in public science (Ryan and Aikenhead, 1992). The great strides of science across history came because scientists sought after knowledge objectively. As Gould (1982) observed, although various

Table 13: Respondents' views on human qualities necessary for doing science

P	ST	T °/₀	The best scientists are always very open-minded, logical and unbiased in their work. These personal characteristics are needed for doing the best science. What do you think?
13	0	10	A. The best scientists display these characteristics otherwise science will suffer.
8	0	0	B. The best scientists display these characteristics because the more of these characteristics you have, the better you'll do at science.
36	57	55	C. These characteristics are not enough. The best scientists also need other personal traits such as imagination, intelligence and honesty.
			The best scientists do NOT necessarily display these personal characteristics:
13	7	10	D. because the best scientists sometimes become so deeply involved, interested or trained in their field, that they can be close-minded, biased, and not always logical in their work.
17	29	20	E. because it depends on the individual scientist. Some good scientists are always open-minded, logical, etc. in their work; while other good scientists can become close-minded, biased, etc. in their work.
11	0	5	F. The best scientists do NOT display these personal characteristics any more than the average scientist. These characteristics are NOT necessary for doing good science.
2	7	0	G. None of these choices fits my basic viewpoint which is.....

In the construction of scientific knowledge, values play an essential role (Longino, 1983). Longino distinguishes between two of such values. Firstly, the "constitutive values" which are science discipline centred, and include being open-minded, logical and unbiased. These values have also been labelled as the scientific attitude (Gauld, 1982; Shrigley, Koballa and Simpson, 1988). Secondly, "contextual values" are thought of as external to the discipline of science, and include ethical, ideological, and cultural values (Longino, 1983). Blier (1988, cited in Ryan and Aikenhead, 1992) supports Longino and has included gender as an additional contextual value.

In the practise of science, Holton (1978, cited in Ryan and Aikenhead, 1992) notes that two contrasting forms of behaviour patterns are exhibited by scientists. In public science, which is the science that is communicated to the public through textbooks, journals and conference proceedings, the scientific attitude or constitutive values are predominantly demonstrated. In contrast, private science is what occurs in laboratories and is discussed in conversations, notebooks and personal letters (Mitroff, 1974, cited in Ryan and Aikenhead, 1992). Most often it is associated with subjectivity, closed mindedness and bias. Each aspect of science (public or private) may therefore involve values contradictory to the scientific attitude. Mitroff (1974, cited

The instrumentalist position was embraced by the vast majority of respondents. This seems to suggest respondents that have a better understanding of the man-made nature of scientific classification than of models. A possible explanation for this is that the standard textbook (Horn, Brink and Jones, 1986) in use in many schools traces the historical development of the periodic table. As a result of this, respondents were possibly aware of the various schemes proposed until the acceptance of the ideas of Mendeleev (1834-1907).

Another contributory factor may be the inclusion of the principles of classification in the General Science syllabus at the Std 5 level (McCarthy, 1994). Although the importance, history, and nature of various classification systems are not addressed at a higher level (McCarthy, 1994), it might be that this early exposure is sufficient to develop sound understandings of the man-made nature of the classification systems. Equally important as an additional factor, is the everyday exposure to the use and/or design of simple classifications systems (e.g. for stamps and groceries in supermarkets).

The imprecisenes of scientific schemes, an impression possibly obtained from the classroom, was articulated by a pupil who wrote "...We don't know the way nature really is and therefore we can only classify the characteristics".

