

VIEWS OF DISTANCE EDUCATION SCIENCE STUDENTS ON THE SOCIAL
RESPONSIBILITY OF SCIENTISTS

by

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submitted in part fulfilment of the requirements
for the degree of

MASTER OF SCIENCE

in the subject

CHEMICAL EDUCATION

at the

UNIVERSITY OF SOUTH AFRICA

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NOVEMBER 2006

“Freedom! A fine word when rightly understood. What freedom would you have? What is the freedom of the most free? To act rightly!”

JOHANN WOLFGANG VON GOETHE
(1749 – 1832), EGMONT.

To Peer and Imaco

ACKNOWLEDGEMENTS

I would like to express my gratitude and appreciation for the support offered by the following:

Prof M. Rollnick, my supervisor, for her professional input even though time was a constraint

Prof M.B. Ogunniyi for unwittingly guiding me towards this study on a flight between Johannesburg and Harare

The students of the Chemistry and Physics Departments for their youthful enthusiasm and animated contributions which inspired this research

Prof M.B. Ramose for his interest in the topic and for engendering an appreciation of philosophy

Prof R. Markham and Dr S.M. Seeletse of the Department of Statistics for analysing and explaining the statistical data

The Unisa Library for its vast and varied resources which informed and augmented this study

The Chemistry Department for affording me the time and opportunity to pursue this vision

Mr M.L. Molepo for his support in putting the script into its final format

And last, but certainly not least, my teachers and mentors throughout my life from whom I learnt so much, and my family and friends who believed in me and encouraged me on this road.

ABSTRACT

Science and technology increasingly impact on society and the environment, making it imperative for scientists to accept their social responsibility and for young scientists to acquire the necessary skills and knowledge to be able to respond to the needs of society. Relevant education must be based on information about students' conceptions and attitudes and the identification of areas of intervention. The aim of this thesis is to obtain base line data on the views of distance education science students on issues surrounding the social responsibility of scientists.

A research instrument based on the Views on Science-Technology-Society methodology was developed in three phases, employing interviews and free and fixed response questionnaires. Taking the views of students as point of departure, qualitative data analysis at each stage provided the input for the following stage. Participants were drawn over a two year period from science students at various levels of academic study at the University of South Africa.

Results reflect the spectrum of factors determining the practice of socially responsible science as well as respondents' associated reasoning. The application of scientific knowledge was seen to be determined by scientific freedom and the ethos of science, with the main focus on the advancement and protection of society. Scientific development in Africa and the role of women in science received special attention. At the science-technology-society interface the key areas which were identified were public communication, decision making and responsibility for the consequences of scientific and technological innovations. Education should provide relevant applied scientific knowledge and social skills, as well as an understanding of philosophical and ethical foundations of science and society. Personal and societal values also determine scientific practice, and there is a need for role models and professional codes of conduct. Science students' voluntary commitment to service in their communities was an unexpected outcome of this research.

TABLE OF CONTENTS

Acknowledgements	iii
Abstract	iv
List of Figures	x
List of Tables	xi
Chapter 1 Introduction	1
1.1 Motivation for this study	1
1.1.1 Background.....	1
1.1.2 The need for education.....	6
1.1.3 The need for research.....	7
1.2 Research objectives	8
1.3 The relevance of the outcomes of this research	9
1.4 Definition of concepts	11
1.5 Summary	12
Chapter 2 Aspects of the Social Responsibility of Scientists	14
2.1 The scientific enterprise	15
2.1.1 Scientific freedom and responsibility.....	16
2.1.2 The ethos of science.....	18
2.1.3 Scientific knowledge.....	20
2.1.3.1 Western scientific inquiry.....	21
2.1.3.2 The power of scientific knowledge.....	23
2.1.3.3 Secret and forbidden knowledge.....	24
2.1.3.4 The technological imperative.....	26
2.1.3.5 Prediction.....	28
2.1.3.6 Indigenous knowledge.....	30
2.1.3.7 Women in science.....	33
2.1.4 The scientific community.....	36
2.1.5 Situated learning.....	38
2.1.6 The scientist as individual.....	44
2.2 Science, technology and society	50
2.2.1 The interdependence of science, technology and society.....	50
2.2.2 Communication and education.....	53
2.2.3 Decisions and consequences.....	57
2.2.4 Professional societies and codes of conduct.....	63
2.3 Summary	64

Chapter 3	Development and Use of the Research Instrument.....	66
3.1	Introduction and overview.....	66
3.2	Measurement of Views and Attitudes.....	67
3.2.1	Background.....	67
3.2.2	The VOSTS instrument.....	70
3.2.3	VOSTS based studies.....	73
3.3	Development and use of the instrument.....	77
3.3.1	Motivation.....	77
3.3.2	Overview of participants, procedures and time frames.....	79
3.3.3	Ethical aspects of the research process.....	80
3.3.4	Phase 1: Interviews and analysis.....	81
3.3.4.1	Introduction.....	81
3.3.4.2	Participants.....	81
3.3.4.3	Interviews.....	84
3.3.4.4	Analysis of interviews.....	87
3.3.4.5	Conclusion.....	101
3.3.5	Phase 2: Open response questionnaire and analysis.....	101
3.3.5.1	Introduction.....	101
3.3.5.2	Formulation of open response questionnaire.....	101
3.3.5.3	Pilot test.....	103
3.3.5.4	Respondents.....	103
3.3.5.5	Analysis of open response questionnaire.....	104
3.3.5.6	Conclusion.....	108
3.3.6	Phase 3: Fixed response questionnaire and analysis.....	108
3.3.6.1	Introduction.....	108
3.3.6.2	Formulation of fixed response questionnaire.....	109
3.3.6.3	Respondents.....	113
3.3.6.4	Data analysis of the multiple choice questionnaire.....	114
3.3.6.5	Development of an attitude profile.....	115
3.3.6.6	Conclusion.....	120
3.4	Summary.....	120
Chapter 4	Results and Analysis.....	121
4.1	The nature of the data.....	121
4.2	The nature of the analysis.....	122

4.3 The scientific enterprise.....	125
4.3.1 Statement 10: Scientific freedom.....	125
4.3.2 Statement 12: Scientists' special responsibility.....	127
4.3.3 Statement 11: Research objectives.....	129
4.3.4 Statement 6: The technological imperative.....	132
4.3.5 Statement 8: Prediction.....	134
4.3.6 Statement 14: Science in Africa.....	136
4.3.7 Statement 17: Women in science.....	139
4.4 The scientist as individual.....	142
4.4.1 Statement 13: Honesty.....	142
4.4.2 Statement 15: Whistle blowing: duty to inform.....	144
4.4.3 Statement 16: Whistle blowing: personal decision.....	146
4.5 Science, Technology and Society.....	148
4.5.1 Statement 9: Moral implications of research.....	149
4.5.2 Statement 20: Collaboration and communication.....	151
4.5.3 Statement 19: Education of the public.....	154
4.5.4 Statement 4: Decisions and implementation.....	156
4.5.5 Statement 5: Monitoring and responsibility.....	158
4.5.6 Statement 7: Consequences of science.....	160
4.6 Education.....	162
4.6.1 Statement 2: Science-related social issues.....	163
4.6.2 Statement 1: Applied topics.....	165
4.6.3 Statement 3: Value education.....	167
4.6.4 Statement 18: Science students and society.....	169
4.7 Conclusion.....	171
4.8 Improvements to the study.....	173
4.9 Summary.....	174
Chapter 5 Discussion and Conclusion.....	176
5.1 Introduction.....	176
5.2 Findings.....	177
5.2.1 Scientific freedom and social responsibility.....	177
5.2.2 Scientists' special social responsibility	177
5.2.3 The responsibility to focus scientific research on the need of society.....	178
5.2.4 The responsibility to prevent scientific research from escalating.....	178

5.2.5	The responsibility to predict the long term effects of scientific and technological developments.....	179
5.2.6	The responsibility with respect to scientific developments in Africa.....	179
5.2.7	The responsibility with respect to women in science.....	179
5.2.8	The responsibility for honesty in scientific work.....	180
5.2.9	The responsibility to inform the public of possible dangers arising from scientific practices.....	180
5.2.10	The personal responsibility for whistle blowing.....	181
5.2.11	The responsibility to consider the moral implications of research.....	181
5.2.12	The responsibility for improved collaboration and communication with society.....	181
5.2.13	The responsibility to educate the public in basic science.....	182
5.2.14	The responsibility to engage in decision making on the implementation of scientific discoveries.....	182
5.2.15	The responsibility to monitor the long term applications of scientific research.....	183
5.2.16	The responsibility for the consequences of scientific innovations.....	183
5.2.17	The responsibility to educate science students to solve science- related social issues.....	184
5.2.18	The responsibility to include relevant applied topics into science syllabi.....	184
5.2.19	The responsibility to create an awareness of values, attitudes and controversies related to science, society and the environment in the education of young scientists.....	184
5.2.20	The responsibility of science students to interact with their Communities.....	185
5.3	Discussion.....	185
5.4	Recommendations.....	196
5.5	Conclusion.....	201
	References.....	203
	Appendix A Newspaper articles.....	217
	Appendix B Development of strand 3 and dimension 3.....	229
	Appendix C 25 statement pairs in open response questionnaire.....	234
	Appendix D Cover page for questionnaires.....	236
	Appendix E The final fixed response questionnaire.....	237

Appendix F Explanatory document for panel members for compilation of attitude profile.....	251
Appendix G Scoring table for attitude profile.....	252

LIST OF FIGURES

Figure 2.1 Aspects of social responsibility: sub-division of topics.....	14
Figure 3.1 Overview of the development and use of the research instrument.....	67
Figure 3.2 Flow diagram of qualitative analysis of interview transcripts.....	89
Figure 3.3 Flow diagram of qualitative analysis of the open response questionnaire.....	105
Figure 3.4 Flow diagram of formulation of fixed response questionnaire.....	109
Figure 3.5 Flow diagram for the development of an attitude profile.....	116

LIST OF TABLES

Table 3.1	Time frames and participants for Phases 1 to 3.....	80
Table 3.2	Composition by race and gender of participants and class.....	83
Table 3.3	Final set of strands and dimensions of the responsibility of scientists.....	100
Table 3.4	Composition by race and gender of respondents and class for open response questionnaire.....	104
Table 3.5	Analysis of open response questionnaire: statements 8.1a and 8.1b.....	107
Table 3.6	Composition by race and gender of respondents and class total for fixed response questionnaire.....	114
Table 4.1	Overview of analysis of questionnaire statements.....	124

CHAPTER 1

INTRODUCTION

Since the start of the 20th century science and technology have changed the world in fundamental ways and are continuing to do so at an accelerated pace. Increasingly unforeseen hazards accompany the benefits of scientific discoveries and this gives rise to questions surrounding the social responsibility of scientists. Scientists are more than ever before expected by society to ensure that scientific and technological innovations are compatible with social needs and values and environmental sustainability. In order to meet these complex demands scientists require the necessary skills to respond to this added dimension of the scientific process. Successful education and training is based on in-depth knowledge of the existing views, attitudes and concepts of students. The aim of this thesis is to obtain insight into the views of science students on issues surrounding the social responsibility of scientists.

1.1 MOTIVATION FOR THIS STUDY

1.1.1 Background

While science and technology certainly have alleviated hunger, illnesses and poverty, the negative effects of such progress are threatening to outweigh the benefits. Scientific developments also impact profoundly on human beliefs and values and demand a reassessment of world views and philosophies. The history of recent wars and the state of the environment as well as the far reaching ethical dilemmas facing mankind testify to the impact of science on society.

The detonation of nuclear bombs which ended World War II in 1945 raised questions among scientists and the general public about the power of scientific knowledge and its responsible application (Badash, 2004; Castell and Ischerbeck, 2003; Schweber, 2000). The physicist Robert Oppenheimer who was the war time director of the

Manhattan Project which developed the atomic bomb quoted from Indian scripture "I am become Death, the shatterer of worlds" on witnessing the first explosion of the bomb (Keller, 1993: 45). This poignant statement captures the realization of the horrific consequences of science when unleashed without ethical consideration as well as the fact that scientists faced a responsibility for it. What had started as a quest for knowledge into the nature of matter and energy resulted in the human tragedy of Hiroshima and Nagasaki in 1945. Ethical questions surrounding the role of scientists during these historical and world changing events remain controversial to this day. After World War II the philosopher Sir Bertrand Russell and Albert Einstein initiated the formulation of the Russell-Einstein Manifesto in 1955 to renounce nuclear weapons (Richards, 1987: 168; Russell, 2003). The Pugwash movement which was launched in 1957 facilitated the collaboration between Russian and Western scientists to reduce the dangers of nuclear war for more than 40 years. Subsequent wars during the 20th century however continued to harness scientific discoveries in the development of chemical and biological weapons. The defoliant Agent Orange which was for example used extensively during the Vietnam War has had a devastating impact on the local population to this day (Siekevitz, 1972: 223). The use of chemical and biological weapons as well as nuclear proliferation continues to be an ever present threat.

Environmental pollution and global warming resulting in climate change and natural disasters can be ascribed to the excessive and irresponsible use of technology. The female scientist Rachel Carson (1907-1964) was one of the first to draw public attention to the wide ranging effects of pesticides on birds and wildlife. Her book "The Silent Spring" was published in 1962 and has decisively influenced the growth of environmentalism world wide and caused governments to ban the use of DDT (Kroll, 2001; Miller, 2005). Since then environmental laws, international conferences such as the World Summit on Sustainable Development held in Johannesburg in 2002 and treaties such as the Montreal Protocol on Substances that Deplete the Ozone Layer (1990) have been endeavours to harness scientific and technological progress in favour of sustainable development and poverty alleviation.

Developments in the field of medicine and biology such as the human genome project, stem cell research and genetic engineering can have extensive and as yet

unknown consequences on health and the environment and give rise to profound ethical and moral questions for mankind, even more far reaching than nuclear weapons. The effects appear to touch the core of what it means to be human and the controversies about basic human values are more intense (Badash, 2004; Caplan, 2004).

The recent history of South Africa illustrates how "the very purpose of science" and "the free discourse of information ... was subverted" for military purposes and human rights abuses (Truth and Reconciliation Commission, 1998: 521). The investigations by the Truth and Reconciliation Commission (TRC) into South Africa's Chemical and Biological Warfare program, also known as Project Coast, during the 1980s and early 1990s gave rise to distrust in the integrity of scientists and concern on how society views these intellectual leaders. The introduction (Truth and Reconciliation Commission, 1998: 510) reads as follows:

"The image of white-coated scientists, professors, doctors, dentists, veterinarians, laboratories, universities and front companies, propping up apartheid with the support of an extensive international network, was a particular chilling one. Here was evidence of science being subverted to cause disease and undermine the health of communities. Cholera, botulism, anthrax, chemical poisoning and the large-scale manufacture of drugs of abuse, allegedly for purpose of crowd control, were amongst the projects of the programme. Moreover, chemicals, poisons and lethal micro-organisms were produced for use against individuals, and applicators (murder weapons) developed for their administration."

In contrast, the Committee on Scientific Freedom and Responsibility of the American Association for the Advancement of Science (AAAS) published an encouraging report in 1987 entitled: "Turning a Blind Eye? Medical Accountability and the Prevention of Torture in South Africa" (Rayner, 1987). It recounts the courageous appeal by the young female district surgeon Dr Wendy Orr to the Supreme Court to stop police from ill-treating detainees under her care.

In South Africa business and industry are increasingly required to perform impact

studies and comply with environmental regulations (King Report on Corporate Governance for South Africa, 2002). Sustainability is fast becoming a basic requirement for any new venture. Personal experience has shown that academic and research institutions on the other hand are as yet largely unaware of legal requirements such as the Hazardous Substances Act No 15 of 1973 or the Occupational Health and Safety Act 85 of 1993. While most laboratories have a basic disposal system for chemical waste in place, there are no fixed standards and waste disposal facilities are not monitored. In addition it is not always recognized that, although the amount of waste generated in research and teaching laboratories may be small in comparison with industry, the nature and environmental impact of the waste could be unexpectedly hazardous due to the presence of unknown chemicals (United Nations Environment Programme. Persistent Organic Chemicals). Such situations clearly indicate the need of greater awareness of social, environmental and safety factors at the level where students receive their basic academic education.

The foregoing examples show that the practice of science can impact severely on society and the environment and that scientists are not always aware of the powerful role they play and may consequently disregard their responsibilities. Examples have also been offered where scientists have made meaningful and sometimes brave attempts to respond ethically to the needs of society and the world at large.

The underlying philosophy and ethos of science tends to confine itself to scientific theory and methodology to the exclusion of social and subjective parameters. Western science originated during the Renaissance with scholars such as Galileo, Copernicus and da Vinci. They broke away from the stranglehold of the Church as well as the holistic philosophy of Plato (Edsall, 1975a: 1; Richards, 1987: 69). Science flourished since the Age of Enlightenment with the rise of rationalism and empiricism and the discoveries of scientists such as Isaac Newton and Charles Darwin. Since then science has been an intellectual enterprise practised predominantly by Western male scientists in isolation from society.

The social philosopher Robert Merton (Merton, 1968: 597; Richards, 1987: 103) described science as a disinterested pursuit of knowledge for its own sake. He identified the norms of science as neutral, objective, impersonal and international,

which as such are value-free. These norms still pervade scientific thinking to a large degree and are transmitted directly or indirectly in the teaching of natural sciences. Adherence to these norms has been the foundation of the success of Western science, but it is also the reason why scientists tend to see science in isolation from society and disregard their responsibility towards society (Lappe, 1971; Pfürtner, 1989; Richards, 1987). The fact that the effects of science and technology on man and nature are getting beyond control has been ascribed to the underlying philosophy and values of science (Kyle, 1999; Pfürtner, 1989).

In 1959 C.P. Snow drew attention to the existence of two distinct cultures, the literary intellectuals and physical scientists, and the lack of mutual understanding and communication between them (Snow, 1965). The values of society have been described by Richards (1987) as being more subjective, interpersonal and local or national in distinction to the above mentioned objective, neutral, impersonal and international approach of science. As yet the gap has not been bridged and there is also general concern over decreasing interest in science and negative public perceptions of science. Disillusionment with science in developed countries has resulted in anti-science sentiments especially among the youth (Richards, 1987). In developing countries there is the additional problem that scientific and technical expertise is often inadequate to take responsible action in the light of practices which are detrimental to the environment or to counteract exploitation by first world industries (Jegede, 1988).

Alan Leshner (2005), Executive Publisher of Science magazine which is the organ of the AAAS, recently pointed out that many scientists still regard the question of values as "anathema" to the independence and objectivity of science. Besides ethical conduct in research involving humans and animals, scientists believe they should be free in the pursuit of knowledge and accountable to no one but themselves. The author however concludes that "the values dimension is here to stay" and suggests that communities should be informed and consulted on "the meaning and usefulness" of scientific work.

Decisions based on scientific knowledge as well as ethical premises are essential in order to balance technological advancement with a sound environment and quality of

life. In a growing democracy and multicultural society as in South Africa, the cultural values, political redress and economic growth are additional considerations. Scientists confronted with such complex decisions cannot rely on simplistic attitudes and basic scientific norms. They need to have an awareness of their responsibility towards society and the requisite skills to address it.

1.1.2 The need for education

As argued in the foregoing, it is the students who are the scientists and intellectual leaders and decision makers of the future that require specialized education and training in how to approach complex situations where there might be a conflict between scientific advancement and social and human values.

The urgency of including social and ethical awareness in science education is voiced by science educators world wide (for example: Andrew and Robottom, 2001; Cross and Price, 1994; Kyle, 1999; Thier, 1985). In an important article which could well inform science education policy in developing countries, Kyle (1999) calls for education in science toward social justice and ethical responsibility. Covering poverty and world economy, indigenous knowledge and Western science, the author shows that science education "must address issues of development and sustainability in a global context" and that learners should be enabled to "work collectively toward a better society".

In this respect it is relevant to note that contrary to the belief in the objectivity of science, science is not culturally independent and depends on world views and values attributed to this knowledge (Kuiper, 1998; Kyle, 1999). Western science as adopted internationally as the only accepted science is informed by the Western mechanistic view of life. The incorporation of African cultural values and indigenous knowledge as a way to counteract the misuse of science for political and economic gain is advocated strongly in the writings of African science educators and philosophers (Kuiper, 1998, Tangwa, 2004).

Currently the incorporation of the ethical and social relevance of science is

accomplished at primary and secondary level by means of Science-Technology-and-Society (STS) education (White 1998). In higher education there is a variety of approaches such as courses in the history, philosophy and ethics of science (Coad and Coad, 1985; Hoshiko, 1993), incorporation of ethics into a subject such as chemistry (Bruton, 2003; Coppola, 2000; Goodwin, 2004; Kovac, 1996) and specialized workshops (Shachter, 2003). At the University of South Africa where this study was conducted the School of Education offers a number of courses in environmental education and management for teachers in training. Relevant modules in the Philosophy Department are "Bio-medical Ethics", "Environmental Philosophy" and "Philosophy of Science", while the School of Religion and Theology offers a course in "Ethics, Religions and Society" as well as "Theological Approaches to Environmental and Economic Ethics". These modules focus on specialized topics for target groups in the fields of education, philosophy or theology and as such are not directly relevant for science students.

The needs and future responsibilities of distance education science students studying in a country where Western and African worlds meet and in a continent which is initiating an African Renaissance require an entirely new and contextualized approach. In order to design course material which addresses these specific requirements, the teaching objectives, strategies and content must be based on relevant baseline data. It is in this light that research into the views of students on the interrelationship of science and society and the question of responsibility is essential.

1.1.3 The need for research

The establishment of relevant baseline data rests upon research into students' views, beliefs, or positions on the topic of social responsibility. The current literature in educational psychology regards attitudes, beliefs, views, positions, motives and interests as being composed of cognitive, affective and behavioural aspects to varying degrees. These are also all influenced by an individual's basic values which ultimately determine the preference for one action above another (Cherian, 1996; Koballa, 1988; Munby, 1983; Oppenheim, 1992; Ramsden, 1998). All these aspects of human functioning are closely related and influenced by such variables as

personality, gender, culture, religious experience and education. (Haidar, 1999; Schibeci, 1984). This study on students' views on the social responsibility of scientists therefore falls within the field of research into attitudes in science education, covering closely related and ill-defined aspects of psychological concepts such as views, positions, beliefs, motives, opinions, interests and values.

1.2 RESEARCH OBJECTIVES

This research into the views of distance education science students on the social responsibility of scientists was inspired by the foregoing exposition of the need for scientists to subscribe to socially responsible attitudes and actions and the need to educate young scientists adequately to meet this task. Social responsibility encompasses a range of concepts and perspectives which, in turn, are interrelated with a complex web of reasons and motives. With research in science education focusing extensively on multicultural and gender based issues, the influence of race and gender onto students' views forms an additional dimension calling for investigation.