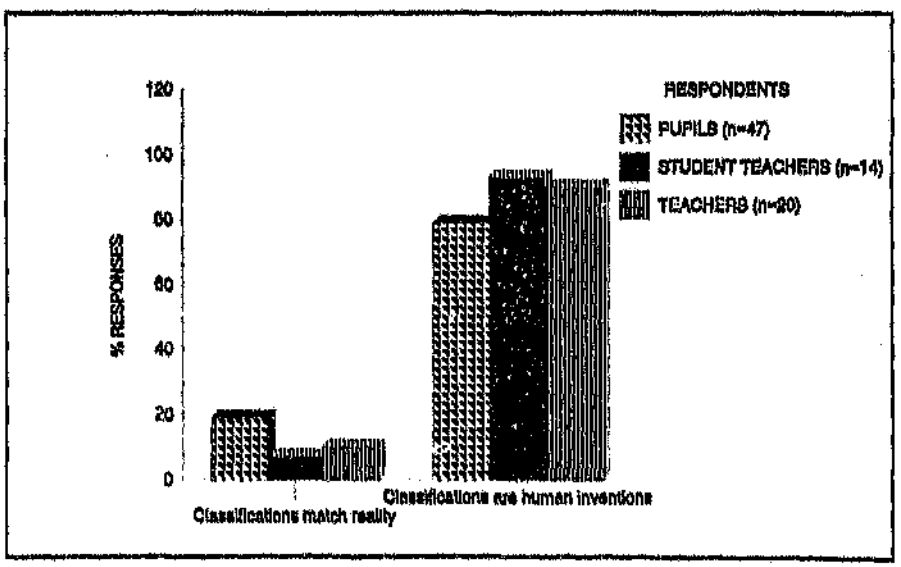


Figure 10: Pupils' and teachers' views about classification schemes

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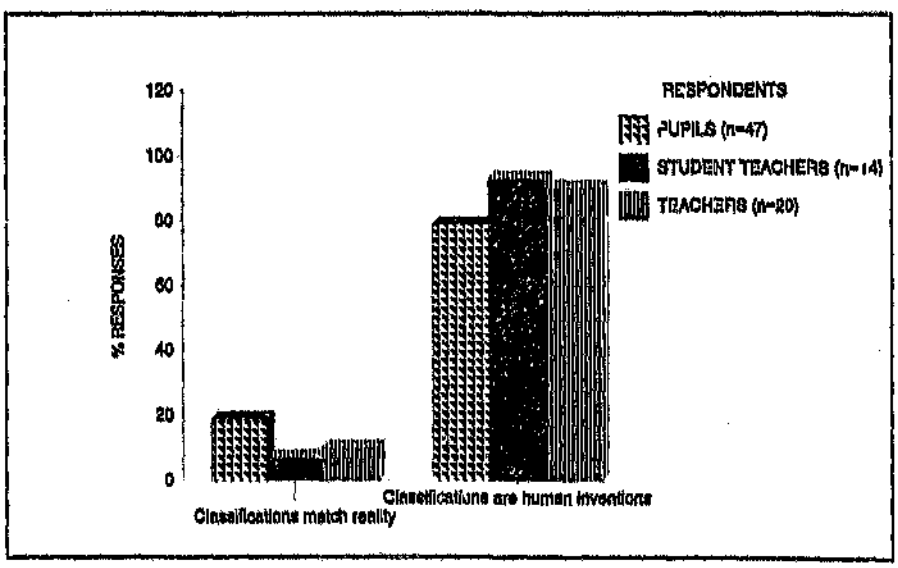


Figure 10: Pupils' and teachers' views about classification schemes

It is always the mediated view of reality that constitutes scientific knowledge. On the basis of their argument, models of Deoxyribonucleic acid (DNA), the atom, etc. should all be seen as mediated view of reality and therefore as invented.

4.11 CLASSIFICATION SCHEMES

Table 12: Respondents' views on classification schemes

P	ST	T %	When *scientists classify something* (*for* example, *a plant* according to its species, an element according to the periodic table, energy according to its source, or a star according to its size), scientists are classifying nature according to *the way nature really is*; any other way would simply be wrong. What do you think?
6	0	0	A. Classifications match the way nature really is, since scientists have proven them over many years of work.
13	7	10	B. Classifications match the way nature really is, since scientists use observable characteristics when they classify.
62	79	70	C. There are many ways to classify nature, but agreeing on one universal system allows scientists to avoid confusion in their work.
17	14	20	D. There could be other correct ways to classify nature, because science is liable to change and new discoveries may lead to different classifications.
2	0	0	E. None of these choices fits my basic viewpoint which is.....

The current view among scientists is that which supports the epistemological nature of classification schemes (Ryan and Aikenhead, 1992). This view recognises the man-made and provisional nature of scientific schemes, and acknowledges the role of community sanctions which encourage one form of the scheme (Ziman, 1984). Option C, therefore represents the current view of most scientists on classification schemes (Ryan and Aikenhead, 1992). However, option D is also considered acceptable.

What are respondents' views about classification? (See Table 12). Two perspectives are considered in this item:

a) Classification schemes match reality (the ontological position) (options A and B).
b) Classification schemes are human inventions (epistemological perspective) (options C and D).

3. **When scientists investigate, it is said that they follow the scientific method. The scientific method is:**

(Please read A to J, and then choose ONE.)

A. the laboratory procedures or techniques, which are often written in a science book or journal by a scientist.

B. recording your results carefully.

C. controlling experimental variables carefully, leaving no room for interpretation.

D. testing and retesting - proving something true or false in a valid way.

E. the identification of a problem, offering a hypothesis, and conducting an experiment to prove it with a conclusion.

F. a logical and widely accepted approach to problem solving.

G. an attitude that guides scientists in their work.

I Considering what scientists actually do, there is no such thing as "the scientific method".

J. None of these choices fits my basic viewpoint which is

_____

_____

2. **When a new scientific theory is proposed, scientists must decide whether to accept it or not. Scientists make this decision by consensus; that is, proposers of the theory must convince a large majority of fellow scientists to believe the new theory.**

What do you think? (Please read from A to G, and then choose ONE.)

Scientists who propose a theory must convince other scientists:

A. by showing them conclusive evidence that proves the theory true.

B. because a theory is useful to science only when most believe the theory.

C. because when a number of scientists discuss a theory and its new ideas, scientists are likely to revise or update the theory. In short, by reaching a consensus, scientists make the theory more accurate.

Scientists who propose a theory do not have to convince other scientists:

D. because the supporting evidence speaks for itself.

E. because individual scientists will decide for themselves whether to use a theory or not.

F. because an individual scientist can apply a theory as long as the theory explains results and is useful, no matter what other scientists believe.

G. None of those choices fits my basic viewpoint which is

_____

_____

1. **Defining science is difficult because science is complex and does many things. But science is mainly:**

A. a study of fields such as biology, chemistry and physics.

B. a body of knowledge, such as principles, laws and theories, which explains the world around us (matter, energy and life).

C. carrying out experiments to solve problems of interest about the world around us.

D. inventing or designing things (for example, artificial hearts, computers, space vehicles).

E. finding and using knowledge to make this world a better place to live in (for example, curing diseases, solving pollution problems and improving agriculture.

F. a way of exploring the unknown and discovering new things about our world and universe and how they work.

G. a human activity oriented towards explaining and understanding the world.

H. None of these choices fits my basic viewpoint which is

_____

_____

APPENDIX 2

PUPILS' OPINIONNAIRE

VIEWS ABOUT THE NATURE OF SCIENCE.

Thank you for participating in this survey. Research has shown that teachers have various views about science.

The aim of this questionnaire is explore *your* beliefs and views about science. For this reason it would be greatly appreciated if you would answer the questions in a frank manner.

There are no right or wrong answers and you may remain anonymous.

INSTRUCTIONS

- Each multiple-choice question begins with a statement about a science topic. Most of these statements express an extreme view on the topic. You may either agree strongly with this view, disagree vigorously, or your own position may be in between the two.
- Next, there is a list of choices on the issue. Choose ONE of these positions, BUT ONLY ONE - the one that comes closest to your personal view or belief.
- Every question ends with this choice: "None of these choices fit my basic viewpoint which is..." This choice should only be used when none of the other choices comes close to your own belief. If you select this option, you MUST write your viewpoint in the space provided.
- Answer every question by drawing a circle around the letter of your choice e.g. Question 1. A

PERSONAL DETAILS.

- Date of birth:_____Standard _____ Sex_____
- Which of these subjects do you take at present? Place a tick (✓) in the appropriate boxes.

[ ] Physical Science [ ] Geography.

[ ] Mathematics. [ ] Biology.

4. Conceptual inventions.

a) Observations are made using the senses. What an observer 'sees' depends in part on what is really there and in part on the observer's past experience, knowledge and expectations. Observations are theory-dependent and therefore subjective.

b) Facts are singular observations which are also theory-dependent.

c) Hypotheses are the ideas, or educated guesses of scientists about problems or issues in science. Hypotheses also constitute very tentative explanations or descriptions that guide investigations.

d) Laws are general statements (generalisations) that enjoy a high degree of scientific confidence. They describe relationships between events of which universal agreement can be obtained.

e) Theories are propositions which are devised to explain observations, facts and laws, and to make predictions. Theories give a sense of understanding to the facts and laws they explain (using models or other visual representations in the explanations). A theory is paradigm-bound, and may enjoy a high degree of scientific confidence as long as no other theory supersedes it or no paradigm-change occurs. It used to be thought that theories were logically derived from laws. Today theories are attributed to imaginative insights which are then developed by conscious thought.