Against this background the main research question is:

- What are the views of distance education science students on the social responsibility of scientists?

Questions arising from the main focus question are:

- What is the range of views pertaining to the social responsibility addressed by the students?
- What reasons do students give for their views on the social responsibility of scientists?
- Do students from different racial and gender groups have different views on the social responsibility of scientists?

In order to assess the views of students on the social responsibility of scientists in a uniquely South African distance education context, an appropriate instrument had to

be developed. This was achieved by means of a three phase process via student interviews and an open response questionnaire to the final multiple choice questionnaire. The design of the instrument therefore is an additional but major objective of this study.

The instrument design is based on an in-depth assessment of the extent of students' awareness of matters surrounding scientists' social responsibility. The two secondary research questions focusing on the range of views and the reasons students provided for these views arose as a result of the type of instrument. The last research question which attempts to establish racial and/ or gender differences in students' views was added as an introductory exploration into these two fields of personal concern to the researcher and may have future potential.

1.3 THE RELEVANCE OF THE OUTCOMES OF THIS RESEARCH

The University of South Africa where this research was conducted is a comprehensive, open learning and distance education institution with the vision: "Towards the African university in the service of humanity". The focus is on the promotion of higher learning, accessibility to all learners, especially from the African continent, and on values which are based on the African principle of the interdependence of humanity (Unisa brand news, 2005). The Africanization of tuition is envisaged to achieve this.

It is of interest to note that the Chancellor of the University, Judge President B. M. Ngoepe, warned that in addition to fulfilling its role as African University with the challenge of serving and transforming society, the inclusion of moral imperatives may not be left out of sight (Ngoepe, 2005). Justice Edwin Cameron added to this that the task of a university is understanding, advancing and defending truth by means of research and teaching. This gives universities an authoritative role in shaping the world, a role which can only be fulfilled in an atmosphere of academic freedom, and an authority and power which carries great social responsibility (Cameron, 2005).

Prominent statements such as the above serve to set the scene for the future. The

outcomes of this research could well inform approaches to the education of science students specifically in realizing the above. These are also supported by national policies such as the passing of the South African Qualifications Authority Act which has resulted in the definition of Critical and Developmental Outcomes for programmes leading to qualifications offered by technikons and universities. (South African Qualifications Authority, 2006.)

The Critical Outcomes are, *inter alia*:

- to identify and solve problems in which responses display that responsible decisions using critical and creative thinking have been made;
- use science and technology effectively and critically, showing responsibility towards the environment and health of others;
- demonstrate an understanding of the world as a set of related systems by recognizing that problem-solving contexts do not exist in isolation.

Two of the five Developmental Outcomes are also relevant:

- participating as responsible citizens in the life of local, national and global communities;
- being culturally and aesthetically sensitive across a range of social contexts.

These outcomes focus repeatedly on responsibility in the social and environmental contexts. In addition, the Working Group on Values in Education has published a report which promotes values such as equity, tolerance, openness, accountability which are derived from the South African Constitution and Bill of Rights. The report emphasizes the important role of educational institutions at all levels in the establishment of a South African national character underpinned by responsible decision making (Department of Education of South Africa, 2000). This study could be of special relevance in laying the groundwork for incorporating the SAQA outcomes and vision of the Working Group into natural science education at tertiary level.

Teachers and lecturers can be instrumental in affecting students' alterable views in formal and informal teaching situations. A field such as social responsibility which relates to subjective values can lend itself to indoctrination and the promotion of

personal beliefs. It is here that well founded baseline data are essential in order to inform teaching and curriculum development as well as assess impacts of intervention strategies. Appropriate science teaching can address students' conceptions by presenting relevant knowledge and clarifying underlying values, and thereby play an important role in affecting learners' beliefs, attitudes and values and bring about informed decision making and responsible actions (Koballa, 1988; Zoller *et al.* 1991). In informal laboratory and tutoring sessions a deeper understanding by lecturers of the values and views held by students will be helpful in promoting a common set of professional and moral values and increase educators' awareness of the impact their unspoken actions and attitudes have on students' perceptions (Lave and Wenger, 1991). Koballa (1988: 120) points out that values are influenced by culture and personal experience and in turn play an important part in influencing attitudes. By focusing on learners' values educators can succeed in bringing about changes of interest.

1.4 DEFINITION OF CONCEPTS

In the context of this study the term "views" encompasses cognitive and affective dimensions, as well as the dimension of values out of which a sense of responsibility arises. The authors of the original Views-on-Science-Technology-Society (VOSTS) instrument which was used as a model for developing the instrument in this study adopted the term "views" in order to cover a broad range of concepts (Aikenhead and Ryan, 1992). In their articles and question statements they refer to views, positions and beliefs interchangeably. For the purpose of this investigation views are taken as opinions or positions of respondents on a topic based more on arguments and reasons than on beliefs. The emphasis is therefore on cognition above affective responses (Zoller and Ben-Chaim, 1994).

Views of students on a topic such as social responsibility therefore closely relate to value systems and could lend themselves to ethical or philosophical interpretation. This research was confined to the range of views addressed by distance education science students and the reasons they provide for those views, following the assumption of Abd-El-Khalick *et al.* (1997) and Ledermann (1992) that students

generally do not hold fixed philosophical positions and that their views fluctuate. Students' views arise from experience and education and are interpreted in terms of personal value systems and world views. The interrelationship between beliefs, opinions, attitudes, values and behaviour is close and complex. In the measurement and description of views and attitudes this complexity must be borne in mind. It accounts for ambivalence and conflicting results.

In its most concise definition the term "responsibility" refers to causality in the sense that someone or something may be the cause of certain effects. Responsibility is however taken further to mean that the responsible person owes an explanation, a response, and that he/ she must be accountable for what was done or is being done (Pfürtner, 1989). The social responsibility of scientists therefore implies that scientists owe society a response for the effects of the application of scientific knowledge. Siekevitz (1972: 241) extends the acceptance of responsibility further by arguing that what is regarded as responsible rests with the public who will call scientists to account and make them responsible for their actions and failure to act. Seen in this context, social responsibility places demands on both the scientists and society.

There is a variety of definitions for science and technology. In the context of this thesis the terms "science" and "scientists" refer to natural science and the physical and biological scientists who investigate the natural world respectively, in distinction to social scientists, for example, who study social phenomena by employing the scientific method of investigation.

1.5 SUMMARY

Chapter 1 sketched the background to the need for scientists to accept their responsibility towards society rather than isolate themselves and disavow the impact of science on society. The education of young scientists needs to enable them to fulfill this role with insight and expertise. Effective education is best based on information about students' perceptions, conceptions and attitudes and the identification of areas of intervention. For education to be relevant it must also take into account world views and the socio-political context. This is especially so in a field

which closely relates to value systems and personal convictions. In a multicultural society in transition such as we currently experience in South Africa the challenge is great. For these reasons it was imperative to design a new research instrument. The type of instrument which was chosen takes the views of students as point of departure and as such is expected to be innovative and informative.

In the following chapter a literature study will clarify the current discourse in the field. This is followed by an in-depth account of the development and application of the multiple choice instrument in Chapter 3. The data will be analyzed in Chapter 4 to establish the variety of conceptions and perceptions held by the students and to identify trends and areas of remediation. The results are expected to inform both formal and informal teaching and learning practice in science as set out in the final Chapter 5.

CHAPTER 2

ASPECTS OF THE SOCIAL RESPONSIBILITY OF SCIENTISTS

Studies in science education and the philosophy and sociology of science implicitly or explicitly address aspects pertaining to the social responsibility of scientists. These aspects are interrelated and mutually influence each other and by their very nature depend on value systems and world views. The ethics of science is however beyond the scope of this literature study. For the sake of clarity and structure this complex variety of factors associated with the social responsibility of scientists is discussed in this chapter under the two main topics of the scientific enterprise and the interface between science, technology and society. Where relevant, the views of respondents from related studies are included. Figure 2.1 gives an overview of the sub-division of topics.

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- 2.1 The scientific enterprise**
 - 2.1.1 Scientific freedom and responsibility
 - 2.1.2 The ethos of science
 - 2.1.3 Scientific knowledge
 - 2.1.3.1 Western scientific inquiry
 - 2.1.3.2 The power of scientific knowledge
 - 2.1.3.3 Secret and forbidden knowledge
 - 2.1.3.4 The technological imperative
 - 2.1.3.5 Prediction
 - 2.1.3.6 Indigenous knowledge
 - 2.1.3.7 Women in science
 - 2.1.4 The scientific community
 - 2.1.5 Situated learning
 - 2.1.6 The scientist as individual
 - 2.2 Science, technology and society**
 - 2.2.1 The interdependence of science, technology and society
 - 2.2.2 Communication and education
 - 2.2.3 Decisions and consequences
 - 2.2.4 Professional societies and codes of conduct
 - 2.3 Summary**

Figure 2.1: Aspects of social responsibility: sub-division of topics

2.1 THE SCIENTIFIC ENTERPRISE

Scientific freedom and professional standards are the principles upon which the production of scientific knowledge rests. The scientific process and the nature of science as well as institutional structures and individual values determine directly or indirectly how scientists interpret and implement their social responsibility. These attributes of the scientific enterprise (Klopfer, 1976: 303) are investigated in the following sections and the complex spectrum of views, paradoxes and constraints on the social responsibility of scientists are indicated.

For purposes of comparison, views of respondents from related research projects are included. Target groups and research questions comparable to this study were not available. However, the distance education students who were involved in the study embodied such a wide spectrum of age groups and activities, so that it was argued that studies involving high school learners and working adults could be consulted. Although such studies did not focus explicitly on scientists' social responsibility, they were selected for the direct and indirect aspects related to the topic as discussed in this chapter. In this respect it must be noted that qualitative and quantitative responses depend to a large measure on the formulation and context of the questions and can only serve as an indication of trends and positions along a continuum. The most comprehensive studies were the "Views-on-Science-Technology-and-Society" (VOSTS) project (Aikenhead, 1987; Aikenhead, Fleming and Ryan, 1987; Fleming, 1987; Ryan, 1987) and the survey on "Europeans, Science and Technology" in 2002 (European Commission, 2002a, 2002b). The former focused on Canadian high school students, while the latter was conducted among 16029 persons from 15 European member states. These European respondents formed a representative sample of all members of the population from the age of 15 years. In most cases the views of young people still studying did not differ appreciably from the respondents as a whole. Differences were rather to be found at national level and correlations could frequently be made between respondents' opinions and their level of education. Reference will be made to other more limited investigations in the appropriate context of the text.

2.1.1 Scientific freedom and responsibility

The foundations of Western science were laid when Renaissance thinkers such as Copernicus, Galileo and Giordano Bruno defied medieval beliefs and the authority of the church (Edsall, 1975a: 1; Resnik, 1998: 59). Since then scientific freedom is regarded as an essential prerequisite for the advancement of scientific knowledge as is academic freedom in general (Edsall, 1975b; Mohr, 1984: 193). Resnik (1998: 60) clarifies this by stating that freedom is indispensable for the creative expansion and validation of knowledge and that it also prevents the loss or stagnation of knowledge and expertise. The effect of political domination of scientific research is illustrated by the devastating and constraining influence of Lysenko's genetic theories under Stalinist dictatorship in Russia between 1937 and 1964 (Medvedev, 1969; Resnik, 1998: 61; Russell, 1967: 53).

Academic freedom and freedom of research is of such crucial importance for a democracy that it is guaranteed by the South African Bill of Rights together with basic human rights such as freedom of religion and a right to education and a healthy environment (South Africa. Government, 1996). This demonstrates the large degree of trust and power conferred upon the scientific community by the government and society.

Freedom and responsibility however go hand in hand (Edsall, 1975a: 5; Maxwell, 2005). While the advancement of knowledge can only take place in an atmosphere of freedom, such freedom equally demands responsible choices and actions. Mohr (1984: 185) emphasizes that choices must be based on sound value judgements while Maxwell (2005) contends that "A person acts without freedom to the extent that he lacks the capacity to realize what is of value".

These values reflect the dual goals of science: a search for truth (van Melsen, 1970) and a concern for society as a whole (Brown, 1971; Agius, 1989). The social responsibility of scientists should thus be viewed against the mutual requisites of scientific freedom and responsible, value-based decisions and actions. There is however no clear consensus on the extent of scientific freedom. Mohr (1984: 193) and van Melsen (1970: 103) define it most clearly as freedom of thought and

freedom of inquiry independent of external constraints such as political, religious, cultural, financial or other factors. The question of freedom of choice, i.e. freedom in decision making, is however controversial. The American Association for the Advancement of Science (AAAS) (Edsall, 1975a) opposed external restrictions on basic research in its investigation into scientific freedom and responsibility. In a discussion on social ethics and the conduct of science organized by the New York Academy of Sciences one of the participants pertinently claimed that “The attitude that a scientist should be forbidden by some person or group from pursuing some line of research harkens back to the condemnation of Galileo...” (Siekevitz, 1972: 221). On the other hand, philosophers such as Mohr (1984: 193) and Resnik (1998: 89) argue that while the goals and objectives of scientific research are largely determined by government and financing bodies, the technological applications should be determined by the values and needs of society.

The additional question of freedom of speech or freedom to publish needs to be balanced between responsibility towards society as in the case of whistle blowing and the dissemination of sensitive or potentially harmful information. The conviction that the results of scientific research findings should never be subjected to external pressure or altered to meet expectations is however uncontested. It relates closely to the ethos of scientific inquiry which aims to ensure scientific quality and integrity. (Edsall, 1975b; Mohr, 1984: 194.)

In the study conducted among Canadian high school students on the nature of the scientific method, up to 55% were aware of the essential element of freedom for producing original and creative scientific work (Aikenhead, 1987). The majority (81% – 86%) of the same cohort of students however also recognized the important influence of the political climate of their country and of government funding on scientific research. Here opinions ranged from one-third favouring independent choice by scientists to approximately one-third in support of a cooperative approach. Among the remaining one-third who appealed for the social control of science in order to ensure human welfare and economic accountability, a sense of social responsibility is apparent. Answers to a follow-up questionnaire statement revealed that more than half (55%) of the students believed that funding and coordination by the state would make scientific research more efficient, while 42% preferred that

government funding should nevertheless leave “the conduct of science to scientists”. (Fleming, 1987.)

The balance between scientific freedom and responsibility underpins all the aspects of social responsibility which will be discussed in the subsequent sections of this literature survey.

2.1.2 The ethos of science

A set of unwritten professional standards has governed scientific conduct since the rise of modern science. Adherence to these standards has been the only responsibility which scientists had while pursuing their primary goal of searching for new knowledge. The social philosopher Robert Merton was the first to describe the ethos of science in 1968 as being based on the four closely related principles of universalism, communism, disinterestedness and organized scepticism (Merton, 1968: 597; Richards, 1987: 103).

Universalism ensures the open nature of science by which new knowledge is evaluated in terms of neutral, objective and impersonal criteria. Valid and reliable data and consistency with existing knowledge are decisive. The race, gender or personal convictions of scientists should not influence the acceptance or rejection of scientific findings.

Communism, also referred to as Communalism (Cross and Price, 1992: 56), promotes the accessibility of scientific knowledge for the benefit of all, and as such prevents secrecy and fraud. Open communication and public ownership of scientific knowledge is imperative for the search for knowledge. Newton’s frequently quoted exclamation: “If I have seen further, it is by standing on the shoulders of giants” clearly expresses the spirit of communalism on which the advancement of science rests (Merton, 1968: 611).

Disinterestedness describes the dedicated search for knowledge for its own sake, without the expectation of personal gain. It is reinforced by the principle of

communality by means of which the scientific community ensures the control of personal fraudulent motives and scientific malpractices.

Organized scepticism is closely associated with the other three norms of scientific conduct. It requires that judgements and conclusions be based on empirical data, reliable facts and critical analysis, and as such forms the basis of the scientific method. (Merton, 1968: 599; Richards, 1987: 103.)

Merton's normative codes which are still frequently cited imply honesty, objectivity, critical awareness and unselfish engagement (Edsall, 1975a: 6; Mohr, 1984: 192; Resnik, 1998: 72). They reflect the ideal to which scientists subscribe and they continue to be binding (Richards, 1987: 103; Siekevitz, 1972: 198). These norms are propagated formally during the education and training of young scientists and informally by implication or by the example of mentors.

The four imperatives however limit the responsibility of scientists to the scientific process alone without reference to society. Scientists have generally isolated themselves in their proverbial "ivory towers", convinced that the secrets of nature which they were investigating were of no concern or consequence to anyone outside the field of science (Siekevitz, 1972: 198). The absolute trust in the neutrality of scientific knowledge and the objectivity of the scientific process has led scientists to disregard any responsibility for the social or environmental impacts of their discoveries as well as any considerations of value related issues (Resnik, 1998: 2, 33). According to the survey among the European population, 84.4% of the participants for example also believed in the neutrality of scientific knowledge, arguing that negative consequences depended on its application (European Commission, 2002a, 2002b). While scientific facts and data may be neutral, the scientific process is subject to assumptions and judgements and depends on funding and conformity with political and economic interests (Richards, 1987: 148; Siekevitz, 1972: 245). Robert Merton (1968: 609) also points out clearly that the universal nature of science rests on the foundations of a democratic society, yet racial and gender discrimination have been practiced for centuries and are only recently being addressed. The protection of new scientific information by means of licenses and patents and the resultant commercialization of science conflict increasingly with the

principles of communality and disinterestedness, especially in biotechnology and the human genome project (Cross and Price, 1992: 56). The principle of organized scepticism is often regarded as the cause of conflict or alienation between science and society (Merton, 1968: 601; Richards, 1987: 104). Scientists are perceived as analyzing issues outside the realm of science too critically and objectively, disregarding the equal validity of time-honoured customs, values and deeply held convictions in religion, culture and politics. This attitude can cause scientists to lose the trust of society and to be seen to act unilaterally from society's point of view. Such frequently occurring situations can only be resolved when the values of science and the values of society have found a common ground.

The conflict between the scientific ethos and the "reality of the powerful impact of science and technology on society and the environment" is apparent (Siekevitz, 1972: 198). Scientific activity, however idealistic, does not and cannot take place in isolation. Only the acceptance by scientists of their responsibility for the social impact of their discoveries can resolve this conflict.

In order to accommodate responsibilities towards society, scientists, philosophers and professional societies have increasingly redefined or complemented the underlying principles of the scientific ethos in general or more specific terms (Edsall, 1975a: 4; Mohr, 1984: 195; Resnik, 1998: 53; Siekevitz, 1972: 203). The AAAS (Edsall, 1975a), for example, focuses on communication, decision making, protection of the public, conflict resolution but also on the preservation of scientific freedom. In his book on science and ethics David Resnik includes the requirement for "socially valuable research" as well as "responsibility for the social impact of research" (Resnik, 1998: 63).

2.1.3 Scientific knowledge

This section addresses a variety of aspects of the production and application of scientific knowledge which have specific implications for the social responsibility of scientists. All aspects are interrelated and the division into sub-topics serves to promote clarity (see Figure 2.1).

2.1.3.1 Western scientific inquiry

Without considering the philosophy and epistemology of science, the following characteristics of Western scientific inquiry are relevant to a clearer understanding of the questions surrounding the social responsibility of scientists. They also confirm Merton's postulates of the ethos of science as discussed in the previous section.

Modern scientific knowledge unequivocally reflects the Western Eurocentric and male-oriented perspective on nature (Ndunda and Munby, 1991; Rosser, 2000: 52). The positivist theory of knowledge informs the scientific method of inquiry. Natural phenomena are thus investigated by means of an objective reductionist-deterministic approach. The observer does not form part of the process and the phenomena under investigation are reduced to simplified models, functions or entities. The resultant knowledge is regarded as objective, accurate and factual (Resnik, 1998: 40) with the potential to change natural and social conditions (Kyle, 1999). Objectivity further implies neutrality and independence from the influences of subjective values and beliefs as well as sociopolitical, economic or cultural factors. (Kuiper, 1998; Kyle, 1999; Rosser, 2000; Toulmin, 1985.)

The nature of Western scientific inquiry influences scientists' attitudes towards the extent of their social responsibility. The belief in the objectivity and concomitant neutrality of scientific knowledge has lead scientists to argue that the responsibility for the effects of science rests with those who implement it (Richards, 1987: 148; Siekevitz, 1972: 258). Objectivity is also regarded as a predominantly male approach leading to a science whose essence is power and domination of nature (Rosser, 2000: 38). The reductionist-deterministic approach further leads to a denial of traditional holistic views of nature which acknowledge the interconnectedness of natural systems (Kyle, 1999). Ecological degradation and crop failures in developing countries have been attributed - at least in part - to these characteristics of Western science (Kyle, 1999; Rosser, 2000: 38).

The nature of Western scientific inquiry as described above gives rise to further questions closely associated with social responsibility. Can scientific knowledge be

misused? Do some aspects have to be kept secret? Can it get out of hand? Can its effects be predicted and prevented? Are there other ways of knowing the natural world? What contributions can individuals and groups make who have been marginalized and exploited for centuries? Before these concerns are dealt with in the following sections, some views on post-modern science may point to a new scientific approach.

In a discussion with policy makers from the National Science Foundation in America the philosopher Toulmin (1985) advocated a less positivistic and deterministic approach to science by means of which scientists should become participants in the natural world which they study. In this role they could accommodate a larger more pluralistic field of inquiry and acknowledge the validity of a wider range of methodologies. By being a participant rather than an observer during scientific investigations scientists would also realize that their knowledge is not value-free and that their responsibility extends beyond science towards the greater common benefit (Toulmin, 1985).

These thoughts resonate with the overarching objective of Science-Technology-Society (STS) education which Aikenhead (1987) identifies as the creation of an “authentic” view of science. Although there is as yet no philosophical theory to underpin such an authentic view of science, it clearly tends towards a logical positivist point of departure. Almost all participants in the Canadian VOSTS-study believed in the tentative nature of science when this was clearly addressed, and 75% saw classification schemes as hypothetical and pragmatic. However, only 45% adhered to an epistemological position with respect to scientific models, thus contradicting their above position and displaying a lack of insight into the influence of external psychosocial factors on scientific thought (Aikenhead, 1987). Student views on other aspects of the interrelationship between science and society further conflicted with the latter opinion and will be discussed in subsequent sections. Such discrepancies may point to a lack of integration of views and attitudes as well as the need for a sound philosophical foundation, i.e. an “authentic” view of science.