Relationships between the conceptual inventions.

Statements of facts observed under different conditions but yielding similar results may be called a generalisation (law).

A hypothesis usually guides a scientific investigation. A theory cannot mature and become a law; rather, it explains the law. Therefore laws and theories are two different forms of statements.

5. Values in science.

While ideally scientists should be objective, open minded, sceptical and willing to suspend judgement if there is insufficient evidence, in reality they may be subjective, dogmatic, credulous, etc. Scientists may also be influenced by ethical, ideological and cultural values which are external to the discipline of science.

Differences in culture among scientists can lead to differences in the production of scientific knowledge.

APPENDIX 1

PROPOSITIONAL KNOWLEDGE STATEMENTS REPRESENTING CONTEMPORARY VIEWS ABOUT THE NATURE OF SCIENCE.

The areas of the nature of science that will be explored are: the meaning of science, the generation and nature of scientific knowledge, conceptual inventions (theories, laws, etc.), and values in science.

1. What is science.

There is no clear-cut, universally accepted definition of "science". A contemporary, all encompassing view regards science as involving the body of scientific knowledge, science processes, and the social context of science.

2. Knowledge generation.

There is no such thing as "*the* scientific method". Scientists use any method that might get favourable results including the method of imagination and creativity.

Science processes which lead to progress in science do not simply involve experimentation and the systematic accumulation of facts. Each major advance in science alters previously established patterns of relationships. The decisive step leading to the development of a theory is often by a leap of imagination, intuition or a flash of inspiration

The observations, hypotheses, etc. of individual scientists do not constitute scientific knowledge. Such ideas first have to be reviewed by peers who constitute 'self appointed experts' in the field. By means of criticism and further empirical research, these experts are able to reach conclusions on the "truth" or otherwise of the conceptual invention, or the adequacy of such experimental procedure. It is this knowledge established by consensus among experts in the field that constitutes scientific knowledge. Scientific knowledge is therefore socially constructed.

3. Nature of scientific knowledge.

Scientific knowledge has the following characteristics. It is:

a) amoral - it cannot be judged as good or bad although the application of scientific knowledge can be judged as such.
b) creative - it is a product of the human intellect and embodies the creative essence of the scientific inquiry process.
c) tentative - scientific knowledge can change with time in light of new interpretations of findings.
d) parsimonious - it attempts to achieve simplicity of explanation rather than complexity.
e) testable - it is capable of being tested against reliable observations.
f) unified - the various sciences contribute to a single organized body of knowledge.

Scientific constructs such as models and classification schemes, are not duplications of reality but rather instruments to assist in the understanding of the world.

The pupils and teachers in this study generally seem to share similar views about the nature of science. This is perhaps not surprising as Herron (1977) points out that ideas about the nature of science are implicitly conveyed to pupils via the teachers' classroom behaviour. The views of the student teachers, on the other hand, are generally more in line with currently accepted views about the nature of science. This is probably because they have recently completed a short course in the philosophy of science. However, despite this course, many students do not seem to have fully grasped or accepted all the current views. One possible reason is perhaps the short duration of their philosophy of science course.

If pupils are to be scientifically literate, authentic conceptions of the nature of science must be conveyed to them (Lederman, 1992). The curriculum is one of the avenues through which this can be done. The conceptions of pupils and teachers suggests the need for a re-examination and possible updating of curricula of both science teachers and pupils.

Another possible solution would be to introduce the nature of science into physical science and biological science curricula, not only as a defined section, but also as a theme which permeates the entire curriculum and impacts on all the content and the way science is taught in the classroom. For example, in order address the outdated view that there is one correct scientific method ("the" scientific method), pupils should be exposed to a variety of inquiry methods and be allowed to design their own experiments. It is the researcher's belief that this could enhance their imagination and creativity, and develop more accurate conceptions of scientific methods.