2.1.3.2 The power of scientific knowledge

The dictum that “knowledge is power” is ascribed to the English philosopher and statesman Sir Francis Bacon (1561- 1626) whose model for the British Royal Society still forms the basis for scientific communities world wide. Bacon professed the unlimited domination of nature by means of scientific knowledge for the use and benefit of humankind (Kyle, 1999; Mohr, 1984: 197; The Internet Encyclopaedia of Philosophy). The eminent 20th Century philosopher Sir Bertrand Russell cautions against the belief in the “unlimited” power of scientific knowledge and warns that, although it can be regarded as neutral, it has the equal potential to harm or benefit man and nature (Russell, 1967: 20). Richards (1987: 148) concurs with Russell, arguing that modern science is “now very largely ruled by the Baconian ideal of dominion over nature” and that science policies identify “knowledge with power”. Here it is of interest to note that the majority (63.2%) of the participants in the survey by the European Commission were inclined to agree with the statement: “Scientists’ knowledge gives them a power which makes them dangerous”, while 24.8% were inclined to disagree and 12.0% did not know (European Commission, 2002b).

The Baconian view has changed the focus of science from a search for truth about the natural world to an endeavour to control and transform it. As a result, the industrial and scientific revolutions have improved life for large portions of humanity (Russell, 1967: 73; Snow, 1965: 67). The appeals by present day prominent world leaders such as Kofi Annan (2003), Secretary-General of the United Nations, and the South African female activist and former managing director of the World Bank, Dr. Mamphela Ramphele (AAAS News Release, 2005), to scientists to uplift developing countries also echo this unqualified conviction in the power of science. The concomitant dangers of this enhanced sense of human power conferred by science are however increasingly evident and the need for attendant human values is increasingly imperative (Gaie, 2002; Resnik, 1998:1; Russell, 1967:71).

In contrast to the above mentioned appeals by Annan and Ramphele, 72.8% of the European population, with the majority among the higher educated citizens, did not support the notion that science and technology could solve all problems. And, in answer to a follow up question, 50% felt that there should be more reliance on social

and environmental policies rather than on science and technology to resolve societal problems such as famine and poverty, while another 78.7% argued that the results of social research should be incorporated into scientific research and industrial innovations. Only 30.4% subscribed to the view that science will help to eradicate poverty and famine, with 52.0% being against it.

The highly specialized nature of science and its power to transform or destroy are consequently seen as imposing a special social responsibility onto scientists (Lowrance, 1986: 71; Rao, 1986). It was only after scientists and the public became aware of the decisive role physicists had played in World War II that such special responsibility was realized (Schweber, 2000: 32). It extends over and above the responsibility expected of citizens in general, and requires ethical considerations in the scientific process and the implementation of scientific knowledge reaching into all areas of society. It is argued here that in the same way that scientific freedom is accompanied by enhanced responsibility, the power of scientific knowledge places a special responsibility upon scientists.

2.1.3.3 Secret and forbidden knowledge

The construction of scientific knowledge rests on Merton's principle of communality (Edsall, 1975a: 21). Such open access to knowledge forms the basis of scientific freedom and any restrictions or secrecy are seen as a constraint on the advancement of knowledge. There are however instances where sensitive information needs to be kept secret or its investigation discontinued for a variety of reasons (Resnik, 1998: 58, 91). Such decisions also need to be weighed up against the right of the public to be informed, as for example guaranteed by the Promotion of Access to Information Act No 2 of 2000 (Promotion of Access to Information). The generation of "forbidden knowledge" (Kempner *et al.*, 2005; Murtagh, 1980) also raises questions, mainly of a personal value-based nature, in the public domain. Although the distinction between secret and forbidden knowledge is ill-defined some important aspects of each are discussed below.

Secrecy is imperative where the interests of scientists, industry, the public or private individuals need to be protected. While research projects are in progress, results are not made known in order to protect intellectual property and avoid undue competition. Scientists working in industry and the military are generally under contract not to publish trade secrets and classified knowledge. Scientific insights are often not made public in order to prevent misuse in the hands of amateurs or undue panic among the uninformed sectors of the population. (Cross and Price, 1992: 61, 63; Kempner *et al.*, 2005; Resnik, 1998: 58.) In studies involving human subjects, confidentiality is essential in order to protect the privacy of individuals and their informed consent must be obtained (Edsall, 1975a: 17, 22; Murtagh, 1980). The need to keep scientific knowledge secret frequently arises when there is a conflict of interest economically or politically, and where needs and values of individuals or society at large play a secondary role (Cross and Price, 1992: 61).

Forbidden knowledge differs from secret knowledge in that it is produced by means of unethical methods or that it can be abused for unethical objectives (Kempner *et al.*, 2005). The use of human subjects in medical research in the concentration camps is an example of the former, while research into genetic differences among racial groups (Cross and Price, 1992) and biological warfare could be an example of the latter (Kempner *et al.*, 2005; Resnik, 1998: 64, 85). The moral sensibilities of members of society are conflicted in such instances. Mohr (1984: 194) claims that public campaigns against such knowledge can also serve to protect ideologies and religious convictions, while Murtagh (1980) points out the existence of the belief that mankind is not authorized to investigate some types of knowledge such as the application of stem cells. On the other hand, it is argued that restrictions on research should not outweigh the benefits such research could bring (Edsall, 1975a). More importantly however, it must be remembered that it is the outstanding feature of mankind to delve ever more deeply into the secrets of life and that the scientific discoveries of great scientists such as Galileo, Einstein, Newton and Darwin have brought about far-reaching changes for mankind (Murtagh, 1980).

In terms of social responsibility, secret and forbidden knowledge should therefore be regarded in the light of scientific freedom and the benefits of scientific innovations on the one hand, and the needs, rights and values of society on the other. Society is

increasingly aware that science and technology affect all spheres of life and that it has a right, and a duty, to be informed and to participate in decisions on the production, utilization and moratoria of sensitive knowledge (Cross and Price, 1992).

2.1.3.4 The technological imperative

The technological imperative refers to the view that in science “what can be done will be done” (Richards, 1987: 145). Scientific and technological progress is thus regarded as inevitable. Lakoff (1980a) refers to it as the “Galilean imperative” based on Galileo’s pronouncement which he cites as:

“to explore every domain, unravel every mystery, penetrate every unknown, explain every process. Consider not the cost, abide no interference, in the holy pursuit of truth”.

Galileo here expresses the enthusiastic and dedicated search for truth still experienced by many of today’s scientists as well as the conviction that in this exploration there can be no constraints on freedom. This sentiment was echoed by a majority (46.0%) of British and Bulgarian undergraduate and graduate students in the humanities and social sciences who agreed that “scientific inquiry can know no limits”, with 34.8% disagreeing and a further 19.3% being neutral or uncertain (Bauer *et al.*, 2000).

The need for scientific freedom as well as the belief in the neutrality of scientific knowledge are regarded as the underlying principles informing the technological imperative. According to the latter principle, scientific advances are not inherently good or bad, their benefit or detriment depending entirely on the use or misuse by those who implement and utilize it. As a result, scientists tend to argue that they need not consider the consequences nor social relevance of their inventions. (Murtagh, 1980; Richards, 1987: 145.)

The consequences of the technological imperative are that generally new technologies are created as new scientific insights are available. Thus improvements and changes are made when the expertise is available and not so much when the needs arise. Such decisions are based mainly on commercial interests. Alternately, beneficial technologies are not developed because they are not financially profitable as is evident in the motor and pharmaceutical industry. (Cross and Price, 1992: 62; Rosser, 2000.) The AAAS strongly rejects the doctrine of technological imperative and warns that all possible consequences of new scientific inventions must be assessed and monitored for their continued public benefit (Edsall, 1975a: 25). Murtagh (1980) adds that new technologies that are detrimental or “morally abhorrent” must be discontinued regardless of financial or other implications.

In situations where technological improvements accelerate to such a degree that they can go beyond control, the technological imperative is at times referred to as the “slippery slope argument” (Murtagh, 1980). The most frequently used example is the history of the construction of the first atomic bomb. A number of authors (Fermi, 1995; Lakoff, 1980b; Richards, 1987; Schweber, 2000) describe the vigorous search for scientific answers and technical solutions and the eventual realization of the extent of the horror at the end of World War II. These events have caused scientists to become aware of the moral dimension of their work (Lakoff, 1980b; Pfürtnner, 1989), and the Russell-Einstein Manifesto (Russell, 2003: 82) and the creation of the Pugwash Movement (Leifer, 1980; Richards, 1987) were the first steps in implementing this realization. Could biological research in the 21st century lead to even greater unforeseen social and ethical dilemmas?

In a book which debates the question of ethics in the natural sciences, Pfürtnner (1989) points out that ethical behaviour requires that human beings should not attempt to do all they are capable of. This principle therefore places the responsibility upon science and technology to limit progress voluntarily and consequently abdicate the belief in the technological imperative and consider the needs and values of society.

2.1.3.5 Prediction

Questions concerning the ability to foresee (Siekevitz, 1972: 219) or anticipate (Resnik, 1998: 64) consequences of scientific and technological innovations closely follow the arguments surrounding secret and forbidden knowledge and the technological imperative discussed in the previous sections.

The implementation of scientific discoveries affects all areas of the animate and inanimate world, and it is often only by hindsight that the consequences are evident (Siekevitz, 1972: 219). The prediction or projection of the effects of innovations is uncertain because there are always unknown and unexpected variables, while human factors are even more complex and unpredictable (Richards, 1987: 153). Reiss (1980: 193) extends this argument further by stating:

“One of the most striking aspects of technological innovation is that we really do not know where it will lead.”

Both Richards (1987: 153) and Siekevitz (1972: 219) also argue that the reason why scientists see themselves as not being responsible for the consequences of their research is because these consequences are difficult to foresee. The notion that the responsibility rests on the end-user may be an additional reason why scientists have not as yet investigated this area of concern adequately (Lakoff, 1980a).

There are however also strong views that the anticipation of the impacts of science is clearly one of the social responsibilities of scientists (Resnik, 1998: 64). Sefa-Dedeh (1986) makes the bold statement that scientists have a “special obligation” to foresee and explain the implications of new discoveries. Similarly, Siekevitz (1972: 219) contends that researchers who are concerned with ethical values are able to anticipate consequences. He points out that their scientific background qualifies scientists more than laypersons to assess and address consequences and that research into the formulation and solution of possible problems could be developed (Siekevitz, 1972: 289). The investigations by the AAAS into the social responsibility of scientists also came to the conclusion that scientists are increasingly able to foresee the effects of science and that it is their responsibility to take the “long-term

view” (Edsall, 1975a: 46). It should however be noted that there are “unanticipated” (Resnik, 1998: 150) ways in which scientific discoveries are implemented, the consequences of which are therefore unknown (Biren, 1980). Equally valid may be the argument that a certain amount of risk needs to be taken in order to ensure progress (Deltour, 1986). This latter view is implicit in Galileo’s above mentioned pronouncement.

The ethical view point is that responsible actions by definition demand foresight of their consequences and that the nature of present actions is always judged in the future by their positive or negative effects. It would for example be irresponsible to proceed with research and applications in biotechnology without considering the possible future consequences (Agius, 1989).

Scientists have already made considerable efforts to forestall potential damage by means of the formulation of safety standards in the industrial sectors such as for chemical safety and waste disposal in the Occupational Health and Safety Acts and by means of consultation on international treaties such as the minimization of persistent organic pollutants (United Nations Environmental Programme. Persistent Organic Pollutants), respectively. Although such laws are difficult to monitor they promote foresight and precaution. Other methods such as risk assessments and theoretical modelling incorporate specialized scientific knowledge to evaluate potential effects of new technologies and economic viability (Biren, 1980).

Most scientific assessments however cannot address the cultural, social and ethical dimensions (Reiss, 1980). Socially responsible priorities for the implementation of technological innovations and acceptable risks should be determined by means of consultations between scientists and society. In such meetings scientists should offer training and expert but independent advice, but acknowledge the equal validity of social and cultural needs and concerns (Eijkelhof, 1986; Siekevitz, 1972).

2.1.3.6 Indigenous knowledge

Western science was introduced into occupied colonies and other non-Western states with little regard for cultural values, existing technologies and indigenous knowledge of medicine and the environment (Richards, 1987: 189; Rosser, 2000: 51). Kyle (1999) who views this from the perspective of the ethos of Western science, points out that the universal, context and value free notion of science creates educational systems which do not take traditional beliefs and values into account, and creates societies dominated by technology. Both Kyle (1999) and Rosser (2000: 93) regard the positivistic scientific world view as a form of scientific colonialism, hand-in-hand with which goes the economic exploitation of indigenous knowledge and biological diversity, the appropriation of mineral resources and degradation of the environment.

Research results of studies by Aikenhead (1997) and Haidar (1999) can serve to highlight the above. Aikenhead (1997) argues that Western science does not sensitize learners to racist and ethnocentrist influences in science and technology. In order to inform science teaching, he used a number of VOSTS items to establish student views on the influence of culture on science. While 50-60% were aware of factors influencing science which may have a racist or ethnocentric origin, only 10% realized that science and culture were interdependent. The remaining 20-30% believed in the universality of Western science. The results from Haidar's (1999) study of Arab pre-service and in-service teachers' indicate that their views on the nature of science and scientists were influenced by Western science as well as by the Islamic worldview. According to the latter, the purpose of science is to discover God's wisdom not only by means of the scientific method but also through intuition and revelation. The author explains that Western science is propagated in science education in Arab countries because it is seen as the only means toward economic development. An inner resistance and alienation has however developed towards the domination of Western science due to its exclusion of deep seated cultural values and religious beliefs. Haidar consequently suggests that teaching science from a socially constructivist view of science would accommodate Islamic cultural and religious values more generously. Aikenhead's study (1997) on the influence of culture on science revealed that 46% of English speaking and only 28% of French

speaking Canadian students agreed that individual differences among scientists could supercede cultural differences. This result also indicates the cultural differences among respondents, where the French speakers can be seen to adhere to a more idealized view of science while the English speakers are more realistic about the fact that the practice of science is not neutral and objective.

African science has been described as being composed of diverse scientific, mystical and religious views with no clear distinction between them (Emereole, 1998; Kuiper, 1998). A study conducted among a group of unschooled Batswana has however shown that an average of 66% offered a scientific explanation, based on deterministic principles, to questions about mechanics, heat and sound. A further 15% gave pseudo-scientific reasons which contained some incorrect conceptions, and 12% of the answers, which could be classified as rational, were based on reason and common sense. Only 9 out of 142 responses (6.3%) posed metaphysical, parapsychological and magical views (Emereole, 1998). An in-depth explanation of African thought is offered by Teffo and Roux (2002: 165): whereas the daily activities of Africans are based on empirically verifiable facts, their interpretation of life and the universe is grounded in their realization of vast and complex relationships between mankind and the environment in its entirety. This can be understood as the use of empirical scientific methods whose results are interpreted more holistically than the reductionist approach allows.

There is a renewed interest in indigenous knowledge and technology in Africa. One of the nine focus areas for research of the National Research Foundation (NRF) for example is Indigenous Knowledge Systems, which is described as knowledge developed within certain populations and which at this stage needs to be explored and “utilized” for the benefit of communities (National Research Foundation, 2006). In spite of this, Western science and technology continue to dominate developing countries in the post-colonial era and are regarded as the key to economic advancement (Annan, 2003; Rosser, 2000: 92). However, in the creation of economic growth and better health and education, the particular needs and unique conditions of developing countries must be considered and their natural wealth protected (Richards, 1987: 173). Imported technologies are frequently outdated or

not sustainable. Bouguerra (1986) and Sefa-Dedeh (1986) also warn that developing countries often do not have adequate legislation for environmental protection and that this makes them vulnerable to exploitation by foreign companies. He regards it as the duty of the international scientific community to assist such countries in protecting their environment and designing regulations suited to their particular situation. The current worldwide research into the healing properties and biological diversity of indigenous plants such as the appetite suppressant *Hoodia Gordonii* and the acquisition of patents by multinational pharmaceutical companies may benefit local communities financially in the short term, but eventually it is at the cost of forfeiting their age-old intellectual property (Ndenze, 2006; Richards, 1987: 183; Rosser, 2000: 47, 93).

The reductionist approach of Western science fragments knowledge and separates it from human values, thereby alienating society, especially cultures and value systems foreign to a Western world view (Richards, 1987: 136, 188). Kyle (1999) describes indigenous knowledge as a “rich social resource” which could offer alternate views on science and education and produce new insights and values into problems such as the ecological crisis where Western science has failed. The National Research Foundation also points out that indigenous knowledge impacts not only materially but also morally on societies (National Research Foundation, 2006). Such valuable contributions to modern science could lead to more sustained economic growth in developing countries, for example in the application of regional traditional farming methods more suited to the soil, climate as well as the culture (Rao, 1986; Rosser, 2000). The integration of “multiple knowledges” and the responsibility of “all cultures to contribute ... to the development and environmental sustainability of our global community” (Kyle, 1999) can further reduce the global effects of Western science and technology and take into account the rights and protection of the poor and marginalized (National Research Foundation, 2006). Osborne (2003) confirms the importance of acknowledging and incorporating non-Western cultural knowledge and values in order to change attitudes towards science. This may not only entail a change in facts, logic and epistemology, but also “a felt commitment” and “a bond with a community” (Osborne, 2003). The collaboration between scientists and indigenous people could thus redefine the scientific ethos

and consequently lead to a socially more responsible way of scientific research and technology application (Rosser, 2000: 54).

2.1.3.7 Women in science

Science has been a male dominated domain from which women have been excluded for centuries. Frequently women's discoveries were usurped and ascribed to men, while in other instances women were marginalized and ridiculed until their unique vision was confirmed by men many years later (Fara, 2004; Keller, 1983).

Studies in science education show that female and male students differ in their attitudes, exposure, interest and achievement and that ethnic, cultural and socioeconomic factors are the main reasons for these differences (Greenfield, 1996; Nichols *et al.*, 1998). Among the European population differences among men and women in their interest in science were evident. Only 39.6% of the female respondents, compared to 51.5 % of their male counterparts, were interested in science. This percentage however increased to 68.1% of women who were concerned about Genetically Modified Organisms (GMOs) and animal experimentation, and to 68.4% of the female population being interested in medicine and the environment (European Commission, 2002a). Canadian science students identify male domination and intimidation, differing fields of interest rather than intellectual differences between male and female, as well as the stereotyping of women's traditional role as homemaker as the main reasons for the unequal gender distribution of Canadian scientists. However, 28% did argue that "women and men are equally capable of being good scientists", and thus, according to the author, the sensitivity and lack of bias among male respondents holds promise for equity among scientists in the future (Ryan, 1987). The need to increase the number of women in science was supported by 70.8% of the entire group of European respondents, but only by 66.8% of young women who were still engaged in their education. There were also large national differences in the percentage responses to this question (European Commission, 2002a). In Canada the majority of students (83%) maintained that there was no difference between female and male students with respect to the scientific discoveries which they make. The two main reasons offered

for this were that “any good scientist will eventually make the same discovery as another good scientist” (26%) and “any differences in their discoveries are due to differences between individuals. Such differences have nothing to do with being male or female”. Only 11% of the target group realized that discoveries made by female scientists could be different due to, for example, differences in values, viewpoints and sensitivity toward consequences. In a separate question, 90% of the respondents did not subscribe to the possibility that male scientists concentrate only on facts while female scientists also consider human values (Ryan and Aikenhead, 1992).

In South Africa a report by the National Research Foundation on women in research (Thuthuka Programme, 2001) revealed that only 25% of professional women were employed in the natural and agricultural sciences and that only 10% were in managerial positions. Lack of support to meet their private and work related commitments as well as lack of funding - rather than discrimination or sexism - were identified as the main barriers to professional success. In South Africa employment equity and special grants are attempts to redress the existing disparities in employment and research output of female scientists. The above report is not representative of Black women scientists as these were under-represented in the institutions targeted for the research. In the context of the present study it is of interest that both Greenfield (1996) and Kyle (1995) point out that the influence of ethnicity or race could be more important than gender. Consequently the perceptions and expectations of women of different races need not necessarily be the same.

Feminist studies include a number of approaches, such as liberal feminism and postcolonial feminism, which are derived from different historical and theoretical contexts. Each framework analyses the nature and epistemology of science from its specific perspective and contributes to a new understanding of the underlying influences, values, assumptions and outcomes of science. Such insights are expected to inform decisions and values in research, science education and technology and thus, in the context of this study, also the views on social responsibility. (Brickhouse, 1998; Rosser, 2000.)

Feminist theoretical perspectives have concluded that the ambient culture and its views on gender determine the practice of science and the role of values. A science which originated and was perpetuated in a male dominated culture can as such also not be of social value as is generally professed (Brickhouse, 1998). Feminism (Ndunda and Munby, 1991, Rosser, 2000) also contends that masculine ways of knowing are predominantly “objective, linear, non-emotional and rational” while feminine ways of knowing tend more towards the “subjective, multiple, relational and intuitive” (Nichols *et al.*, 1998). Accordingly, in male dominated patriarchal Western societies the scientific and technological approach is objective and holds the belief in power and domination over nature, which in the extreme is the cause of exploitation and destruction (Brickhouse, 1998; Praetorius, 1989; Steigleder, 1989).

Feminist research has further shown that female scientists can bring new approaches, interpretations and values to science (Brickhouse, 1989; Rosser, 2000). Postcolonial feminism for example draws attention to the effects of colonization and globalization on indigenous knowledge and exploitation of the environment in developing countries. In her book titled: “Women, Science, and Society: the crucial union” Sue Rosser (2000) reports that the International Monetary Fund (IMF) has recognized that the failure to focus on the needs of African women and to incorporate their age-old farming methods has led to the failure of modern agricultural technologies on that continent. She further points out that the feminist perspective on the human genome project is that it is not in the interest of the majority of the world population whose illnesses are largely caused by poverty, malnutrition and environmental factors. The interpretation of cellular processes by women has changed the focus of research into unexpected directions, the most extraordinary being the visionary work of the Nobel Laureate Barbara McClintock (Keller, 1983; Nichols *et al.*, 1998).