While it is acknowledged that certain solutions have been generated by this research, it is clear that further research in this area is needed. This study has focused on schools in the greater Johannesburg area. An extension of the study into other regions and population groups will help provide a general view of pupils' and teachers' conceptions of the nature of science.

a) In their choice of definitions of science, both groups were divided over the content and process approach and ignored the social aspect of science.
b) Pupils in both groups seem to better appreciate classification schemes as human inventions than they did scientific models.
c) A majority of pupils (64 per cent of Canadian pupils; and 68 of per cent South African pupils) expressed a simple hierarchical relationship between hypotheses, theories and laws.
d) Only a small percentage of pupils (2 per cent of Canadian pupils; and 11 per cent of South African pupils) chose the option which stated there is really no such thing as "the" scientific method.
e) The dominant views of both groups of pupils differed on the status of scientific theories. The largest percentage of South African pupils (47 per cent) agreed with the ontological perspective, while 40 per cent of Canadian pupils selected positions in between the ontological and e istemological viewpoints.

It is interesting to note that Brunkhorst (1987, cited in Ryan and Aikenhead, 1992), in a preliminary study using VOSTS, reporte ' that American and Canadian students responded similarly to the items. The pupils in this study cannot be said to be representative of all pupils in South Africa and therefore no general claims can be made.

5.4 CONCLUSIONS AND IMPLICATIONS

Although the results from this study are not generalizable to the whole population, they do give an indication of the views certain pupils and teachers have about the nature of science. The responses from teachers and pupils on some of the items suggest that they are not abreast with the changing philosophies on the nature of science. Their views tend to be underpinned by outdated philosophies of science. One such discredited philosophy which still seems to have much influence is positivism, in which scientific knowledge means proven knowledge - proven either by the power of the intellect or by the evidence of the senses (Lakatos, 1970). Even though philosophers of science such as Popper and Kuhn have questioned the proving power of the intellect or the senses, it appears that these arguments generally have not reached the classrooms and lecture halls. If scientific literacy is to be achieved by the entire population, it is the researcher's belief that higher percentages of respondents than those shown in this study should have accurate conceptions of the nature of science.

5.2.4 Conceptual inventions

Models and classification schemes in science. The view of 50-60 per cent of pupils and teachers (but not of student teachers) is that models come close to reality - a vestigial ontological perspective. However, a different stance was noticed in their consideration of classification schemes. Here, between 80-90 per cent of all samples see classification schemes as human inventions - an instrumentalist view. Pupils and teachers seem to be more familiar with classification schemes than models. However, it should be noted that a large percentage of student teachers (60 per cent) had accurate views about both models and classification schemes. In other words, the student teachers seem to have a well defined view of the role and status of such conceptual inventions.

Considering the two items above, student teachers clearly exhibited clearer conceptions of conceptual inventions than teachers and pupils. To foster better conceptions, the challenge to curriculum developers is to encourage the use and understanding of scientific models.

5.2.5 Values in science

Scientific attitude, and the effect of politics on scientists. There are no simple answers to the values that promote good science. It is encouraging to note that most respondents displayed views that are supported by contemporary research.

Various reasons were selected suggesting how politics affects scientists. It seems however, that student teachers and teachers had a clearer view of how scientists are affected than pupils. This perspective is significant for a country that went through a long period of international isolation due to its politics. Some pupils had naive views about scientists being isolated from society and therefore not affected by politics.

To conclude this summary, it is worthwhile to compare the main findings with those of Ryan and Aikenhead (1992) who conducted a similar study with 17-year-old Canadian pupils. The positions selected by pupils in both studies show remarkable similarity. A brief comparison is made of the responses of pupils to some items which were common to both studies:

About 40 per cent of pupils and 50 per cent of teachers expressed acceptable and current perspectives about the nature of scientific observations. More than 85 per cent of student teachers seem to have the view that scientific observations are theory-laden.

The classroom implications of the biased nature of observations are significant. They demand that pupils be guided in order to make the necessary inquiry in the science laboratory or field. For example, biology teachers should not expect pupils to see what they as teachers see when looking down a microscope or at a micrograph. For pupils to recognise certain structures, they must a first be led to consider and conceptualise, even roughly, what to expect. With similar expectations, pupils are more likely to make similar observations.

Characteristics of knowledge produced. Although the vast majority of respondents held acceptable views about scientific knowledge being provisional, only a minority understood why knowledge changes. About a quarter of the pupils seem to think that experiments yield facts which may not change, or that facts in science are immutable. If science is seen as a body of facts (the content view of science), it is hypothesized that proponents will not readily submit that scientific knowledge changes. In this respect, pupils views on the definitions of science seem to correspond to their views on how scientific knowledge changes. The views of student teachers and teachers do not correlate as well on this issue.

In summary, generally respondents' understanding of the assumptions underlining scientific knowledge were not sound. The role of theory in observations was only appreciated by about half the pupils and teachers. Most of them saw theories as either simple or complex but not as always tending towards simplicity. Respondents were also confused about the meaning of, and the relationship between, hypotheses, theories, and laws. A hierarchical relationship was implied.

It is essential that the assumptions that undergird the discipline be made common knowledge to learners. This is necessary if a realistic image of science is to be formed. For example, the hierarchical image of hypotheses, theories and laws would suggest an immutable image of scientific knowledge to pupils. It is argued that should some scientific laws change in future, this would shatter their false dreams about the reliability of science and might lead to their questioning the value of science.

great discoveries have been accidental, science for the most part cannot be considered as haphazard.

These results generally indicate that respondents do not have a clear and acceptable view about how knowledge is generated in science. About two-thirds of pupils and teachers were unaware of the current debates on scientific method and how consensus is reached. The views of student teachers and pupils on how scientific discoveries occur were also inadequate.

5.2.3 Assumptions underlining scientific knowledge.

Nature of scientific ideas. Although respondents were not asked to define theories, an understanding of the nature of theories was required. The majority of respondents believe that hypotheses with supporting evidence can mature into theories, and theories into laws. The support for a hierarchical relationship between hypotheses, theories and laws was more than 65 per cent among all three samples. Horner and Rubba (1979) called this view, which is also prevalent among American samples, the "laws-are-mature-theories fable". The influence of everyday language and science textbooks were cited by the researcher as contributing to such erroneous ideas.

The nature of theories. The general viewpoint among over 80 per cent of all three samples is that theories can be either simple or complex. The fact that the majority of respondents never saw theories as the simplest possible explanation of observed and phenomena may help explain the aversive attitudes of pupils towards science (Hi l). It is feasible that if theories were perceived as simple, pupils would have favourable attitudes toward them. When theories are seen as complex, less favourable attitudes are displayed towards them. The need of science educators to emphasize the simplicity of theories is therefore important.

Nature of scientific observations. Pupils and teachers seem to be evenly divided in opinion over the nature of scientific observation. Over 45 per cent of pupils and teachers believed observations are not theory-dependent. This view supports the realist view that scientists discover reality, and the logical positivist view that science reveals absolute truth which is independent of the investigator's background and beliefs (Aikenhead, 1987).

5.2.2 Knowledge generation

Consensus-making in science. When scientific theories are invented, they do not constitute scientific knowledge until their validity is supported by peers who are experts in the field. Although over 70 per cent of pupils, student teachers, and teachers believed in the consensus view, the notion of providing "conclusive evidence to prove a theory true" featured prominently in the selected options of both pupils and teachers. This view does not take into account the revisions, updating and final agreement that goes into consensus-making. If the literal meaning of the word "prove" is taken for granted, most pupils' and teachers' views would be classed as falsificationist. However, the researcher did not establish what pupils meant by the phrase "to prove a theory true". As Lederman and O'Malley (1990) observed, it is possible for a mismatch to exist between the language of the researcher and the respondents. Thus, the respondents' notion of proving a theory true may be found to be consistent with current notions of providing supporting evidence, as was established by Lederman and O'Malley (1990).

The falsificationist view expressed by respondents, although not considered in science literature as current, is nevertheless not naive or archaic.

Scientific method. For a sizeable percentage of respondents (80 per cent of pupils, 43 per cent of student teachers and 60 per cent of teachers), the scientific method is a series of experimental steps. Only a very small percentage of respondents selected the acceptable position that there is no such thing as "the" scientific method.

As discussed in the critique on page 71, the format for this statement may have influenced the responses. But it seems apparent that respondents have not been exposed to the debate over scientific method.

Progress in science. The most favoured opinion is that scientific discoveries result from a logical series of investigations. However, over 50 per cent of pupils and teachers noted that science was not always logical: some discoveries come through trial and error or by a flash of imagination.

Although 34 per cent of pupils, 21 per cent of student teachers, and no teachers felt that most scientific discoveries were accidental, this opinion is not supported by research. Although some

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APPENDIX 3

COVER PAGE OF TEACHERS' AND STUDENT TEACHERS' OPINIONNAIRE

VIEWS ABOUT THE NATURE OF SCIENCE.