Feminism has also been instrumental in furthering the role women can play in science, and consequently there are many efforts to rectify the past discrimination against female scientists. Yet, to be successful, women are expected to comply with the existing mechanistic, reductionist approach of Western science (Nichols *et al.*, 1998; Praetorius, 1989). The male dominated scientific enterprise offers little or no room for the feminine view on life and nature which is more life-affirming and holistic,

intent on social usefulness and practical applicability, as well as incorporating insights from the humanities, ethics and the social sciences. Due to this “epistemological marginalization” female scientists themselves have been making an active choice for careers in biological sciences and medicine which are more compatible with the female nature (Nichols *et al.*, 1998; Osborne, 2003; Rosser, 2000: 20). With biotechnology and environmental sciences rapidly gaining predominance over the previously important physical sciences there is great potential for female scientists. If given the scope, they could redefine priorities, influence research agendas and provide their feminine perspectives, insights and interpretations, which could in turn give rise to new ways of interpreting natural phenomena and a larger awareness of underlying values. The responsibility of the scientific community is to accommodate women and their ways of approaching scientific problems, while the responsibility for female scientists specifically is to expose and transform the domination, exploitation and potential for ultimate destructiveness inherent in Western science. A scientific enterprise inspired by the more comprehensive vision of women will be more socially responsible and will benefit all life on earth, but especially so, women globally and the poor in developing countries.

In the previous sections of this review seven (7) different but interconnected aspects of scientific knowledge and their impact on social responsibility have been addressed. Facets of the scientific community at large, the teaching of science and challenges facing scientists in their individual capacity will be emphasized in the following sections before turning to the complex interrelationship of science, technology and society.

2.1.4 The scientific community

The scientific community consists of a distinct group of people united globally by their pursuit of knowledge about the natural world and the distinct professional ethos they follow. The connotation of ‘scientist’ is generally reserved for researchers in basic or applied fields. The American Association for the Advancement of Science also classifies “engineers, physicians, public health workers, technicians and others

who must use some expert knowledge in their work” as scientists, and includes students, technicians and teachers (Edsall, 1975a). Social responsibility can therefore be seen to extend to all of the above groups who are engaged in the natural sciences.

Scientists were - and frequently still are - regarded as men and women of supreme intelligence occupying a rather elitist status in society and being dedicated selflessly to the advancement of knowledge about nature in the isolation of the proverbial ivory tower. This idealized notion does not generally apply to the modern day members of the scientific community. While most scientists certainly are motivated by an interest in nature and how it functions, being a scientist also provides an above average livelihood and a respected and rather elitist status in society. (Mohr, 1984; Richards, 1987.) The lack of involvement of scientists in society and the simultaneous exclusion of the marginalized of society such as women, members of other races and cultures and the poor, is untenable in a world dominated by science and technology (Rosser, 2000).

The function of the scientific community is to generate as well as validate new scientific knowledge. Mohr (1984) defines science as “a systematic attempt of the human mind to obtain certified knowledge”. Specific institutional objectives determine whether the work is basic or applied. The scientific ethos sets the norms for the production of the scientific knowledge. Adherence to this ethos creates confidence in scientific results which is a necessary requisite for the validation of new scientific knowledge (Richards, 1987: 72). The validation of knowledge is achieved by means of the peer review system which operates locally, nationally and internationally. It depends on scientists’ freedom to communicate openly as well as on the maintenance of scientific norms and values.

The control of the scientific community over the validation of new knowledge can however result in a stranglehold over new ideas and the exclusion of less conventional knowledge systems and interpretations offered by marginalized individuals or minorities or even by society (Cross and Price, 1992). In this respect Richards (1987: 63) refers to the philosopher Kuhn’s description of scientific revolutions where the latter postulates that it often takes outsiders or a new

generation of scientists to accept and propagate new ideas. Richards writes: “The replacement of existing paradigms by more comprehensive or dramatic new ones is revolutionary, often only fully integrated by new generations”. Prejudices, vested interests and competition for funding can also lead to the exclusion of scientists by reviewers of publications and editors of journals. Social responsibility requires that space be created for less conventional ideas such as indigenous knowledge systems or feminine interpretations.

Contrary to the scientific ideal of creating objective and neutral knowledge, science is not practiced in isolation. Not only do the above mentioned factors within the scientific community affect the generation of scientific knowledge, external political and economic pressures as well as social and cultural influences cannot be disregarded (Mohr, 1984). Scientists are dependent on financial support which is generally provided either by industry or the government, whose objectives are in turn dictated by economic and political motives respectively (Richards, 1987: 148). Tighter control of funding and stronger competition for dwindling resources and financial rewards for research outcomes have been found to lead to unethical practices (Resnik, 1998).

The internal mechanisms of the scientific community as well as the external control on the production and validation of knowledge have a direct and indirect bearing on responsible practices. Ultimately scientists are accountable to society for the funding they receive and the application of their generated knowledge (Mohr, 1984).

2.1.5 Situated learning

In the foregoing sections aspects of the social responsibility of scientists have been discussed mainly in the context of their activity as researchers. At the University of South Africa where this research was conducted, the function of scientists extends beyond research to teaching and community involvement. The need to educate science students for their role as socially responsible scientists was emphasized in the introductory chapter. Before addressing the conflicts and responsibilities faced by scientists in their personal capacity and at the science-technology-society interface,

a description of aspects of teaching and learning science with special reference to the Theory of Situated Learning is relevant.

The teaching and learning of science has been underpinned by a variety of theoretical frameworks and epistemologies, none of which can successfully capture all aspects of educational practice (Atwater, 1996; Duit and Treagust, 1998). Cognitive learning theories view the learning process as the internalization and assimilation of knowledge by means of transmission and discovery. Here the focus is on cognitive processes and cognitive structures. This approach does not adequately consider the learner as person, the activities, the social situation and their mutual relationships (Chaiklin and Lave, 1996; Lave and Wenger, 1991). Social constructivist theory recognizes the importance of the sociocultural context in the construction of knowledge. In her motion for multicultural science education based on a social constructivist epistemology Atwater (1996) contends that social constructivists also "... challenge scientists' position of pre-eminence, because they evaluate the impact of the social context of scientific actions on peoples' cultures". The Theory of Situated Learning is seen to be closely related to social constructivism (Hay, 1993, 1994; McLellan, 1996a). It bridges cognitive processes and social practice and draws on the Theory of Social Practice (Lave and Wenger, 1991). The latter focuses on interrelationships between people, their actions and their environment and describes learning as "an integral and inseparable aspect of social practice" (Lave, 1997).

The Theory of Situated Learning was developed by Lave and Wenger and is based on Lave's field work in Liberia, where she observed how apprentice tailors learnt their craft and progressed to becoming masters of the trade. Through interaction with experts in practical situations, which by their very nature involved the entire person and had cognitive, affective, ethical, social, cultural and historical dimensions, apprentices became increasingly knowledgeable. Such action and interaction in a social setting always brought about change and transformation, not only of the apprentice/ learner but also of the social world, the expert/ teacher and the skills and tools in question. Being able to view the entire process of tailoring and being assured access to the tools of the trade, apprentice tailors perceived their engagement as relevant and their motivation was intrinsic. Added to this is the important fact that on

completion of the apprenticeship a high percentage became masters themselves and had the opportunity to be fully legitimate members of the fraternity. (Lave, 1997.)

Based on the above, the Theory of Situated Learning views a person as member of a sociocultural community and, accordingly, knowledge, attitudes and skills are only meaningful if they are socially negotiated (McLellan, 1996b). Learning is thus viewed as “situated activity, where the participants, the sociocultural system and the activities of thinking, knowing, doing are integrated and mutually constitute each other”, thereby shaping the social world through interaction with it (Lave, 1997). The notion that conceptualization is based on prior activities and perceptions in the social world is defined by Brown and co-workers (1989) as “situated cognition”, which is seen to vary with the social context and as such is transformed in the process of situated activity. The learning context is described as a complex and dynamic relationship between participants, activities and the social world. This includes personal background, the learning community and activities, the rules, skills, tools and instruments, the society and culture at large, and especially their political and historical aspects (Burke and McLellan, 1996, Chaiklin and Lave, 1996). The combination of the cognitive aspects of learning, the physical context as well as the activity is defined by Brown and Duguid (1993) as “cognitive apprenticeship”. The supportive social context is regarded as the most important contributing factor in the creation of meaning and understanding and the prevention of “confusion and disillusionment” (Brown and Duguid, 1993). On a final note, with respect to the foregoing explication on Western scientific inquiry, it is of interest to note that according to Hay (1993) the Theory of Situated learning is reminiscent of postmodernism which “views truths as socially constructed, historicized, cultural, temporal, contextual, subjective”.

The concept of “Legitimate Peripheral Participation” was developed to analyze and describe the activities and conditions of Situated Learning. The three aspects of legitimacy, peripherality and participation are integrated and each is related to the other. The complex term attempts to capture the practical and relevant engagement by learners in the social world and the accessibility and sense of belonging to the community in which the activity takes place, and by means of which the learner is able to progress towards increasing partnership. More specifically the concept

attends to the following: the importance of being a recognized participant in the learning process and having access to resources, the increased participation and responsibility which leads to increased empowerment, the multiple ways of involvement in social practices, the diversity of relationships and interactions in and among communities, the production of skilled persons and the reproduction and transformation of communities. Legitimate Peripheral Participation can be practiced in formal education and training situations as well as in everyday situations where persons participate in activities. It has been translated into educational practice and is used to focus on fundamental aspects of which the following, discussed in the paragraphs below, can be of particular relevance to the transmission and practice of social responsibility and the transformation of the scientific community. (Lave and Wenger, 1991.)

The relationship among apprentices and masters, learners or students and experts or teachers, as seen in the light of Situated Learning and Legitimate Peripheral Participation is paramount in guiding the novice towards responsible conduct. Lave (1997) described apprentice tailors as being intrinsically motivated and that they learned from the experts through participation, informal interaction, observation and language, and not so much through action and reinforcement. She comments on their aspiration to emulate their masters. She also remarks that in this setting novices were able to obtain an overview of all aspects of the craft. The diversity of relationships among mentors and participants in the practice also facilitates contact with and inclusion of related communities, for example the contact and interchange between a learner's home community and the scientific community in which s/he participates. This affords the reciprocal exchange of knowledge between society, students and teachers. Schlager and co-workers (1996) emphasize that mentoring can proceed from an informal to a formal level, and that mentors are an important "resource" and can act as "consultants". Their ability to situate skills and knowledge in a context which reflects cultural values and social expectations is essential in the creation of knowledge, and in the context of this research, essential in the transmission of socially responsible conduct. With respect to the teaching of practical science subjects the observation of Tripp (1993) is particularly relevant. He writes that practical knowledge can "neither be taught nor learned" and that it can only be "acquired" by "apprenticeship to a master" whereby the "covert aspects of the

practice” can be “assimilated”. And, very pertinently to this research, Damarin (1994) points out that graduate students are in a unique position of cognitive apprenticeship. They are able to acquire the “languages of research and scholarship, the norms of university and research lives, and the traditions and history of their field; at the same time they are building human bonds with their colleagues”.

Much of the knowledge acquired by means of situated participation is implicit. Participants in any socially situated activity adopt language, behaviour and world views of the social group, and thus become part of the culture, both consciously and unconsciously. What is communicated and acted out, both explicitly and implicitly, forms part of the acquired knowledge and behaviour. Observation of knowledgeable persons in the field gives learners a sense of how expertise is manifest in conversation and other activities. Often the ambient culture is acquired more easily and permanently from implicit attitudes than from what is taught by means of formal tuition (Brown *et al.*, 1989). Brown and Duguid (1993) explain this further by stating that: “Little of the complex web of actual practice is explicit instruction. A great deal remains implicit in the practice itself.” They point out that attempts to make implicit aspects more explicit to learners are often unsuccessful and incomplete, and that some practices may need to remain implicit, covert, unsaid and unexplained. Subtle actions by tutors in the laboratory may, for example, be decisive for social responsibility to take root in a student population. Similarly, students reading newspapers and never finding statements by scientists on current world issues such as sustainability, pollution or HIV/ Aids, may conclude that these are political and social rather than scientific issues.

Closely related to the acquisition of implicit knowledge is the acquisition and modification of attitudes. The Theory of Situated Learning considers the whole person in the real world and as such includes values and attitudes. Attitudes are not directly evident but influence intentions, motivate learning and determine behaviour. Attitudes can be changed and learners can be inspired and motivated by participation in real and relevant situations. The role of mentors and the increased involvement of novices towards eventual full access and participation as described by Legitimate Peripheral Participation is seen to influence attitudes, motivation and values positively, and ultimately leads to greater freedom and responsibility

(Simonson and Maushak, 1996). Streibel (1993) further argues that situated learning promotes “responsible freedom” in learners which also encompasses “justice” and “equality”. Freedom here is not regarded as the liberation from biographical and historical constraints of the past, but as having the responsibility to embrace individual, social and historical contexts and to participate in their continued recreation and transformation. This is what true empowerment is seen to be, and as such every relationship and situated activity carries with it an ethical dimension and responsibility.

Legitimate Peripheral Participation expressly focuses on relationships of power and the access to and control of resources in communities of practice, thereby creating an awareness how these can marginalize or empower participants. Lave and Wenger’s (1991: 52) statement that “participation dissolves dichotomies” is not only significant in the context of teaching and learning science, but also in the context of the social engagement of scientists. Through increased and free access to resources and increased involvement, learners gradually progress from limited engagement towards full participation, responsibility, authority and expertise in the practices of the community (Brown and Duguid, 1993). With respect to relationships of power Damarin (1993) argues that the dominance of gender, race, class, knowledge systems, cultures and communities can be reduced by adopting the principle of Legitimate Peripheral Participation. This will not only make education accessible to the previously marginalized, but will also promote the inclusion of diverse perspectives, so that knowledge is no longer the exclusive domain of the current “scientific elites” (Damarin, 1993). She defines this accessibility and inclusivity as the “Emancipatory Potential of Situated Learning” (Damarin, 1994).

In terms of the Theory of Situated Learning and the concept of Legitimate Peripheral Participation a person is always regarded as member of a community. Therefore students and aspiring scientists must be seen to belong to the scientific community. Moreover, the other communities with which they are associated and their respective values, traditions, political and economic structures, must be recognized and honoured, thus preventing the cultural alienation of students in their role as scientists (Hay, 1993). Being involved in the construction and transformation of knowledge, communities are also continuously developed and transformed. This incorporation of

different groups of people who utilize science in different ways and have different views on social responsibility is also, according to Eisenhart and co-workers (1996), an important way of enhancing scientific literacy among students. From this point of view it is therefore possible for students to participate in several communities and proceed increasingly towards greater participation and responsible action within a number of communities (Hay, 1993). Roth and Lee (2004) add that legitimate participation in community life also prepares students for life long engagement in society. Moreover, the scientific community which is in itself bound by an ethos and by rules, paradigms, instruments and methods, is thus produced and reproduced by the activities and relationships of its members (Brown, Collins and Duguid, 1989). Greater inclusivity of students and younger members as well as outside communities and society at large, could well serve to transform the scientific community towards greater transparency, accessibility and social responsibility.

The relevance of the Theory of Situated Learning has become evident in the development of the instrument for this research, which was based on student responses to interviews and open and fixed response questionnaires. (Details are given in Chapter 3.) The process confirmed that respondents had acquired their views, attitudes and opinions about the social responsibility of scientists through interactions with their home communities, their workplace, the media and their engagement with fellow students, scientists and lecturers. The group interviews also clearly demonstrated how knowledge was negotiated among participants and how new meaning and relevance was acquired in a particular context. Participants tended to be inspired and animated at the end of an interview, and may well have gained an enhanced awareness of their responsibilities in their role as scientists.

2.1.6 The scientist as individual

Society respects scientists as members of an intellectual middle class and also expects scientists to reflect the ethos of science in their private capacity and thus to be more objective, honest and disinterested, even more dedicated, open minded and accurate, than members of other professions (Klopfer, 1976; Resnik, 1998: 41). Approximately two-thirds of Canadian science students confirmed that scientists

were equally objective in their research work and private lives as a result of their training in the scientific method and their insightful scientific knowledge. Thirty percent (30%) supported this by their belief that the nature and consequences of scientific work demanded a greater degree of objectivity and accountability (Ryan, 1987). In Europe scientists enjoy the second highest measure of public respect after medical doctors, but, significantly, in the event of disasters, 62.7% of the population would rather trust the opinion of a scientist compared to 55.3% who would trust a medical doctor (European Commission, 2002a).

The notion that scientists are unemotional, asocial “nerds” is added to society’s perception of what it means to be a scientist (Mohr, 1984; Ramsden, 1998). Scientific work however does not prohibit men and women from having values, personal beliefs and aspirations which conflict with their professional standards and scientific findings (Mohr, 1984). Scientists come from different cultures and adhere to their fundamental cultural and/ or religious values (Resnik, 1998: 40). This makes scientific inquiry a deeply human enterprise where world views, personal and cultural values as well as expectations, ambitions, loyalties and external pressure play a role. A group of university scientists who were progressively sensitized to feminist perspectives on science during a series of seminars on “Promoting Women and Scientific Literacy”, tended to acknowledge more readily at the end that scientists were not always as “open-minded, logical, unbiased, and objective” as they had originally endorsed, and that personal and societal factors did indeed influence scientific research (Bianchini *et al.*, 2002).

The interface between science and religion has been investigated by a number of studies. Researchers engaged in the Europeans, Science and Technology project found that 45.4% of the target population of over 16000 believed that “we put too much trust in science and not enough in faith”. They argue that this belief is associated with the notion held by 61.3% that “science is changing our ways of life too quickly” (European Commission, 2002a). Canadian students were approximately equally divided in their opinion whether or not religious and ethical convictions could influence scientific research. This result should be evaluated together with an associated response in which more than 57% of these students believed that a Godhead could indeed alter natural events (Aikenhead, 1997). Shipman and co-

workers (2002) identified four different approaches to the science and religion interface. The group of people described as “distinct” separate their views on science and religion, believing that each is unique and independent of the other. “Convergent” thinkers on the other hand acknowledge that integration between a scientific and a religious view of the universe is possible and desirable. “Transitional” views reflect a superficial degree of awareness of a commonality between science and religion. “Confrontational” persons represent those who argue that science and religion are in conflict and that science has the definitive answers to questions about the universe. Shipman’s study showed that 49% of a class of 84 fell into the “distinct” group, 14% held “convergent” views and 34% were “transitional” in their thinking. There were no students with “confrontational” opinions, and over a period of three years there were only two students who objected to the inclusion of religious aspects in a science course.

The question that needs to be asked is whether scientists carry an individual or a collective responsibility towards society. Authors differ widely on this matter. Richards (1987: 187) clearly contends that researchers who are isolated in academic institutions or bound by contracts in industry or the military cannot be held responsible for the applications and consequences of their research. He places the responsibility for the effects of science on “science as an institution”. In this respect it may be argued that such diffuse accountability will ultimately hold no one accountable. The researcher Arthur Galston who demonstrated that the chemical compound known as 2,4,5-T could be used as growth inhibitor is unequivocal in his demand that a scientist must trace the application of his/her discoveries at every possible stage. This compound was subsequently employed under the name Agent Orange as defoliant in the Vietnam War, causing widespread destruction and human suffering (Siekevitz, 1972: 223). Badash (2004) regards the decision whether to take responsibility or not as a personal one, while Richards (1987:136) believes that individuals need to weigh up their obligations towards the norms of the scientific community and the norms of society when either of them is compromised.

Whistle blowing (Resnik, 1998: 64, 125; Richards, 1987:137) is one such instance where an individual is compelled to make a personal choice by weighing up loyalty to an institution or even the desire for a secure livelihood against exposing dangerous

or unethical practices publicly in order to protect uninformed laypersons. Although whistle blowing is widely encouraged and admired, the outcome is frequently that these individuals fall victim to powerful corporate structures and face dismissal. Professional societies are increasingly required to represent and protect their members in resulting legal battles (Edsall, 1975a). Seltzer (1985), reporting on a Student Pugwash conference on Scientists' Individual responsibility, commented on the "unusual blending of commitment and passion" about the topic under discussion, "but also serious interest to find out more – that is, open minds". With respect to the conflict between professional loyalty towards a company and personal ethical and social values, the views of established scientists and of students differed significantly. A senior participant argued that a scientist would need to quit a company in the event of an unresolvable conflict and that whistle blowing should only be considered if public health and safety were at risk. Students on the other hand firmly believed that an individual could always bring about positive change in the workplace without relinquishing his or her personal convictions. They also spoke out in favour of ground level workers empowering themselves by becoming more scientifically literate and thus being able to effect procedural improvements. This corroborates Richards' aforementioned statement that only "new generations" will be able to fully integrate "new" and "revolutionary" principles.

Extreme situations calling for whistle blowing are however rare. More often personal ambitions and professional pressure bring scientists face to face with the need to make value-based decisions. The recognition which the scientific community grants for scientific work as well as the respect of their peers is regarded as the prime motivation and reward for scientists and gives them status and power (Edsall, 1975a: 10; Mohr, 1984; Richards, 1987:104; Schweber, 2000: 28). This search for acknowledgement together with the competition for funds and professional advancement, and institutional pressures to deliver creative work and to publish can frequently lead to secrecy and plagiarism (Edsall, 1975a: 10), as well as falsification or misrepresentation of results (Bateson, 2005; Resnik, 1998). Such instances not only compromise the responsibility to adhere to the normative scientific code, but also the responsibility towards society to deliver truthful facts for the greater common good. As unethical activities come to light the public image of scientists is tarnished, resulting in anti-science perceptions and a decrease of public trust in science.

At this juncture the views of high school students on what motivates scientists are of interest. While recognition by the scientific community and financial rewards were each acknowledged by approximately 10% of the respondents, up to 73% argued that scientists were driven by curiosity about the mysteries of nature and up to 41% believed that scientists were motivated to “make the world a better place to live in” (Aikenhead, 1987). The researchers point out that the type of scientific research which students were aware of was largely in the field of medical science and that this may have influenced their opinions. In a group of Bulgarian and British students 60.2% also believed that for scientists their research earned them recognition rather than material benefits (Bauer *et al.*, 2000).

The role of personal values such as integrity and honesty which inspire responsible attitudes, decisions and actions is seldom addressed in the literature on scientific responsibility and cannot be enforced. These however play an important role in situations which are not directly controlled by professional standards. By means of interviews Fleming (1986) investigated the reasons upon which adolescents based their decisions in conflicting societal issues involving scientific facts. The author distinguishes between moral and personal reasoning. The former is concerned with the prevention of harm and utilizes scientific information to manage risks and uncertainties. Personal reasoning on the other hand is motivated by personal protection and benefits. The interviewees’ mature social awareness was evidenced by the fact that 70% of their decisions was based on moral rather than personal reasoning. At an international conference of the Ethics in Science and Humanities program high school students from six different countries representing a variety of different religious denominations were stimulated by different perspectives on ethical questions. While one female student, for example, justified her right to abortion another proposed the following novel argument in favour of the rights of an unborn child: “As a former foetus myself, I believe my right to life supersedes your right of choice”. This type of debate illustrates not only the spectrum of moral values and views, but also the necessity for scientists to question their own moral standing and motives as well as to accommodate those of others (Sappir, 1998). Similarly, the participants at the Student Pugwash conference were appreciative of the multiplicity of viewpoints and aspects pertaining to an issue. This gave them an insight into the

complexity of decision making and also confirmed that their concern for social responsibility would not exclude them from the practice of pure science (Seltzer, 1985). Amram, the co-founder of the above mentioned Ethics in Science and Humanities program is convinced that interrogation of one's role as scientist is as important as the passion for one's discipline. His statement: "I don't live on an island. I am not cut off from my environment. As society has given to me, I want to give something back to society" (Sappir, 1998) is astonishingly reminiscent of the utterances of two science teachers during the interviews held for this research project.

Political pressures or convictions have also contributed to the misuse of the practice and ethos of science in the past (Lappe, 1971; Truth and Reconciliation Commission, 1998). The scientists involved in the construction of the atomic bomb were compelled to consider the national interest above personal convictions, although patriotism and a lack of leadership among the scientists also played a considerable role (Schweber, 2000). The Lysenko case in the Soviet Union is another well document example where adherence to an ideology lead to the reformulation of the theory and practice of genetics (Medvedev, 1969). In this matter it is encouraging to note that the Committee on Scientific Freedom and Responsibility of the American Association for the Advancement of Science (Rayner, 1987) states unequivocally that it

"believes that scientists, engineers and health professionals must not be silent and acquiescent to human rights violations".

The report even encourages scientists from other countries to assist such individuals who "uphold ethical standards" and may face political "reprisals".

Commitment to certain codes of conduct as are prescribed for the medical and engineering professions may be a way to provide incentives and exercise control. The importance of professional societies and the formulation of codes of conduct are discussed in the final section of this literature review.

From the foregoing it is evident that scientists are exposed to a wide range of pressures as well as personal choices which can render the execution of social responsibility difficult and conflicting.

2.2 SCIENCE, TECHNOLOGY AND SOCIETY

In the previous sections the social responsibility of scientists was considered within the context of the internal sociology of science (Aikenhead and Ryan, 1992; Richards, 1987). The importance of scientific freedom, the role played by the scientific community, its ethos, its individual members and aspects of teaching and knowledge production were shown to have important implications for the social responsibility of scientists. Science however is not only practiced within the confines of the scientific community and must be considered in the context of the external sociology of science (Adams, 1999; Aikenhead and Ryan, 1992; Klopfer, 1976). The philosophies, beliefs, values, needs and priorities of society are determining factors in the production and application of scientific knowledge. It is at the interface between science, technology and society that unanticipated questions arise as well as conflicts between the differing values of science and of society. Consequently, it is at this interface that the appeal to scientists to consider their social responsibility is most acute (Merton, 1968: 599). The following sections will address these aspects, starting with a broad overview of the complex relationship between science, technology and society.

2.2.1 The interdependence of science, technology and society

While science is concerned with the production of knowledge, technology is engaged in the application of knowledge and the production of hardware. Although technology should not be confused with science, in practice there is often no clear distinction between these two functions (Aikenhead and Ryan, 1992; Fleming, 1987). Basic or pure science and applied science interpenetrate each other, and similarly basic and applied science and technology are mutually dependent. The financing of research by industry further underscores the mutual dependence of science and technology

on each other. While scientific freedom is a prerequisite for research, the expectations of funding agencies who are motivated by profit, technological progress or political considerations determine research priorities and can influence research outcomes (Cross and Price, 1994: 48). Similar reciprocal relationships and dependencies as between science and technology exist between society on the one hand and science and technology on the other.

This influence of society on science and technology is captured by Klopfer's (1976) statement that "science is, in a large measure, the product of the prevailing culture of the society in which it exists". Socioeconomic, political and cultural priorities therefore determine the focus and the extent of the practice of science. Powerful forces such as modern day consumerism experienced in most Western cultures prescribe market trends and tend to make demands on science and technology and influence research and development. This social context of science and the sociology of scientific knowledge was clearly recognized by science students, their main reason being that "a scientist can be helped by incorporating ideas, experiences, or enthusiasm of those with whom he socializes" (Aikenhead, 1987). Science policies and government funding are informed by national priorities and international trends such as economic, political and health factors and in turn affect the growth or decline of scientific disciplines and areas of research. The military is a powerful agent in procuring funds, secret information and services (Cross and Price, 1994). However, while economic factors such as poverty alleviation, health factors such as the HIV/Aids pandemic and political factors such as the threat of chemical and biological warfare impact on science and technology, the general cultural climate of a nation is equally important. It determines people's attitudes towards science, society's support or distrust of science and the provision of an educational system dedicated to the promotion of science and the training scientists and technologists (Aikenhead and Ryan, 1992; Klopfer, 1976). In addition, the influence of world view, philosophies and value systems which inform a culture as well as the models, processes and values of science cannot be ignored (Kuiper, 1998). The holistic African indigenous knowledge or the ancient Chinese inventions (Needham, 1976; Spurgeon, 1995) are examples which stand in stark contrast to Western science. Here it may be enlightening to note that among the participants in a citizen science project in the United States an average of 90% favoured a holistic paradigm in which

humans are participants and custodians of nature in distinction to the 5-11% who adhered to the anthropocentric worldview (Brossard *et al.*, 2005). All these factors which embed science and technology in society determine directly or indirectly how scientists can exercise their responsibility towards society (Cross and Price, 1992).

The influence of science and technology on society is generally more visible than the influence of society on science and technology as discussed in the previous paragraph. It ranges from positive developments such as the improvement of health and alleviation of poverty to negative impacts such as pollution and ecological degradation. A high percentage (83.2%) of the European community for example portrayed an appreciation of the value of basic research for the long term production of knowledge and technological development as well as confidence in the potential of science and technology to cure diseases such as cancer and AIDS (80.5%), and to improve the quality of life of the population (70.7%) (European Commission, 2002a). Positive advances such as in health care services frequently also have their negative consequences such as unchecked population growth.

Although the voice of scientists may be powerless in many resolutions on the implementation of scientific know-how, the association of science and scientists with such events persists in the perceptions of society and contributes to fear and distrust of science. Public trust is further eroded by scientists' sometimes blatant unethical practices and lack of foresight. The scientific basis of nuclear, chemical and biological warfare is one such example which creates a negative image of science. Society however does not only hold science accountable for negative impacts such as environmental degradation but also for the sciences' apparent inability to resolve social problems such as poverty, unemployment, overpopulation and the threat of nuclear war (Fleming, 1987) or foreseeing natural disasters such as the tsunami in south east Asia.

Concurrent with the innovations and economic growth brought about by science and technology, societies are required to adapt to ever accelerating changes in socioeconomic and political conditions which in turn influence values, world view and religious outlook (Klopfer, 1976). Even though, as mentioned above, over 60% of the European population felt that scientific innovations were "changing" their lives "too

quickly” (European Commission, 2002a), these changes impact even more on societies in developing countries who are faced with far reaching technocratic decisions and who frequently do not have enough understanding of science to be selective and prevent damage, as well as execute their democratic rights in public decision making processes. It is at the juncture where science and technology impact on society that scientists need to interact directly with the public, even at an international level, and be aware of their social responsibility (Sefa-Dedeh, 1986). The organization of Doctors Without Borders (Medecins Sans Frontieres) could serve as an example to natural scientists to collaborate at an international level in assisting developing countries. The statement of Jean Bradol, the Managing Director of Doctors Without Borders (2006) inspires with his statement:

“There is so little care available that the only responsible ethical response is to take action”.

Decision making on the implementation of scientific discoveries and technological innovations, and responsibility for their effects or consequences are the most contentious areas surrounding the social responsibility of scientists. Decisions must however be based on sound insights and communication, which necessitate public understanding of science as well as scientists’ understanding of society’s needs and values. The following two sections will address these issues in more detail.

2.2.2 Communication and education

In modern societies dominated by science and technology the public communication of science and basic scientific literacy of the population are imperative. A correct understanding of scientific matters enables persons to use science and technology wisely and to assess risks. Moreover, the public has a democratic right to know how public money is spent and how scientific discoveries affect them. Mistrust and even hostility towards science appear to be on the increase among the public. Knowledge is empowering in democratic decision making and the continued social support and financing of science depends on public understanding and trust. (Cross and Price, 1992, Wilsdon *et al.*, 2005.)

The polarization of Western society into “two cultures”, the humanities and the natural sciences, described by C.P. Snow (1965) is based on the mutual incomprehension of each other, and this eventually results in increasing mistrust and hostility towards science. In non-Western societies which are also under the influence of Western science and technology, the indigenous culture contributes to even greater diversity and needs to be accommodated. Science is regarded as the basis for the technological and economic development of the African continent (AAAS News Release, 2005; Annan, 2003). It is therefore imperative that all sectors of the population should be scientifically literate in order not only to benefit from science but also be aware of its limitations.

The public image of scientists is that they are isolated from society in their pursuit of scientific knowledge. Scientists on the other hand also view themselves in that manner and generally do not concern themselves with public communication. Information on scientific matters affecting society is communicated mainly by journalists. Media reports can be misleading and have been found to reinforce the image of scientists and the separation of science from society. Although most scientific information was obtained via television, radio and the press, 53.3% of the European public for example believed that journalists did not have adequate scientific knowledge, and 36.5% felt that the media propagated a negative view of science and technology. The majority (85.9%) called for better communication of scientific information by scientists and was convinced that scientists had the better ability to communicate (European Commission, 2002a). Cross and Price (1992: 71) point out that “science is presented as a separate culture, apart from other human endeavours” and as a result the public remains in awe of science and does not question scientific knowledge. This approach tends to leave the public disempowered, and science and society alienated from each other. The question therefore is: how far is it the social responsibility of the scientists themselves to engage actively in public communication and basic adult education? The AAAS states in its report that society as well as the scientific community increasingly requires scientists to engage with the public and deal with public issues (Edsall, 1975a: 40). This was confirmed by 75% of Canadian students who felt that scientists should be responsible for communicating their findings to the non-scientific

community, because the public had the right to know how innovations might affect them and how research funding is utilized. Improved scientific literacy would also enable the public to make responsible choices and be aware of scientific progress (Ryan, 1987).

The extensive field of natural science and technology produces a multiplicity of facts and applications, but information of the public is generally limited to current topical issues. The need for communicating technical language in accessible understandable terminology is especially relevant in indigenous communities (Siekevitz, 1972: 242). For a true understanding and appreciation of science, the tentative nature of science, the rigorous peer review system and even the aesthetic beauty and complexity of science should however also be included into the discourse. The truthful explanation of the presuppositions and processes of science will promote confidence in the objectivity of the scientific process but also engender an appreciation of its limitations. This will enable members of the public to engage in constructive discussions with scientists (Edsall, 1975a: 10, 42). Cross and Price (1992: 100) contend that a society which cultivates and appreciates science can base decisions on a sound understanding of the present and thus create a future where science is of greater benefit to all. The social responsibility of scientists to enter into dialogue with the public is therefore not only imperative but rewarding. Scientists are generally advised to limit their responsibility in public discussions to the provision of unbiased technical information, limitations of the scientific results and possible projections and/ or impacts (Cross and Price, 1992: 100; Siekevitz, 1972: 274).

The degree to which the public should be informed about controversial issues continues to form part of the debate on the social responsibility of scientists. Apart from the ethically required protection of the privacy of individuals, there is much secrecy about research in sensitive areas such as the use of stem cells or environmental and technological risks. Such secrecy can further aggravate the distrust which society has in the motives and integrity of scientists, a distrust which can only be prevented from escalating when scientists are seen to communicate truthfully and act responsibly (Edsall, 1975a: 40). There is however frequently the concern among scientists that scientific freedom could be compromised by

communicating openly and that scientific knowledge may be misused by non-professionals. Whistle blowing is a typical situation which involves the communication of sensitive knowledge, often requiring that a scientist questions his/her personal sense of morality and responsibility. In spite of this, whistle blowing is regarded by the AAAS as a central responsibility which scientists cannot renounce (Edsall, 1975a: 29). In European countries the dominant opinion (89%) was that scientists had the responsibility to inform the public of potential dangers. Significantly, this view was however not held by the group of senior executives in the food and agricultural industry who had also participated in the Europeans, Science and Technology survey (European Commission, 2002a; 2002b).

At a conference in India on science and technology education and human needs, Sefa-Dedeh (1986) stated “In developing countries there should be a bold attempt to increase science consciousness of the population”. This call has been echoed by many authors. It should however not only be limited to education of the youth, but should be available to all sectors of the population in the form of mass education (Sefa-Dedeh, 1986) or basic scientific literacy programs (Personal communication: Prof M.B. Ramose). Kyle’s (1999) “Social Justice for All Vision Education” aims to encompass all members of society throughout their life time. Apart from formal schooling it also aims to meet the learning needs of society and incorporate multiple knowledge systems. It may be that at this level there could be a two-way communication between scientists and society, where society not only learns about science, but where scientists can learn about indigenous wisdom.

In conclusion, the social responsibility of scientists to enter into dialogue with the public on scientific topics of common interest and common concern is imperative. It is in the area of communication and decision making that scientists can tangibly fulfil their social responsibility. Aspects of decision making and taking responsibility for the consequences of decisions are discussed in the following section.

2.2.3 Decisions and consequences

Decision making on the production and utilization of scientific knowledge relies on effective communication between scientists and society. The resolutions arrived at can in turn give rise to both beneficial and harmful consequences. The questions here concern who should be involved in decision making, and who is responsible for the consequences of implementing scientific innovations. Scientists on the one hand wish to exercise their scientific freedom to do research. They also have the appropriate scientific insight to determine the effects of such knowledge. Society on the other hand is increasingly aware that scientific knowledge touches the very core of being human and conflicts with religious and moral value systems, and that society has the right to regulate and limit scientific research. Lakoff (1980b: 29) writes that “scientists who participate in public debate and decision making processes are performing a function vital to the effectiveness of democracy”, but there are multifaceted complexities facing scientists - as well as the members of the public - attempting to fulfil their social responsibility in this respect.

Scientific freedom is the basis of all scientific activity and participation by outsiders in decision making can readily be perceived as a constraint on scientific freedom (Siekevitz, 1972: 221). The AAAS adds that scientists need both the freedom to speak out and the responsibility to influence policy, but warns that the freedom scientists claim for themselves is not independent of the needs and values of society (Edsall, 1975a: 40, 45).

Scientists are no doubt the experts in their field and as such expect to be the sole decision makers in order to be able to take responsibility. It is furthermore argued that the public has not kept pace with the rapid developments in science and technology and is therefore not qualified to make informed judgements (Lakoff, 1980b: 27; Siekevitz, 1972: 208). Interference or excessive scruples by non-scientists are also seen to retard research unnecessarily and eventually lead to greater uncertainty (Cross and Price, 1992; Edsall, 1975a).

The survey conducted among Canadian high school students indicated that they believed that scientists based their decisions mainly on scientific facts (Aikenhead, 1987). This is congruent with the approximately 50% who were in favour of scientists and engineers having the authority to decide on important national concerns such as the use of energy, chiefly because they had the requisite expert knowledge. The remaining 50% of respondents who preferred a more democratic model of decision making based their arguments on the fact that society as a whole was affected and that societal values and concerns needed to be addressed by relevant experts (Fleming, 1987). Generally students were less aware of the role of personal opinions and motives, political and social pressures, and the important role which values and morals play when scientists are faced with decisions (Aikenhead, 1987). Ten years later Aikenhead (1997) established that 82% of English speaking Canadian students were aware of the determining influence of politics on science, which he interprets as an affirmation of governmental control of science. Among the European population, 72% argued that politicians should rely more on the opinions of scientists and 82.4% demanded that industry should be better regulated (European Commission, 2002b). These foregoing findings appear to be contradicted by two studies conducted in the United States. Research conducted by Bell and Lederman (2003) among professionals with backgrounds in science, science education, philosophy, engineering, history or English showed that their understanding of the nature of science played a minor role in their evaluation of scientific and technological facts in making decisions on issues such as global warming, foetal implantation, smoking and cancer. Social and political issues, ethical considerations and personal values took precedence over current scientific evidence. A similar investigation into how students relate the nature of science and socioscientific issues clearly revealed that they were generally unable to interpret scientific data on global warming. They regarded societal factors such as economical priorities, personal views, beliefs and relevance, social causes (such as transport and pollution) and the social effects on health and population migration as more important (Sadler *et al.*, 2004).

Although scientists are frequently disinclined or unqualified to engage in public debates, their participation is essential. The goal of science communication is precisely to provide the public with enough scientific understanding to be able to make decisions that do not compromise their values. Public disagreements among

scientists can also cause non-scientists to lose the trust they place in scientific facts. Frequently such differences are as a result of subjectivity or divided loyalties, different weighting of scientific data or personal values and interpretations of the social impact of a scientific issue. (Harrison, 1986; Lakoff, 1980a: 27, 228; Richards, 1987: 135, 217.) The argument that disagreements among scientists are mainly due to personal, cultural and social factors rather than the interpretation of scientific data, was confirmed by 56% of English speaking Canadian students (Aikenhead, 1997).

Cross and Price (1992: 37) contend that in a democracy all citizens have a right to decide on matters of general concern and that a sustainable future depends on collaboration among experts and laypersons in the understanding of scientific and technological questions and joint decision making on matters affecting society. Scientists' belief in objectivity and empirical facts however conflicts with the norms of society which are subjective, interpersonal and local and can impair communication and decision making. The specific needs of society are largely determined by its values, and social problems cannot be solved by technical facts alone, and there may even be regional variation in a population. Cultural differences, for example, determined students' value based decisions in a study conducted in three different geographical areas in the United States. The region in which the students grew up affected their value systems and religious convictions, which in turn determined their individual choices. According to this study, neither age, gender nor the educational level of their parents played any significant role (Spain *et al.*, 2002). Social, ethical and philosophical dimensions of a problem, even hopes, fears and uncertainties should therefore be addressed by relevant experts and spokespersons and receive equal consideration in decision making. Agreements between what is scientifically sound and what is preferred by society are only possible when the respective norms of science and society are fully understood and accepted by all participants. (Lakoff, 1980a: 223; Richards, 1987: 145; Siekevitz, 1972: 245). Sjoberg (1986) adds to this discussion that the needs of women and marginalized cultures require extra consideration and sensitivity, and also that women specifically can contribute to the formulation of more egalitarian and ethically sound decisions.

The rights of democracy also imply duties or responsibilities as citizens. With respect to joint decision making the responsibility resting with members of the public is to

take an interest in scientific matters intimately affecting their lives, to engage actively in society and to become knowledgeable about the basic scientific facts. Society still tends to relegate science to the experts, but scientists cannot fulfil their social responsibility without public interest and participation in public debate (Cross and Price 1992: 37; Lakoff 1980a: 198). In South Africa a national survey on the public understanding of science and technology in 1995 by the Foundation for Research Development (1996) revealed differences between racial groups, and South Africans as a whole scored poorly compared with other nations. Respondents with a higher level of education also had a more favourable attitude towards science and technology, contributing to 75% of the positive responses. The authors emphasize the importance of improved scientific literacy and attitudes towards science and technology as these are essential for national growth and social development. The findings of the European Commission (2002a, 2002b) revealed that, in spite of the positive image enjoyed by scientists in European society, more than half (53.4%) of its young people do not portray an interest in science, with 45% of the population as a whole being neither interested nor informed about science. This testifies to the isolation of science from society. The report adds that this is accompanied by a feeling of uncertainty about scientific innovations such as the current introduction of Genetically Modified Organisms (GMOs). The majority of the population (85.9%) wanted more information on GMOs, while 94.6% wanted to have an option whether or not to use GM foods, and 56.4% regarded them as dangerous. The higher the level of education, the more aware individuals were of the negative effects of GMOs. Younger men were found to be the least adverse to the utilization of GMOs, which the authors ascribe to the fact that younger persons may be less concerned about possible risk factors. An investigation in England into views of students on genetic engineering of animals for medical research showed that 57% of all age groups were “a bit worried” about genetic engineering and 12% were very worried, while, in contrast to the study in Europe, older students with more information were generally more positive about genetic engineering than the younger ones (Hill *et al.*, 1999).

The effects of scientific innovations are always both positive and negative and questions surrounding responsibility for the consequences of science are complex. There can be no unequivocal answers on what or who is socially responsible. Siekevitz (1972: 258) defines responsibility as being called to respond, and contends

that society will call upon scientists to respond and be accountable in the event that the effects of science are perceived as being harmful, and he warns that society will then impose external controls on science. Merton (1968: 599) and Cross and Price (1992: 61) concur, stating that society will judge science and hold it responsible for harmful effects. In the scientific community where many scientists collaborate at different levels and base their work on previous data, it may be difficult to identify one single individual or even to hold an entire group responsible. In this respect it may be more feasible to require scientists to identify critical stages in the research process where risks and consequences can be assessed and policy decisions made (Lakoff, 1980a: 24, 203). Simultaneously ethical and social dimensions could be incorporated to assess the impact on society (Edsall, 1975a: 23).

As has been pointed out, science, technology and society mutually interact with each other. If the consequences of the scientific enterprise are viewed in the larger social context, it is clear that scientists and their research form only part of the wider application, which they cannot entirely foresee nor control. The utilization of scientific research and technological applications is driven by political, economic and social currents and is consequently a collective concern. This view makes the responsibility for the effects of science one of concern of society as a whole. Lakoff (1980a: 164) states that the questions raised by science cannot be answered by science. Therefore, apart from the justified demands for scientists to be socially and morally responsible, humanity as a whole should cooperate and accept responsibility for the implications of scientific progress on future sustainability. (Cross and Price, 1992: 61; Lakoff, 1980a: 24, 203; Siekevitz, 1972: 208).

The range of factors impacting on the responsibilities for the effects of scientific discoveries is also evident from student views. The majority of respondents in the Canadian study felt that scientists should be concerned about the consequences of their discoveries, and that they should not only prevent negative effects but also be committed to improve the quality of life. These views clearly indicate how these students perceived this aspect of scientists' social responsibility. It is also encouraging to note that there was indeed a large measure of trust in scientists' concern for greater benefits to humanity and the prevention of the harmful effects. However, in spite of their demand for scientists' concern for the impact of their

discoveries, the majority of students placed the ultimate responsibility on the end-users of science and on scientists and society alike. The inability to predict the long-term effects of their discoveries and the impossibility to control how non-scientists applied scientific results were regarded as constraints. A minority of respondents defended scientists' absolute freedom in the pursuit of knowledge without the discouraging need for concern about possible consequences (Ryan, 1987). The overall opinion of the European Community was that scientists share the responsibility for the application of their discoveries with society (69.1%). In addition, approximately equal numbers believed that scientists are responsible for the misuse of their discoveries by others. Responses to statements referring to the outbreak of Bovine Spongiform Encephalopathy (BSE) or "mad cow disease" however revealed that industry (74.3%), politicians (68.6%) and farmers (59.1%) were held responsible, while only 50.6% argued that scientists bore a great deal of responsibility for the crisis (European Commission, 2002a). In the survey among British and Bulgarian students just more than one-third (37.2%) of the respondents felt that science cannot be held responsible for the detrimental application of their innovations, but more than half (59.7%) were not convinced that "all science is good science" (Bauer *et al.*, 2000). Here the statement of one of the participants in the Student Pugwash Conference on Scientists' Individual Responsibility (Seltzer, 1985) is significant:

"I think that scientists are responsible for whatever use is made of things they develop ... they should follow up, and if they see something is being misused, they should at least bring it to public attention and try to get it stopped".