Thank you for participating in this survey. Research has shown that teachers have various views about science.

The aim of this questionnaire is explore *your* beliefs and views about science. For this reason it would be greatly appreciated if you would answer the questions *in a frank manner*. There are no right or wrong answers and you may remain anonymous.

INSTRUCTIONS

Each multiple-choice question begins with a statement about a science topic. Most of these statements express an extreme view on the topic. You may either agree strongly with this view, disagree vigorously, or your own position may be in between the two.

Next, there is a list of choices on the issue. Choose ONE of these positions, BUT ONLY ONE - the one that comes closest to your personal view or belief.

Every question ends with this choice: "None of these choices fit my basic viewpoint which is...". This choice should only be used when none of the other choices comes close to your own belief. If you select this option, you MUST write your viewpoint in the space provided. Answer every question by drawing a circle around the letter of your choice. e.g. Question 1. A

PERSONAL DETAILS.

1. Academic qualification (include name of institution + date).
   e.g. B.Sc.(Wits) 1985.

   _____

2. Professional qualification (include name of institution + date).
   e.g. HDE (Natal) 1989.

   _____

Please complete the following table to indicate your teaching experience in biology, physical science, general science and mathematics.

	Subject	Standard	Number of years
e.g.	biology	6	0

13. **Politics in South Africa affects South African scientists, because scientists are very much a part of the society (that is, scientists are not isolated from society).**

What do you think? (Please read from A to G, and then choose ONE.)

Scientists ARE affected by South African politics:

A. because funding for science comes mainly from the government which controls the way the money is spent. Scientists sometimes have to lobby for funds.

B. because governments not only give money for research, they also set policy regarding new developments. This policy directly affects the type of projects scientists will work on.

C. because scientists are part of society and are affected like everyone else.

D. because scientists try to help society and thus they are closely tied to society.

Scientists are NOT affected by South African politics:

E. because the nature of a scientist's work prevents the scientist from becoming involved politically.

F. because scientists are isolated from society; their work receives no public media attention unless they make spectacular discovery.

G. None of these choices fits my basic viewpoint which is

_____

_____

12. **The best scientists are always very open-minded, logical and unbiased in their work. These personal characteristics are needed for doing the best science.**

What do you think? (Please read from A to G, and then choose ONE.)

A. The best scientists display these characteristics otherwise science will suffer.

B. The best scientists display these characteristics because the more of these characteristics you have, the better you'll do at science.

C. These characteristics are not enough. The best scientists also need other personal traits such as imagination, intelligence and honesty.

The best scientists c NOT necessarily display these personal characteristics:

D. because the best scientists sometimes become so deeply involved, interested or trained in their field, that they can be close-minded, biased, and not always logical in their work.

E. because it depends on the individual scientist. Some good scientists are always open-minded, logical, etc. in their work; while other good scientists can become close-minded, biased, etc. in their work.

F. The best scientists do NOT display these personal characteristics any more than the average scientist. These characteristics are NOT necessary for doing good science.

G. None of these choices fits my basic viewpoint which is

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_____

11. **When scientists classify something (for example, a plant according to its species, an element according to the periodic table, energy according to its source, or a star according to its size), scientists are classifying nature according to *the way nature really is*; any other way would simply be wrong.**

What do you think? (Please read from A to E, and then choose ONE.)

A. Classifications match the way nature really is, since scientists have proven them over many years of work.

B. Classifications match the way nature really is, since scientists use observable characteristics when they classify.

C. There are many ways to classify nature, but agreeing on one universal system allows scientists to avoid confusion in their work.

D. There could be other correct ways to classify nature, because science is liable to change and new discoveries may lead to different classifications.

E. None of these choices fits my basic viewpoint which is

_____

_____

10. **Many scientific models used in research laboratories (such as the model of the wave, the neuron, DNA, or the atom) are copies of reality.**

What do you think? (Please read from A to G, and then choose ONE.)

Scientific models ARE copies of reality:

A. because scientists say they are true, so they must be true.

B. because much scientific evidence has proven them true.

C. because they are true to life. Their purpose is to show us reality or teach us something about it.

D. Scientific models come close to being copies of reality, because they are based on scientific observations and research.

Scientific models are NOT copies of reality:

E. rather they are simply helpful for learning and explaining, despite their limitations.

F. and therefore they have no use in science.

G. None of these choices fits my basic viewpoint which is

_____

_____

9. **Scientific observations of the same thing made by two competent scientists will often be different if the scientists believe in different theories.**

What do you think? (Please read from A to G, and then choose ONE.)

A. Yes, because scientists will experiment in different ways and will notice different things.

B. Yes, because scientists will think differently and this will alter their observations.

C. Yes, because what a scientist already knows will affect what he observes.

D. Scientific observations will not differ very much even though scientists believe different theories. If the scientists are indeed competent their observations will be similar.

E. No, because observations are as exact as possible. This is how science has been able to advance.

F. No, observations are exactly what we see and nothing more; they are facts.

G. None of these choices fits my basic viewpoint which is

_____

_____

8. **Scientific ideas develop from hypothesis to theories, and finally, if they are good enough, to being scientific laws.**

What do you think? (Please read from A to F, and then choose ONE.)

A. Theories can't become laws because they are different types of ideas. Theories are based on scientific ideas which are less than 100% certain, and so theories can't be proved true. Laws, however are based on facts only and are 100% sure.

B. Theories can't become laws because they are different types of ideas. Laws describe things in general. Theories explain these laws. However, with supporting evidence, hypotheses may become theories (explanations) or laws (descriptions).

Hypotheses can lead to theories which can lead to laws:

C. because an hypothesis is tested by experiments. If it proves correct, it becomes a theory. After a theory has been proven true many times by different people and has been around for a long time, it becomes a law.

D. because an hypothesis is tested by experiments. If there is supporting evidence, it's a theory. After a theory has been tested many times and seems to be essentially correct, it's good enough to become a law.

E. because it is a logical way for scientific ideas to develop.

F. None of these choices fits my basic viewpoint which is

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6. **Even when scientific investigations are done correctly, the knowledge that scientists discover from those investigations may change in the future.**

What do you think? (Please read from A to F, and then choose ONE.)

Scientific knowledge changes:

A. because new scientists disprove the theories or discoveries of old scientists. Scientists do this by using new techniques or improved instruments, by finding new factors overlooked before, or detecting errors in the original "correct" investigation.

B. because the old knowledge is reinterpreted in light of new discoveries. Scientific facts can change.

C. Scientific knowledge APPEARS to change because the interpretation or the application of the old facts can change. Correctly done experiments yield unchangeable facts.

D. Scientific knowledge APPEARS to change because new knowledge is added on to old knowledge; the old knowledge doesn't change.

E. Scientific knowledge does not change because it consists of proven facts.

F. None of these choices fits my viewpoint which is

_____

_____

5. **For this statement, assume ..at a gold miner "discovers" gold, while an artist "invents" a sculpture. Some people think that scientists discover scientific THEORIES. Others think that scientists invent them.**

What do you think? (Please read from A to G, and then choose ONE.)

Scientists **discover** a theory:

A. because an idea was there all the time, just needing to be uncovered.

B. because it is based on experimental facts.

C. but scientists invent the methods to find the theories.

D. Some scientists may stumble onto a theory by chance, thus discovering it. But other scientists may invent the theory from facts they already know.

Scientists **invent** a theory:

E. because a theory is an interpretation of experimental facts which scientists have discovered.

F. because inventions (theories) come from the mind - we create them.

G. None of these choices fits my basic viewpoint which is

_____

_____

4. **Progress in science occurs as a result of a series of investigations, each one building on an earlier one, and each one leading logically to the next one, until the discovery is made.**

What do you think? (Please read from A to E, and then choose ONE.)

A. All scientific discoveries result from a well-planned series of investigations. Experiments (for example, the experiments that led to the model of the atom, or discoveries about cancer) are like laying bricks onto a wall.

B. **Usually** scientific discoveries result from a logical series of investigations. But science is not completely logical. Discovery sometimes comes by a flash of imagination, or by trial and error.

C. **Most** scientific discoveries are accidental, or they are the unpredicted product of the actual intention of the scientist. **Some** discoveries result from a series of investigations building logically one upon the other.

D. Scientists do not know what to expect when they do experiments. Therefore and scientific discoveries do **not** occur as a result of a logical series of investigations.

E. None of these choices fits my basic viewpoint which is

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