The complex issues surrounding scientists' social responsibility with respect to issues such as communication, decision making, accountability for possible consequences, but also issues within the scientific community such as plagiarism and falsification of data increasingly call for professional societies which can support and monitor scientists. The following and final section will address some aspects of how social responsibility can be promoted by such organisations.

2.2.4 Professional societies and codes of conduct

Scientists are increasingly required by society and by the scientific community to engage in public dialogue in order to deal with scientific problems and to allay mistrust and hostility towards science. The actual implementation of socially responsible behaviour appears to be hampered by pitfalls and conflicting situations, loyalties and demands which individual scientists generally cannot manage on their own.

Professional scientific organizations can provide valuable support structures for scientists in the individual or collective execution of their social responsibilities (Lakoff, 1980a: 16; Siekevitz, 1972: 254). Similarly, whistleblowers could be afforded protection by professional bodies in cases where employers are non-supportive or victimize employees (Edsall, 1975a: 35). Existing ethical standards are also inadequate to answer questions arising from the accelerated developments in science and technology which touch on entirely new aspects of human life and morality (Siekevitz, 1972: 245). Lowrance (1986: 77) adds to this that non-specific or ill-defined demands for social responsibility are inadequate in inducing scientists to act accordingly. There is therefore a legitimate need for clear professional guidelines which however will, by their very nature, tend to limit scientific freedom and creativity (Malakoff, 2004; Resnik, 1998: 177).

In this light the role of professional societies is not only to support its members but also to act in the public interest. While the rights and responsibilities of members should be defended, members can also be monitored and expected to act according to the codes of conduct. Cases of misconduct and complaints could be processed. Advisory committees should assess research proposals, supervise research, estimate and minimize risks and monitor research ethics (Edsall, 1975a: 3; Resnik, 1998: 174). Professional societies should further publicise their activities and offer balanced views on current issues and areas of concern in the media. If scientists do not express their professional viewpoints on controversial topics openly, the public perception is that they tacitly approve of it. Clear collective statements could bring

across a strong message of public engagement. (Edsall, 1975a: 30; Siekevitz, 1972: 245).

Among the European population there was an overriding call for ethical constraints of scientific conduct. Although 45.4% of the population were in favour of animal experimentation, with 41.3% against it, a total of 80.3% required scientists to observe ethical codes of conduct, and thus limit the degree of scientific freedom within the field of human medical research (European Commission, 2002a). Siekevitz (1972: 198) regards the formulation of and adherence to codes of conduct as one of the responsibilities of scientists. This is of such importance that he adds that “ethical guidelines ... will enable the human species to survive and prosper in harmony with the rest of the world”. These codes should define individual and corporate responsibilities and deal mainly with their ethical aspects. There is some controversy about who should formulate the guidelines. Scientists have the specialized knowledge of the scientific process and understand the complexities of individual disciplines (Pförtner, 1989; Siekevitz, 1972: 198). Such self-regulation has however been criticized on the grounds that scientists in so doing attempt to preempt the imposition of external regulations. Comprehensive guidelines should therefore include the views and ethical considerations of non-scientists and society at large (Lakoff, 1980a: 189; Siekevitz, 1972: 200).

Adherence to the codes of conduct can generally not be enforced as they have no legal status. They can merely serve to raise awareness of ethical considerations and commitment to professional standards (Edsall, 1975a; Malakoff, 2004). Exposure of misconduct and moral pressure by the scientific community can be applied in instances of non-compliance (Siekevitz 1972: 26). And finally, Segerstedt (1979: 87) states that

“No law or external regulation can protect the public and scientists from untoward effects of science like responsible and responsive self governance of the scientific process. This kind of self determination is the ultimate test of the ethical basis of science”.

2.3 SUMMARY

This literature study investigated the current discourse on a variety of aspects pertaining to the social responsibility of scientists. Factors comprising a complex topic such as this are interrelated and feed back into each other. An attempt was made to group the variety of views into the internal and external sociology of science. The latter relates to the interface between science, technology and society and includes public communication of science, decision making and the consequences of science as the most important questions surrounding scientists' social responsibility. The internal sociology pertains to the ethos of science, scientific freedom, knowledge production and the roles of the scientific community and individual scientists. Knowledge production addresses areas of concern such as the power of scientific knowledge, secrecy, prediction of the effects of science, the technological imperative, the role of women and indigenous knowledge.

The literature study served as a background against which the research instrument was designed, informing the researcher at critical stages of the complexity and variety of aspects of social responsibility of scientists. The following chapter describes the process in detail.

CHAPTER 3

DEVELOPMENT AND USE OF THE RESEARCH INSTRUMENT

3.1 INTRODUCTION AND OVERVIEW

The aim of this study is to elicit distance education students' views on issues related to the social responsibility of scientists. The nature of the data requires a careful consideration of the choice of an instrument. A research instrument based on the Views on Science-Technology-Society (VOSTS) study was developed, employing interviews and free response and fixed response questionnaires. Qualitative data analysis at each stage of the development of the instrument provided the input for the following stage. Participants were drawn over a two year period mainly from Chemistry students at various levels of academic study at the University of South Africa. Participants and procedures are described separately for each of the three phases in the development of the instrument. The final data analysis was done qualitatively as well as quantitatively. The organisation of this chapter is presented in Figure 3.1.

3.1 INTRODUCTION AND OVERVIEW

3.2 MEASUREMENT OF VIEWS AND ATTITUDES

- 3.2.1 Background
- 3.2.2 The VOSTS instrument
- 3.2.3 VOSTS based studies

3.3 DEVELOPMENT AND USE OF THE RESEARCH INSTRUMENT

- 3.3.1 Motivation
- 3.3.2 Overview of participants, procedures and time frames
- 3.3.3 Ethical aspects of the research process

3.3.4 PHASE 1:

Interviews
& analysis

1. Introduction
2. Participants
3. Interviews
4. Analysis (Steps 1-10)
5. Conclusion

3.3.5 PHASE 2:

Open response
questionnaire
& analysis

1. Introduction
2. Formulation
3. Pilot test
4. Respondents
5. Analysis (Steps 1-3)
6. Conclusion

3.3.6 PHASE 3:

Fixed response
questionnaire
& analysis

1. Introduction
2. Formulation (Steps 1-5)
3. Respondents
4. Data analysis
5. Attitude profile
6. Conclusion

3.4 SUMMARY

Figure 3.1 Overview of the development and use of the research instrument

3.2 MEASUREMENT OF VIEWS AND ATTITUDES

3.2.1 Background

The definition of both the terms 'views' and 'attitudes' contains cognitive and affective dimensions or constructs. Views have also been described as being constructs of an overall attitude (Bennett *et al.*, 2001). The problems associated with the measurement of attitudes and the strategies to reduce these problems can therefore be seen to apply equally to the measurement of views in this study.

Attitude research in science education focuses mainly on learners' attitudes to a variety of science-related issues. Attitude inventories employing Likert-type, Thurstone-type or semantic differential scales are the most common data collection

tools. Other types of instruments include rating scales, multiple choice or fixed choice questionnaires. Data collection by means of written records, interviews or a combination of both have been employed to a lesser degree, while projective techniques which are used extensively in research in psychology have been largely neglected (Gardner, 1975; Gauld and Hukins, 1980; Oppenheim, 1992; Osborne, 2003; Ramsden, 1998). The LISREL method which analyzes causal networks has not received much attention, but could hold promise in quantifying the influence of background variables such as gender and race on specified attitudes (Schibeci and Riley, 1986; UNESCO, 1999).

The problems associated with the quantitative measurement of attitudes using scaling techniques have been the subject of many research papers. (See for example Gauld and Hukins, 1980; Koballa, 1988; Munby, 1983; Ramsden, 1998 and Schibeci, 1984.) A lack of consideration of the nature of attitudes and a lack of theoretical frameworks are the two main causes of inadequate research design and methodologies which consequently produce untrustworthy results (Brossard *et al.*, 2005; Oppenheim, 1992; Osborne, 2003).

Attitudes as well as views, opinions, beliefs and values are non-factual data. They are multidimensional and of subjective origin in contrast to unidimensional factual data of cognitive origin. It is therefore essential that the attitudes under investigation are specified and that the focus is restricted (Ramsden, 1998; Schibeci, 1984). Munby (1983), for example, performed a conceptual analysis of the widely used Likert-type Scientific Attitude Inventory (Moore and Sutman, 1970; Moore and Foy, 1997). The conceptual validity was found to be questionable, because not only attitudes to science but also scientific attitudes and philosophic views of science were included in the test items.

The lack of theoretical frameworks in many studies has been widely criticized. (See for example Ramsden, 1998 and Schibeci, 1984.) Such frameworks are necessary to define and measure attitudes and predict and explain research findings. Their absence is often the reason for inconclusive results (Koballa, 1988; Oppenheim, 1992; Schoneweg Bradford *et al.*, 1995 and Shrigley and Koballa, 1992). Psychological theories on attitude development such as the Theories of Reasoned Action and Planned Behaviour have also been successfully applied in education research. (See for example Crawley and Koballa, 1994; Shrigley and Koballa, 1992).

Other problems associated with the measurement of attitudes include the reliability and validity of instruments, instrument design and the analysis and interpretation of data (Ramsden, 1998). Partial reference to these aspects has already been made in the foregoing paragraphs. The following pertinent issues can cast more light onto these problems.

Attitudes can change as learning takes place and it is therefore important to address the reliability and reproducibility of data (Ramsden, 1998). Attitudes can also change with social values and an attitude statement may have a different meaning in a different social or cultural context (Murphy *et al.*, 2006; Oppenheim, 1992). The transfer of test results between different population groups such as high school and college students should also be exercised with caution (Schibeci, 1982). In addition to the focus on specific attitude constructs and conceptual analysis as referred to above, the validity of test items can be assessed by means of a judging procedure similar to the one used in the construction of Thurstone scales (Gauld and Hukins, 1980). This procedure however pre-supposes that the meaning which the judges attach to an item is equivalent to the meaning held by the target population. Additional validation would therefore be required in this instance. Similarly, the validity of instruments which are based on the philosophic model of the author is questionable. Such instruments often do not reflect the attitudes or views of the target group, because in answering questions respondents can subjectively attach their own meaning to the statements (Murphy *et al.*, 2006; Ramsden, 1998; Sadler *et al.*, 2004). Consequently research results are not a true reflection of the target group's perceptions and can lead to misinterpretations (Lyons, 2006; Sadler *et al.*, 2004). Qualitative research methodologies are used to remediate this discrepancy.

Instruments which employ a variety of data collection techniques such as interviews, written paragraphs and observation are successful in enhancing validity. In approaching the topic by means of different techniques, the subjective, multidimensional nature of attitudes or views can be captured. Bias which could arise as a result of context, formulation of statements and emphasis is also reduced hereby (Bell and Lederman, 2003; Oppenheim, 1992).

Most attitude scales consist of multiple items whose scores are added up to produce a single score. This method assumes that the items are unidimensional. The multidimensional nature of attitudes however cannot be adequately represented in a single quantitative measure (Gardner, 1996; Lyons, 2006; Osborne, 2003). Lucas (1975) also commented that the same total score which can be obtained from a

variety of different combinations of answers cannot reflect individual differences. In an analysis of different ways of assessing student views on Science-Technology-Society topics, Aikenhead (1988) for example found a discrepancy of up to 80% between Likert-type responses and interviews, while written paragraphs only had an ambiguity of between 35% and 50% as compared to interviews. The interpretation of attitudes based on quantitative results must therefore be exercised with caution.

The problems and necessary precautions associated with the measurement of views and attitudes determined the design of the instrument in this study. An in depth investigation into the development and application of the Views on Science-Technology-Society (VOSTS) instrument provided further motivation for the choice of methodology (Aikenhead *et al.*, 1987, 1992). This instrument measures cognitive views of students on the interaction of science, technology and society. Its item pool has however also been used in attitude studies because the methodology aims to overcome many of the problems associated with quantitative instruments measuring attitudes (Osborne, 2003).

3.2.2 The VOSTS instrument

The VOSTS instrument is an empirically designed multiple choice questionnaire developed by Aikenhead and co-workers (Aikenhead *et al.*, 1987, 1992). The instrument monitors Grade 11 and 12 Canadian high school students' conceptions on a variety of science, technology and society (STS) issues in order to provide base line data for teachers and curriculum designers. The pool of 114 multiple choice questions covers the following concepts: definitions of science and technology, mutual interactions among science, technology and society (the external sociology of science), characteristics of scientists, social construction of scientific knowledge and technology (the internal sociology of science), and the nature of scientific knowledge.

Each questionnaire item consists of a statement expressing a view on an aspect of the interaction of STS, followed by 6 to 8 multiple choice items ("position statements") expressing reasons or opinions in agreement or disagreement with this statement (Aikenhead *et al.*, 1987). These reasons were not derived from theoretical or researcher-based viewpoints as is generally done in the development of test instruments; they were developed in a five step process from student writings and a series of interviews which were used to refine and validate the content and wording of each item. The instrument is therefore developed from empirical data about

students' reasoned responses and as such can provide more valid data for researchers, teachers and curriculum specialists.

The instrument design rests on the following considerations:

1. Knowledge of students' pre-existing ideas is essential before appropriate learning materials can be designed by curriculum developers and teachers. Quantitative test scores do not give an indication of learners' underlying misunderstanding. A qualitative approach which will reveal misconceptions in a descriptive way is considered to more appropriate (Aikenhead, 1973; Lucas, 1975). The VOSTS instrument evaluates students' reasons why they agree or disagree with stated views.
2. The assumption in most test instruments that both researchers and respondents attach the same meaning to a test item is questionable and could lead to invalid test results (Aikenhead *et al.*, 1987; Aikenhead and Ryan, 1992; Ramsden, 1998). In the VOSTS instrument these concerns are addressed by focusing on the variety of reasons that students gave to justify an opinion.
3. Clear and unambiguous wording of test items is of importance in all instruments. The developers of the VOSTS instrument analysed students' written paragraphs and confirmed the contents by means of interviews. The multiple choice options were subsequently paraphrased as closely as possible to the students' language and represent the opinions or positions of respondents. Ambiguity was hereby considerably reduced and test validity improved. An average interjudge reliability of 84% was achieved by discussions among three researchers on their identification of categories and wording of response options.
4. The theoretical framework of most test instruments is based on models from the philosophy of science. In addition the VOSTS instrument draws on the social context of science in order to include and interpret views reflecting social interaction, values, communication and decision making (Aikenhead, 1987; Fleming, 1987; Ryan, 1987).
5. The distinction between attitudes and views is not clear-cut. In the development of the VOSTS instrument students' conceptual understanding of STS related issues was addressed by monitoring the reasons that the

students provided to justify an opinion. The authors suggest that attitudes could be inferred from these opinions.

6. Questionnaire responses often do not reflect true opinions or accommodate ambivalence and consequently their validity is reduced. In order to reduce the effect of stereotype answers and bias, the converse of every statement was included. This use of positive and negative statements also assisted in collecting a wide range of responses and detecting misunderstandings among students. In the final version of the instrument the clearer of the two statements was incorporated.
7. The instrument adopts the unique response model which allows only one response most closely matching the personal viewpoint to be selected from 6 to 8 possible options. An open response option to accommodate other individual viewpoints is included. Aikenhead and co-workers confirmed by means of follow-up interviews that the restriction to one choice only did not increase the ambiguity of the results. The open response option was not frequently selected.
8. Being an empirically formulated instrument within the qualitative research paradigm, the instrument does not lend itself to test-retest comparisons and hypothesis testing using inferential statistics. Results were analysed in terms of perspectives found in the literature and the philosophy of science and can be used to inform STS education and the philosophy of science. If quantitative tests are required, the grouping of response items into categories expressing similar viewpoints was recommended by the authors.

The VOSTS instrument has been termed a new generation instrument. It is a naturalistic inquiry which evaluates the perspectives of students on a topic. Mishler (1990) argues that for this type of study the concept of validation rather than validity is applicable, where 'validation' is described as the process of the social construction of knowledge. Validation depends on whether the scientific community "evaluates reported findings as sufficiently trustworthy to rely on them for their own work." It is therefore a social discourse in which the trustworthiness of the research process and its observations, interpretations and generalizations are evaluated. The trust which researchers place in the design of the VOSTS instrument will consequently determine its validity. (Lyons, 2006; Sadler *et al.*, 2004.)

Similarly, the reliability in qualitative research depends on the research methodology and results are dependable if they are credible within the context (Osborne, 2003; Rubba *et al.*, 1996; Sadler *et al.*, 2004). Statistical assessment of reliability is not appropriate for non-parametric data such as the VOSTS items. The authors suggest that individual items can be selected from the pool for use in specific assessments and that the instrument can be used to make cross-cultural comparisons.

3.2.3 VOSTS based studies

Studies based on the original VOSTS instrument have been done in a variety of different contexts and with different objectives and target groups. In some instances the entire instrument was used or a set of relevant questions was selected from the original item pool. In other instances the items were modified to fit different needs and contexts, additional items were generated or entirely new instruments based on the original design were developed. In many cases different methods of data analysis were employed. The following studies exemplify this. Results also indicate adaptations to the methodology.

The views of preservice science teachers in Britain on science and technology and the epistemology of science were evaluated by replacing references to Canada by references to Britain in the VOSTS questionnaire (Botton and Brown, 1998). The responses provided a basis for bringing about conceptual change in teacher trainees. The reliability of a number of items in the instrument was determined and only 17 out of a total of 29 items were reselected consistently which could thus be found to be completely reliable. Students often experienced difficulties in differentiating between responses. By grouping such responses together, the reliability improved to an acceptable level. These authors also noted that respondents often could not distinguish clearly between concepts such as hypothesis, theory and law and that questionnaire items containing such concepts produced a low degree of reliability. Other concepts such as reality and truth are often used interchangeably by non-specialists and separate questionnaire statements containing these concepts could be understood to have the same meaning. Although the VOSTS statements were formulated on the basis of written student paragraphs and interviews, the wording is sensitive to interpretation and could affect the dependability of test results.

Zoller and coworkers selected items from the original VOSTS instrument which reflected three categories in STS education, i.e. STS views or positions, STS beliefs or attitudes and STS literacy (Ben-Chaim *et al.*, 1991; Zoller *et al.*, 1990; Zoller *et al.*, 1991). Response profiles on these categories were successfully used to evaluate the impact of STS courses on high school students' understanding of STS. Comparison of male and female profiles revealed some gender dependence (Zoller *et al.*, 1990). Differences in the profiles of students and their teachers suggested successful changes in STS beliefs and positions after exposure to an STS course, as well as the need for implementing improved teaching strategies (Zoller *et al.*, 1991). Baseline data from previous studies in Canada was used to make informed predictions for research among high school students and teachers in Israel (Ben-Chaim *et al.*, 1991).

The VOSTS instrument was designed and tested in the context of Western scientific culture. Botton and Brown (1998) state that the instrument "provides a summary of Canadian (Western) opinions that can be used either for the purposes of identification or as a means to promote further education and philosophic development". Studies in non-Western contexts are of special interest to the present research. Ben Chaim *et al.* (1991) confirmed the transferability and generalizability of results of previous studies to different contexts, but Zoller *et al.* (1990) warned that the local context of the target population must be taken into consideration if the instrument is used in cross-cultural studies and for comparing response profiles. The following investigations show how the VOSTS instrument has been adapted to a Near Eastern situation.

Haidar (1999) described Arab preservice and in-service teachers' views on the nature of science within the context of traditional Western and constructivist views, and compared them with Arab/ Muslim religious views. Questionnaire items were drawn from the original VOSTS instrument as well as from other instruments, theory and the author's experience. The author also incorporated items from the VOSTS pool in a survey of Arab professors' views on the influence of various aspects of Arab society on science and technology (Haidar, 2000). Additional questionnaire items which specifically focused on regional policies and Arab universities, scientists, technologists were developed by the researcher. Results were described in terms of the influence of societal agents and cultural values. In a comprehensive study in Lebanon a modified version of the VOSTS questionnaire was used in conjunction with clinical interviews and teachers' concept maps to assess the teachers' understanding of the nature of science as well as their knowledge of their scientific

disciplines (Abd-El-Khalick *et al.*, 1997). Findings suggest that the test items were culturally dependent and that the single choice option could limit the validity of the research outcome as respondents' views may be a combination of several viewpoints or may not be represented at all. This work on views on the nature of science (VNOS) was subsequently extended, based on the VOSTS methodology but using an open ended questionnaire in conjunction with follow-up interviews in order to improve the validity (Bell and Lederman, 2003; Lederman *et al.*, 2002).

Studies utilizing the VOSTS instrument focus on issues pertaining to the teaching and understanding of science, technology and society. By drawing on the methodology for developing the original VOSTS instrument a new instrument was developed to assess students' attitudes to the study of chemistry in the context of a South African university (Bennett *et al.*, 1999, 2001; Rollnick *et al.*, 2001). The only major difference in the procedure was that the initial statements were extracted from student interviews rather than from student paragraphs. Baseline data on two different groups of students were gathered and attitude profiles of students with different attitudes and levels of achievement were developed. Areas of intervention and remedial action could subsequently be identified. This work is of special relevance to the present study. The methodological details described by these authors were closely adhered to in the development of the instrument for this research.

The analysis of data gathered with the VOSTS instrument has been the subject of a number of investigations. Aikenhead and co-workers used the results to describe and compare views about STS among various groups (Aikenhead, 1987; Fleming, 1987; Ryan, 1987). There has however been a growing need for a scoring system for the VOSTS instrument which could lend itself to inferential statistical analysis. Empirically developed items are however not suitable for the testing of hypotheses or for comparing pretest-posttest results statistically, and if such tests are required, response items should be grouped into categories expressing similar viewpoints (Rubba *et al.*, 1996). The following attempts to develop a quantitative scoring system for the instrument indicate their potential and limitations and clearly show the need for a concurrent descriptive analysis of the findings.

Reference has been made above to the work of Zoller *et al.* (1990, 1991) who grouped responses into STS views, beliefs and literacy and compiled profiles of the target groups. A different scoring method employing three categories, i.e. Realistic (R), Has Merit (HM) and Naive (N) with ordinal values 3, 2 and 1 respectively,

evaluated teachers' conceptions of STS interactions statistically (Rubba *et al.*, 1993, 1996). A panel of five judges classified the multiple choice responses according to these categories. The same procedure was followed in an investigation into the extent to which a STS course and a Physics course contributed towards improving college students' views on STS interaction (Schoneweg Bradford *et al.*, 1995). Pretest and post-test data was collected from a questionnaire which was compiled from 16 original VOSTS items. A panel of five to seven judges drawn from the scientific community independently classified the response items. This scoring scheme enables comparisons to be made between groups and over periods of time, but does not eliminate the need for a descriptive analysis of the responses.

The work of Rubba and Schoneweg Bradford has certain constraints. The selection of only a limited number of VOSTS items from the pool must be done with a clear definition of the construct to be measured. The choice of just one different item from the pool could alter the construct and produce different test results (Rubba *et al.*, 1996). The classification of the response items into the 3 categories could compromise validity. The adjudicators experienced this process as demanding and it was compounded by the problem of reaching consensus. The authors speculated that scientists generally do not ponder STS interactions and that they also have divergent personal opinions. The statistical findings proved that differences in opinion among the judges impacted on the assessment results. An increase in the number of judges and panel discussions before a final value is assigned to a response item could have improved the degree of consensus. It is also important that the perspective of the judges and the objectives of the particular assessment should coincide (Rubba *et al.*, 1996).

Subsequently mathematical calculations showed that the above scoring system can produce the same total score for different response patterns and leads to generalized conclusions only (Vazquez-Alonso and Manassero-Mas, 1999). A change to the definitions of the three scoring categories to Appropriate (A)/ Plausible (P) and Naive (N) was suggested in order to avoid confusion with the philosophical definition of realism. By giving the Naive answer a zero value and by attaching weights to the Appropriate and Plausible answer the scoring range could be enlarged and generalizations avoided. It was further argued that the unique response model used by Aikenhead, whereby respondents only select the one choice which might match their opinion most closely, loses a large portion of the information which can potentially be provided by the VOSTS questionnaire. A

multiple response model would reflect respondents' views and attitudes more holistically.

The above discussion gives an indication of the wide range of applications of the VOSTS instrument, the precautions necessary for the adaptation of the instrument for new contexts as well as the various aspects of data analysis. It is these that inform the design and development of the instrument for the present study.

3.3 DEVELOPMENT AND USE OF THE INSTRUMENT

3.3.1 Motivation

The socially relevant nature of the research problem within the South African distance education context as well as the study of literature determined the choice of a qualitative research design which does justice to the social context in which answers to the questions were sought. It was felt that the present exploratory investigation into the views of students on the social responsibility of scientists could not be quantified. A qualitative paradigm would provide in-depth, though not generalizable, knowledge of the meanings participants attach to a situation. Schulze (2003) confirms this as follows: "Qualitative research is more useful for exploring phenomena in specific contexts, articulating participants' understanding and perceptions and generating tentative concepts and theories that directly pertain to particular environments."

The methodology employed in the VOSTS project addresses the weaknesses associated with the measurement of views and attitudes and as such is suitable for this research project. The following reasons will serve to support the need for developing a new instrument which specifically focuses on students' views on the social responsibility of scientists:

1. There is no instrument which directly addresses the research questions and there are no studies which use empirically developed instruments. Some items in the original VOSTS pool address aspects of social responsibility implicitly, for example

"Canadian scientists should be held responsible for harm that might result from their discoveries " (Ryan, 1987).

The statements are however formulated to establish high school students' views on science-technology-society interactions. The associated multiple choice options may also not cover the opinions of South African students.

2. Progress in science and technology is fast and the implications of new discoveries such as genetic engineering are profound. With the advance of the internet, students are more informed about developments. Views and attitudes as well as social values adapt to these rapid changes. The transfer of questionnaire items from an item pool which was developed over 10 years ago could influence the reliability and reproducibility of the data.
3. Considering the uniqueness of the South African context with its different cultures, its history and its current situatedness in Africa and the world, unique aspects of the social responsibility of scientists could be expected.
4. Distance education students come from a broad range of backgrounds. They are generally seen as mature students who can study independently. Many have experience in the workplace. Such students' viewpoints might differ from those of full-time students entering university directly after school.
5. For most South African students English is not their first language. The authors of the instrument have repeatedly warned about the difficulties of the English language and the importance of precise wording (Aikenhead *et al.*, 1987). Oppenheim (1992) also points out that the same statement may have a different significance in a different social context. Obtaining opinions on the subject matter directly from students and paraphrasing them as closely as possible to their colloquial language will reduce misunderstandings.
6. No theoretical framework has been used in the formulation of questionnaire statements. The social responsibility of scientists overlaps with ethics, law and even religion and politics. The present study is an exploration into the topic within in a specific context. The current literature was merely used as a guideline with the main focus being on topics addressed by the students.

3.3.2 Overview of participants, procedures and time frames

The University of South Africa (Unisa) where this study was conducted is one of the largest distance education universities in the world. "It affords equal education and employment opportunities to qualified persons regardless of race, gender, sex, ethnic or social origin, colour, sexual orientation, age, disability, religion, conscience, belief, culture or language" (Unisa, 2001). The heterogenous nature of its student body is evident in the following percentage composition: Of the 130347 students who were enrolled in 2001, 47% were Black, 36% White, 12% Asian and 5% Coloured. Unisa's students are distributed geographically all over the world. While the majority, 92%, of students are South African, 6% are from the rest of Africa, and 2% from Europe, the Americas and Australasia. The average age of registered students is 30 years and many are employed. In 2006, when this thesis was completed, the total number of students had risen to 244875, partially due to the merger of Unisa with the Technikon SA. The ratio of Black : White : Asian : Coloured students had changed to 57.80% : 26.05% : 9.94% : 6.17% respectively. A slightly larger percentage (94.8%) was registered in South Africa, with 5.1% from the rest of Africa, and 1% from Europe, Asia, the Americas and Oceania. The average age fell between 25 and 34 years. (Unisa, 2001; Unisa, 2006.)

Students registered in the Science Faculty only form 5% of the entire student population. The distribution along gender lines is slightly in favour of female students, with 57% females versus 43% males in 2001 (Unisa, 2001). In 2006 these figures had not changed appreciably (Unisa, 2006). Most participants in this study were students in the Chemistry Department of Unisa. Chemistry students come to the campus mainly to attend the compulsory practical laboratory courses, for which they have to qualify on the basis of their theoretical assignments. These practical sessions are held mid-year for the third level students and at the end of the year for the first and second level students. Students from all over South Africa as well as African countries such as Namibia, Zimbabwe and Mauritius attend. Some postgraduate masters and doctoral students who do their research in the laboratories on campus are available on a more regular basis. Participation in this project was voluntary and the sample throughout can be described as a convenience sample.

The development of the instrument closely follows the procedure used by Bennett *et al.* (1999, 2001). In the present study the procedure is divided into 3 phases according to the main steps in the development of the instrument, i.e. the interviews, the open format (free response, open response) questionnaire and the fixed response (multiple choice) questionnaire. Phase 1 includes the data collection by means of extensive interviews and the detailed qualitative analysis of the interviews. In Phase 2 the results from the interviews were used to formulate an open response questionnaire which was then piloted, tested and analysed. The results of the open response questionnaire were used in Phase 3 to formulate a fixed response questionnaire which was tested and analysed to produce the final results of the investigation. (Also see Figure 3.1.) The study took place over a period of 22 months between April 2000 and February 2002, the conducting of interviews and the administration of questionnaires being dependent on the availability of students in the distance education setting. Table 3.1 summarizes the objectives and time frames for each phase as well as the student body from which the subjects were drawn.

	PHASE 1	PHASE 2	PHASE 3
Objective	Conductance and analysis of interviews	Compilation, administration and analysis of open response questionnaire	Compilation, administration and analysis of fixed response questionnaire
Time frame	April 2000 to December 2000	January to September 2001	October 2001 to February 2002
Student body	3 rd level Chemistry and post graduate Physics and Chemistry students	3 rd level Chemistry students	1 st and 2 nd level Chemistry students

Table 3.1 Time frames and participants for Phases 1 to 3

Following this outline of the separate phases in the development of the instrument, each phase will be discussed separately with respect to participants and procedures.

3.3.3 Ethical aspects of the research process

The qualitative nature of the information necessitated adherence to ethical principles throughout the research process, relevant details of which are indicated at every

stage of the description of the methodology. In general, the personal and sensitive, even controversial, information which was elicited, was protected by emphasizing voluntary participation in the interviews and in answering the questionnaires. This was further supported by giving students the option to have access to their verbal or written contributions and to change or withdraw any statement at any stage. In order to protect the identity of participants, interview transcripts were coded and questionnaires results were numbered. Personal data which could be obtained from student numbers was used by the researcher for the sole purpose of being able to establish racial and gender profiles and to contact interviewees in order to clarify interview statements. Access to students was achieved via the lecturer in charge. No undue pressure was ever placed on students, and the researcher and lecturer emphasized that academic records would not be affected either positively or negatively. Students were however encouraged to participate by pointing out the value of their contribution to research and science education. A book prize was offered as incentive for completing and handing in the questionnaires.

3.3.4 PHASE 1: Interviews and analysis

3.3.4.1 Introduction

Interviews were used to elicit views and opinions of students on the interaction between scientists and society and as such form the main source of information for the design of the instrument. The qualitative analysis of the interviews into categories and sub-categories is an iterative process which required considerable time and detailed attention.

3.3.4.2 Participants

When the project started in April 2000 the only students permanently on campus and as such available for pilot interviews were postgraduates in the Chemistry and Physics Departments. These students, most of whom were known to the researcher, were contacted personally to invite them to participate in the study. The objectives were broadly explained as an investigation into the interaction between scientists and society. Attendance, though voluntary, was encouraged by emphasizing that their opinions would make an important contribution to the project and to science

education as a whole. Confidentiality was assured, as well as the fact that participants could withdraw their input and have access to interview transcripts. Of a group of 8 postgraduates all except one white male agreed to participate. Three third year students who had come to hear of the project volunteered. As there was only one female student among the postgraduates, a female laboratory technician with a background in Chemical Engineering was approached to take part. In total there were 11 participants, the majority being Black males, with one White male and two Black females. Three pilot group interviews were conducted, the groups consisting of 3 or 4 members each. The composition of the groups could not be predetermined; participants attended sessions as their time schedules permitted.

The main interviews were held during the practical course in June 2000. Permission was obtained from the lecturers in charge of the practical course to address the students. As before, the broad aim of the project was explained and students were requested to volunteer for group interviews. Over a three week period, 7 group interviews (2 to 4 participants each) and 4 individual interviews were conducted. The size of the groups was limited to a maximum of 4 members in order to facilitate group coherence and ensure the clear recording of the discussion. Similar to the pilot interviews, groups were mixed with respect to race and gender, the composition of the groups depending entirely on who was available. A total of 25 students of the 109 third level students at the practicals (23%) participated. Table 3.2 reflects the racial and gender distribution of the participants in each session and compares the distribution of the participants with that of the third level practical class as a whole. (Data on students who attended the pilot interviews is not listed because they cannot be included in comparisons with the class total.) The group was heterogeneous with respect to race and gender (female : male = 52% : 48%), broadly reflecting percentage composition of the class in total. Ages ranged between 23 and 42 years. A total of 68% of the group was employed as teachers, in research laboratories and industry, while the remaining 32% pursued their studies full-time.

	African female	African male	White female	White male	Asian female	Asian male	Total
Group 1		3					3
Group 2			1	1	1	1	4
Group 3			3				3
Group 4	2	2					4
Group 5		1	1			1	3
Group 6	2						2
Group 7				1	1		2
Individual 1				1			1
Individual 2	1						1
Individual 3		1					1
Individual 4	1						1
Totals: participants	6 24%	7 28%	5 20%	3 12%	2 8%	2 8%	25 100%
Totals: 3 rd level practicals	20 18%	34 31%	15 14%	22 20%	8 7%	9 9%	109 99%

		African	White	Asian
Race	Participants total	52%	32%	16%
	Class total	49%	34%	16%

		Female	Male
Gender	Participants total	52%	48%
	Class total	52%	48%

Table 3.2 Composition by race and gender of participants and class

During practical sessions students are under considerable pressure to perform a prescribed number of experiments and to submit reports in a limited period of time. Students who are not employed in research or industry usually have less laboratory experience and spend more time completing their experiments. Consequently the volunteers mainly comprised those students who had completed their experiments for the day or who had a special interest in the project. This could explain the slight

discrepancies in representivity between participants and the class total as evident in Table 3.2. The interviews are only the first step in the design of the multiple choice instrument, which further incorporates respondents' views in the open response questionnaire. Furthermore, the interviews were continued until no new information emerged, and the interview analysis was performed on a qualitative basis without undue loss of important data. As a result, the slight discrepancy mentioned above is not expected to affect the research appreciably.

3.3.4.3 Interviews

The design of the instrument rests on the rationale that students' views rather than those of researchers or theoreticians must be reflected in the questionnaire. Group interviews lend themselves well to the qualitative exploration of multiple views among a variety of participants in a relatively secure and friendly setting (Vaughn *et al.*, 1996). The direct contact among participants encourages candour and promotes participation. The researcher has the opportunity to get an overall impression of the degree of consensus and differences as well as of extraneous views among the target population. Participants often motivate and inspire one another when working in groups.

A background study of the literature had sensitized the researcher to key issues surrounding the social responsibility of scientists such as whistle blowing, the slippery slope argument and participative decision making. The perception of the researcher was that South African students had little awareness of these issues. (This perception, it may be noted, was proven totally incorrect by the participants in the study, and the researcher was taken by surprise about the depth of insight and experience which transpired during the interviews!) One reason for this perception was that the student population largely comes from educationally neglected backgrounds where there has been little exposure to information. Another reason was that in the distance education setting there is little opportunity for fruitful discussions on themes that are not directly related to the factual content of the study material. In order to stimulate the interviewees to form opinions on social responsibility and the role science and technology play, the decision was made to

expose them to a collection of newspaper articles on current issues in the South African media. The following headlines show that these articles covered a wide range of topics such as environmental pollution, unethical research practices, the HIV/AIDS controversy and the opinions of dissident scientists:

Miners 'fried' by radiation (Stephen, 2000).
Iskor 'poisoned our water' (Brümmer, 2000).
US environmentalists visit Durban hotspots (Kirk, 2000).
The heat is on in the Arctic (Arlidge, 1999).
Dammed if you do, dammed if you don't (Matlou, 2000).
Deadly day of sun and unions (Bowcott, 1999).
Challenge to the Aids dissidents (Davison, 2000).
Mixed messages from government (Mail & Guardian reporters, 2000).
Politicians unwilling to accept stubborn science (Le Page, 2000).
Irrational Aids debate rides rough-shod over patients (ka-Mankazana, 2000).
TV station seeks Bezwoda patients (Magardie, 2000).
Human organs made to order (Bullen, 2000).
The gene scientists who are remaking human life (Porter, 2000).

These articles indirectly refer to the role of science and scientists play society. (See Appendix A.) Only one student remarked that he was overwhelmed by the number of topics, while another thought he had to comment on each topic. During the pilot interviews the newspaper articles were displayed on the table around which the researcher and the interviewees gathered. For the main group interviews the newspaper cuttings were taped onto a wall, which enabled interviewees to read the articles or scan the headlines beforehand.

All interviews were recorded on tape. During the pilot interviews the initial tape recordings were unclear because the tape recorder and microphone were placed in the middle of the table among the newspaper clippings. The recording technique was subsequently improved by removing the newspapers as explained above and by handing the microphone to each member when it was his or her turn to speak. The size of the group was limited to a maximum of 4 members. This ensured comfortable seating around a table, facilitated clear voice recording and enabled the researcher to coordinate interaction among members. Interviews lasted 30 minutes to an hour, when the often lively discussion had to be terminated on several occasions.

Frequently the researcher was drawn into further discussions after the interviews. Verbal feedback on the interviews was always animated and positive, referring to the importance of the topic under investigation and expressing a desire for more similar occasions to explore such matters of concern.

As an introduction to each interview session the researcher again broadly described the purpose of the project without directly referring to the research questions, emphasizing the crucial role these students would have to play as the future intellectual leaders of the country. The importance yet confidentiality of their opinions in the projects was confirmed. Reference was made to the newspaper articles on display to start the discussion. Depending on the group, it was sometimes necessary to prompt the interviewees or to sketch other scenarios than those in the articles in order to enable the participants to verbalize their opinions or place themselves into an imaginary situation where they could ask themselves how they would react. As soon as communication was established, the role of the interviewer was limited to requesting further explanations to statements which had been made, and, without being directive, to keep the discussion focused. Subsequent to the pilot interviews the researcher was more aware of group dynamics and could ensure that all interviewees had an opportunity to relate opinions or experiences.

Irrespective of how the groups were constituted along racial or gender lines, the interaction among interviewees was always lively, often resulting in friendly yet constructive arguments. The language medium was mainly English. Black students for whom English is their second or third language appeared comfortable and were generally eloquent. Contrary to this, Afrikaans speakers preferred to use their mother tongue, which was accommodated in one mixed interview among 2 English and 2 Afrikaans speakers and one interview among 3 Afrikaans speaking women. The range of experience which participants brought to the interview was wide. One individual, for example, had been exposed to occupational hazards as a mine worker; one had been working in the pharmaceutical industry and had insight into research on HIV/AIDS; one was faced with questions related to genetically engineered fruit, while another two were dedicated teachers in rural areas.

After each interview the main ideas that had been addressed were summarized by the researcher and the extent of coverage was evaluated, being mindful that unforeseen aspects could still emerge. An impression was written of the general trends and differences and how viewpoints could depend on individual backgrounds and experiences. Notes were made on group interaction, inconsistencies and themes that needed further exploration. On two occasions it was clear that follow-up interviews had to be done. In the first case the participant was asked to clarify his opinion on what motivated scientists to do research. In the second case two participants were requested to explain their statements involving African culture. After the seventh group interview most of aspects pertaining to the topic at hand had been covered extensively. At this stage the number of volunteers had also diminished and those that were still available could not be accommodated in groups due to time constraints. The decision was made to conduct four individual interviews in which aspects which had not been adequately explored, such as the role of women, could be addressed. The interviewing sessions then came to their natural conclusion.

3.3.4.4 Analysis of interviews

The tape recordings of the interviews were transcribed verbatim. The Afrikaans only interview was translated into English, while for the mixed language interview the Afrikaans statements were translated. Translations were done merely for the purpose of providing evidence – which in fact was not requested at any stage – to any non-Afrikaans speakers and were not checked. The researcher regarded herself as adequately bilingual for the purpose for which the translations were done. Transcripts were not returned to the interviewees for checking their accuracy. After the lengthy transcription process students had left the campus. The contents of the group and individual interviews as well as the pilot interviews were incorporated in the analysis.

The qualitative analysis of the large amount of information contained in the interviews closely followed the procedure recommended by Dey (1993). In order to ensure that the resultant data was a true reflection of the interviewees' statements,

an open approach and detailed involvement with the data was required. Generally the overall impressions gained during the interviews and the transcription process were consistent with the background literature and the expectations of the researcher. There were however unexpected trends which necessitated cross-checking the original tapes or transcripts on two occasions, as explained in the previous section. In addition, the interview notes which were written immediately after each interview served to confirm the context and overall flow of the conversations.

The purpose of the qualitative analysis of the interviews was to identify a number of main categories or topics pertaining to the social responsibility of scientists and a number of sub-categories pertaining to different aspects of the main topics. Following the terminology adopted by Bennett *et al.* (2001) the main categories are denoted as “strands” and the sub-categories as “dimensions”. These dimensions were eventually formulated into questionnaire statements in Phase 2. The analysis is an iterative refinement process of allocating interview statements to strands and dimensions, whereby both the strands and their dimensions are identified, grouped and regrouped until a structure is obtained which logically reflects the content of the interviews and serves as a basis for the formulation of the questionnaires and the final analysis of the results. The flow diagram in Figure 3.2 provides an overview of the lengthy process. It is followed by step-by-step details and examples.

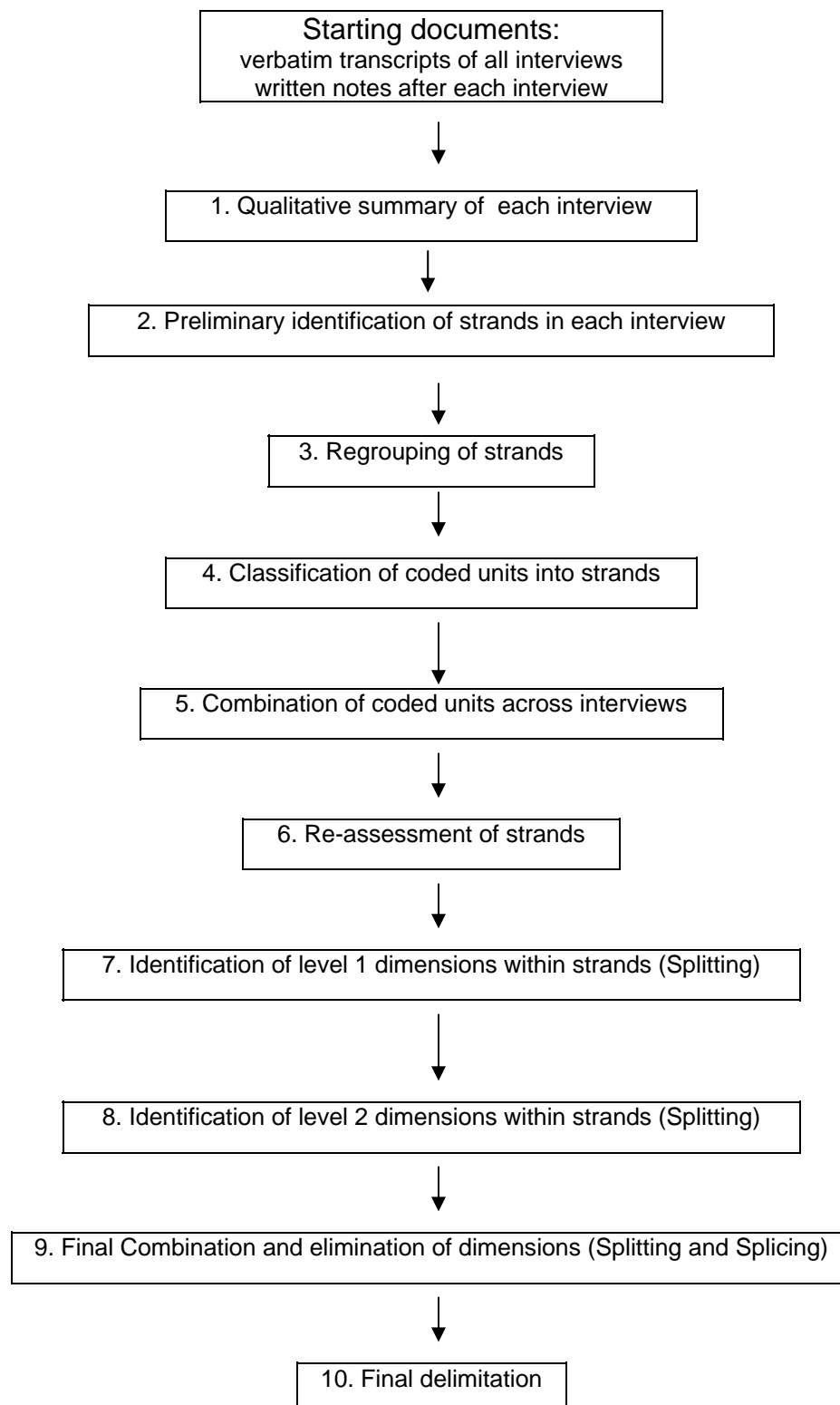


Figure 3.2 Flow diagram of qualitative analysis of interview transcripts

1. Qualitative summary of each interview

Reading through each transcript and taking into account the notes which were made on group interaction and coverage of topics after completion of each interview, a summary was made of the discussion that took place. This summary served to obtain an overall impression of students' views of the social responsibility of scientists. The flow of the discussion was noted and salient points under each topic were included. Individual statements could thus be placed into context and compared with viewpoints of other participants. Differences among groups and individuals became evident, and an overall picture of the breadth and depth of the subject emerged. For example, the summary for Interview VII reads:

"The interviewees were 2 Black men, Mt and Ma, and 2 Black women, Mk and N. The women appeared confident, motivated and enthusiastic, while Ma seems disillusioned with his role as student and scientist. Although Mt is older and successfully employed, his rare contributions do not say much. The underlying theme of the interview comes across as being about what can be done to uplift society by whatever means available. The flow of the discussion proceeded from 'scientific literacy' to the 'impact of science' to the 'international nature of science' to 'problems in tertiary education' and finally to 'scientists in the community'."
(VII.summary)

In contrast, the summary of Interview III is:

"Lively group though dominated by M. Varying viewpoints ranged from idealism about pursuit of scientific knowledge to disillusionment about the control of research and development by money, to criticism about the lack of scientists' personal responsibility." (III.summary)

2. Preliminary identification of strands in each interview

The transcripts were read with no fixed set of categories in mind and no material was excluded at this stage. A wide range of preliminary strands (broad topics or themes) could be identified tentatively, while always referring to the qualitative interview summaries to take the context into account. For example, the range of topics in Interview III above was:

Impact/ control of scientific enterprises,
individual responsibility and whistle blowing,
scientific knowledge and purpose of research,
decision making: role of scientists, government and the public,
communication between scientists and society, and
education.

In interview IV on the other hand, the following preliminary strands were identified:

School education,
tertiary education,
role of scientists in education,
environment: harmful discoveries,
whistle blowing,
secrecy about scientific discoveries,
job creation,
value education: African values,
scientific research: African values and the environment,
scientists as people, and
communication and AIDS.

3. Regrouping of strands

In order to place the preliminary strands into the wider analytic context, the question, was asked: what facet of social responsibility could this be? (Dey, 1993: 97). In this way overarching topics could be identified and the preliminary strands could be

consolidated. New categories also evolved as more coded units were sorted and compared. This step took place concurrently with step 4: as more coded statements were identified in step 4, more strands were added to the list in step 3, until the following 9 strands were arrived at:

1. Education: general, tertiary
2. Decision making / choices
3. Impact of scientific activity / control of research
4. Education of the public
5. Communication: science - society / public awareness
6. Scientific knowledge and research / freedom and responsibility / purpose / funding
7. Scientist as individual / individual responsibility / whistle blowing
8. Women in science
9. Science students

4. Classification of coded units into strands

All meaningful statements, phrases, sentences or paragraphs in each interview were broken up into data units which represented statements having one distinct meaning. By including the entire meaningful contents of each interview, the researcher ensured that strongly worded arguments were not emphasised above more general or repetitive ones. Where statements of participants seemed inconsistent or contradictory, the context of the interview session and the flow of the discussion contained in the qualitative summary of each interview were consulted.

The identified data units were transcribed verbatim onto large sheets of paper and were coded to denote the interview number, transcript page and statement number. Data from the different interviews was kept separate at this stage and by using large sheets the overall picture and interaction among topics was retained.

The classification of data was done by asking the question: what facet of social responsibility could this be? As an illustration, the following 3 statements were classified in the strand ‘Scientific knowledge and research’:

“The higher aim of research is to probe into the physical world”,
(III: 32-3.4(14))

and

“Research into viruses ended up in us not being able to control what we thought we could”, (III: 31-3.4(10))

as well as the opposing view of

“You can see what the future effect will be”. (III: 33-3.4(12))

Several coded units resorted under more than one strand. For example:

“The community needs to be able to identify problems science creates”
(II: 8-6)

was classified as: ‘Impact/ control of research’; Communication between scientists and society’ as well as ‘Education of the public’. While the statement

“Guidelines should be in place to control processes and eliminate decisions of individuals” (V: 14-9)

was classified as: ‘Individual responsibility’ and ‘Impact / control of research’. This statement also implicitly refers to scientific freedom which forms part of the strand ‘Scientific knowledge and research’.

The classification of coded units was refined in a number of cycles until strands containing clearly identifiable coded units evolved.

5. Combination of coded units across interviews

In step 4 the coded units of each interview were assigned separately to one or more of 8 strands. In step 5 the coded units per strand were combined across all interviews. This was done by first photocopying the sheets with the classifications done in step 4 (in order to retain the original), then separating the data in the various strands by cutting up the photocopied sheets into 8 or less portions (in cases where

not all topics had been addressed) and finally collating the data per strand for all interviews. In this manner an overview of all the coded data units per strand was obtained.

At the end of the process a large amount of data was contained in each strand and sub-categories started to emerge. The decision was made to re-assess the number and description of strands at this stage and plan the further refinement of strands and dimensions within strands.

6. Re-assessment of strands

The 9 identified strands were re-assessed by comparison with the following 13 categories which had been broadly identified in the initial literature study:

- Special responsibility of scientists
- Autonomy and Scientific Freedom
- Consequences, impact of scientific activity
- Objectives of scientific activity
- Decisions, solutions, values
- Self-regulation, codes of practice, accountability,
- Gender
- Communication
- Education
- Whistle blowing
- Values
- Culture
- Risk assessment

Concept maps and tables were compiled to confirm that the 13 categories overlapped with the 9 strands. The conclusion was that too many categories would result in some having only one sub-category and that the 9 identified strands represented a more rigorous overview of all the aspects covered in the interviews.

A further approach at re-assessing the division into 9 strands was by identifying four different roles where scientists could be expected to exercise social responsibility, i.e. as community members, as researchers, as teachers and in their private, individual capacity. The 9 strands could be matched with the 4 identified roles. In this case it was evident that 4 strands would contain too many sub-categories and that there would be considerable overlap among sub-categories.

A final comparison was made with pertinent statements from the original VOSTS questionnaire, i.e. those which covered 'Decision making', 'Scientific research: purpose, reporting and impact', 'Characteristics of scientists' and 'Gender issues' (Aikenhead, 1987; Fleming, 1987; Ryan, 1987). In this instance it was found that a broader spectrum of topics had indeed been addressed in the interviews.

The 9 strands were consequently retained in the assurance that they reflected the interviews adequately and that they could accommodate a number of diverse aspects in the sub-categories without too much overlap. In a qualitative analysis the creation of categories must be seen as an attempt to classify a large amount of data and depends on the objectives of the study. Any different set of categories could be equally valid.

7. Identification of level 1 dimensions within strands (Splitting)

The large number of coded data units within each of the 9 strands represented a variety of aspects and a further analysis and organisation into a variety of dimensions (sub-themes, sub-categories) was required. This was achieved by allocating each coded data unit to a dimension within the strand and transcribing it in abbreviated form onto a card system. The original references to the interview were included. A new (consecutive) numbering system was introduced to identify the coded data unit according to the dimension. Some data units were identified as reasons which students had offered for their statements. These were included on the card, opposite the corresponding statement. This process ensured that while distinctions were being made, there was still an intimate involvement with the original

data and no exclusion of information. An attempt was also made to limit the number of dimensions in order not to lose focus.

Each strand was sub-divided into 3 to 8 dimensions, with each dimension containing up to 40 coded data units. Taking Strand 3 (Impact of scientific activity) as an example, the following 5 dimensions were identified:

- 3.1 Input to / from society
- 3.2 Control is necessary
- 3.3 Risk management
- 3.4 Whose responsibility is it?
- 3.5 Drawing the line / personal values

The following transcript of the card for dimension 3 (Risk management) illustrates the consecutive numbering system, the corresponding coded data unit, reference to the interviews and reason:

3. IMPACT	Ref.	Reason	Ref.
3.3 Risk management			
3.31 Scientists should be 100% sure	I.6.7		
3.32 You can see what future effects will be	III.6.12		
3.33 There is no control.. it is out of hand	III.6.10		
3.34 Prediction of effect is necessary	V.6.5		
3.35 Prediction is possible	V.6.6	that's what we learn	V.6.7
3.36 Prediction of effects in advance	VI.6.1	<u>but</u> new developments come too fast	VI.6.2
3.37 If you can't measure (= 3.45)	VI.6 3a/b	you can't accept responsibility	VI.6 3a/b
3.38 Scientists should look ahead before disasters occur	X.6.10		
3.39 Broadcast only when 100% sure (= 3.13)	I.3.8	create false hopes	I.3.14
3.310 Risks necessary: automation can cause job losses (= 3.51)		better to be productive	IV.3.1
3.311 Research must suggest improvements, reduce danger	I.7.56		

8. Identification of level 2 dimensions within strands (Splitting)

The dimensions identified in Step 7 still contained a large number of diverse concepts which required further refinement. In an intensive process, the coded units we re-read in their original context, rewritten into new tables and frequently re-allocated to different dimensions. Simultaneously, the most expressive verbatim statements were identified, similar statements grouped together and less revealing or relevant statements eliminated. Due to the wealth and breadth of the data, not all finer distinctions could be included.

To continue on the above example of Risk management (dimension 3 of strand 3), the following aspects could be distinguished, with the numbers of the coded units from Step 7 in brackets:

- 3.3.1 Future effects can be determined (3.31, 3.32, 3.34, 3.35, 3.36, 3.38, 3.39)
- 3.3.2 Control is out of the hands of the scientists (3.33, 3.27)
- 3.3.3 If you cannot measure it, you cannot be responsible (3.36, 3.37)
- 3.3.4 Risks are necessary for progress (3.310, 3.51, 3.53, 3.515)
- 3.3.5 There must be more research before releasing new findings (3.311)

Appendix B.1 shows the development of strand 3 into its 5 dimensions with dimension 3 given in detail. This is followed by Appendix B.2 where the 5 aspects of dimension 3 are distinguished and the coded units and references to interviews are included, as outlined above. This abstract from the analysis also shows how the researcher started to formulate possible questions (i.e. below 3.3.1), and how responsibilities and reasons and their opposites started to emerge. It is also evident how some aspects were still moved to other dimensions (e.g. 3.2.2). Appendix B.3 shows the final refinement which is described in the following paragraph.

9. Final combination and elimination of dimensions (Splitting and splicing)

The large number of level 2 dimensions identified in Step 8 could not be addressed in a single questionnaire. While retaining the focus on the overall topic, the number of distinctions needed to be limited and their relevance established. Each level 2 dimension with the accompanying coded units was scrutinized by asking questions on the who, to whom, for what and how of the particular responsibility. This is illustrated by the following abstract from the analysis for strand 3.

IMPACT OF SCIENTIFIC ACTIVITYResponsibility

Who?	: Scientists or individual scientists
	: all, society, users
To whom?	: society
For what	: internal regulations
	: control of applications
	: consequences
	: risk assessment
How?	: moral implications

This process served to identify relevant aspects of scientists' social responsibilities including a variety of opposing views. Consequently statement pairs which are a feature of the open-response questionnaire started to emerge. A number of dimensions were found to be duplicated in different strands and were moved or eliminated. Other dimensions were identified as reasons for a particular responsibility. These 'because' statements are the expected outcomes of the open-response questionnaire, and subsequently feature as the options in the fixed response questionnaire.

Continuing on the example of risk management (refer to Appendix B.3), the first dimension

3.3.1 Future effects can be determined

could be seen as a positive responsibility of scientists, while dimension

3.3.2 Control is out of the hands of the scientists

could be seen to negate this view, with dimension

3.3.3 If you cannot measure it, you cannot be responsible

providing a reason for dimension 3.3.2, while the following two dimensions:

3.3.4 Risks are necessary for progress

3.3.5 There must be more research before releasing new findings

confirm the necessity of risk management.

10. Final delimitation

The entire process of analysing the interviews qualitatively requires a lengthy and intimate involvement with the data. It entails constant reviewing, rewriting, re-examining, re-interpreting, recombining or discarding of data. In the final stage,

decisions were made which dimensions to include over all 9 strands so as to limit the open-response questionnaire to 25 items. Not all strands contain an equal number of dimensions. The final set of strands and dimensions of the responsibility of scientists is summarized in Table 3.3. These form the basis for the formulation of statements for the open response questionnaire in Phase 2.

1.	RESPONSIBILITY IN EDUCATION
1.1	Content of syllabus: pure versus applied
1.2	Purpose
1.3	Value education
2.	RESPONSIBILITY TOWARDS DECISION MAKING
2.1	Who must decide on the implementation of science and technology
2.2	Basis for decision making
3.	RESPONSIBILITY FOR IMPACT OF SCIENTIFIC ACTIVITY
3.1	Responsibility for control of applications of scientific research
3.2	Self-regulation and codes of practice by scientists
3.3	Risk assessment
3.4	Responsibility for consequences of scientific activity
3.5	Moral, ethical implications of scientific research
4.	RESPONSIBILITY FOR EDUCATION OF THE PUBLIC
4.1	Who should educate the public
4.2	Equity
5.	RESPONSIBILITY FOR COMMUNICATION WITH THE PUBLIC
5.1	Communication between scientists and the public
5.2	Forbidden knowledge
5.3	Public involvement of scientists
6.	RESPONSIBILITY OF SCIENTISTS IN RESEARCH
6.1	Scientific freedom and responsibility
6.2	Purpose of scientific research
6.3	Special responsibility of scientists
6.4	Personal motives / integrity
6.5	International character of science
6.6	Unique role of science
7.	INDIVIDUAL RESPONSIBILITY: WHISTLEBLOWING
7.1	Information of public
7.2	Personal moral decision
8.	WOMEN AND SCIENCE
8.1	Women's role
9.	SCIENCE STUDENTS
9.1	Interaction / separatism

Table 3.3 Final set of strands and dimensions of the responsibility of scientists

3.3.4.5 Conclusion

This section has shown how in Phase 1, the initial data collection was done by means of mainly group interviews chiefly among postgraduate and third level Chemistry and Physics students. The step-by-step analysis of the interviews is detailed by means of examples. Phase 1 concludes with a table identifying how, for the purpose of formulating the open-ended questionnaire, the social responsibility of scientists is divided into a number of main categories (strands), each with one or more sub-categories (dimensions) denoting relevant aspects of the topic.

3.3.5 PHASE 2: Open response questionnaire and analysis

3.3.5.1 Introduction

In the development of the VOSTS instrument Aikenhead and co-workers (Aikenhead and Ryan, 1992) used an open response questionnaire containing pairs of opposite statements in order to obtain the reasons why students agreed or disagreed with statements pertaining to STS issues. The formulation of statement pairs is described in the section below. This is followed by the pilot and formal testing of the open response questionnaire to a large group of students. The analysis of the responses concludes Phase 2. (See also Figure 3.1.)

3.3.5.2 Formulation of the open response questionnaire

By referring to students' verbatim statements which were once again considered during the formulation of questionnaire items, a selection of 3 to 5 pairs of opposite statements was compiled for each dimension. Care was taken to reflect the informal language and the inherent messages conveyed during the interviews and avoid ambiguity (Aikenhead *et al.*, 1987; Botton and Brown, 1998). Contrary to the statements in the VOSTS questionnaire, no specific examples were cited. Although this approach could lead to insignificant or ambiguous feedback, it may also limit respondents' focus (Aikenhead *et al.*, 1987). In each pair of opposite statements, the second statement was either a direct negative of the first statement, or it addressed a slightly different aspect of a topic. For example, the statement:

Scientists are responsible for damage, such as pollution, to the environment and its negative

Scientists are not responsible for damage, such as pollution, to the environment,

as compared to the statement:

The public has a right to know about all scientific developments

and a different aspect

There should be certain scientific developments that should be kept secret from the general public.

The selection of 3 to 5 pairs of opposite statements for each dimension was submitted to the supervisors of this project (Bennett *et al.*, 2001). The objective of each pair of statements was clearly defined by asking: Whose responsibility? To whom? For what? and How? The supervisors and the researcher together discussed the versions, reformulated them where necessary, and finally agreed on the most appropriate version with respect to content and use of language.

Appendix C contains the final selection of 25 statement pairs which comprise the items for the open response questionnaire. As the purpose of this questionnaire is to elicit a broad spectrum of reasons in agreement or disagreement with each statement, the following format was used for each statement, providing several open rows for respondents to explain their reasons:

As a scientist one does not have a special responsibility towards society
I AGREE / DISAGREE this statement because

.....
.....

Opportunity was also provided for respondents to offer their own definition of the social responsibility of scientists on the first page of the questionnaire and to offer their comments on the questionnaire at the end.

The cover page of the questionnaire (Appendix D) defined the purpose of the project as being research into the relationship between scientists and society. Participants were informed that their input was voluntary and confidential, but that it was an opportunity to make a valuable contribution. The possibility of winning a Chemistry textbook by means of a lucky draw was used as incentive for participating.

3.3.5.3 Pilot test

Two different versions of the open response questionnaire, each consisting of 25 items, were compiled by combining different positive and negative statements. Fourteen lecturers and postgraduate students were selected on the basis of race and gender and requested to complete the questionnaire, to record the time taken to complete the questionnaire and offer comments and suggestions. Only two responses were received.

Respondents commented on the very large number of questionnaire items and the time and effort it took to formulate appropriate responses. The problem that some items appeared to overlap was also noted. In a qualitative study categories and sub-categories cannot be clearly delineated and necessarily overlap to some degree. The reasons offered in agreement or disagreement to different statements could also be similar, thus further creating the impression of repetition. Consequently the total number of statements was not reduced at this stage.

For the final open response questionnaire, however, the number of statements to be answered per student was reduced to 16. This necessitated separating the 50 (positive and negative) statements into groups of 16, each containing some dimensions from each strand and each containing 8 positive and 8 negative formulations. The sequence of the questionnaire items was also varied. A total of 16 different versions was compiled.

3.3.5.4 Respondents

The open response questionnaire was administered in June 2001 to third level students during the practical sessions. Permission was obtained from the lecturers in charge of the practical courses to address the students. The broad aim of the project and the importance of student input were explained. Each student was given a questionnaire. Due to time constraints while doing their experimental work, participants were granted permission to answer the questionnaire at home.

There are 4 compulsory third level practical sessions. Not all students attend all sessions in the same academic year and consequently some of the interviewees from 2000 were also present at the practical sessions in 2001. Of the total of 71 third level students, 22 (31%) answered the questionnaire, of which 4 students had also participated in the interviews the year before. The distribution by race and gender of the 22 respondents broadly reflects the distribution of the class as a whole, as is evident from Table 3.4.

	African female	African male	White female	White male	Asian female	Asian male	Total
Respondents	6 27%	6 27%	4 18%	3 14%	1 5%	2 9%	22
Class total	20 28%	16 23%	10 14%	12 17%	7 10%	6 8%	71

		African	White	Asian
Race	Respondents total	54%	32%	14%
	Class total	51%	31%	18%

		Female	Male
Gender	Respondents total	50%	50%
	Class total	52%	48%

Table 3.4 Composition by race and gender of respondents and class for open response questionnaire

3.3.5.5 Analysis of the open response questionnaire

As a first approach to the analysis, the respondents' definitions of the social responsibility of scientists on the first page of the questionnaire were summarized. Definitions focused on a broad range of topics, from improving the quality of life to the protection of man and the environment, education of communities, concern for the effects of scientific applications as well as integrity and moral values. Some students made special reference to the use of drugs, hazardous chemicals, soil erosion, education on HIV/ AIDS. These definitions did not add to the strands and

dimensions which had been identified and thus merely served to confirm that the content of the questionnaire adequately covered all aspects of the topic at hand.

Only 5 respondents utilized the opportunity at the end of the questionnaire for additional comments. These comments referred to the importance of moral decision making by scientists, “technology education” and the need for public communication of science by scientists. The questionnaire was experienced as lengthy but thought provoking.

The in-depth qualitative analysis of the open response questionnaire is an important stage in the overall development of the instrument as it provides insight into students’ reasons or opinions on why they agree or disagree with certain statements. It is in this stage that the VOSTS-type instrument differs from other instruments. Due to the fact that the volume of data was considerably less and the contents was more concise, the analysis was done according to a simplified procedure of the one followed in the analysis of the interviews. The procedure which involves separating reasons into common groups and re-assigning and combining groups until a clear pattern is evident, is outlined in Figure 3.3 and described below.

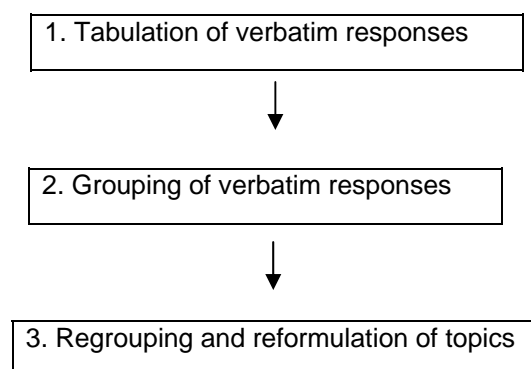


Figure 3.3 Flow diagram of qualitative analysis of the open response questionnaire

1. Tabulation of verbatim responses

The verbatim responses for each of the 25 positive and 25 negative statements were tabulated under an 'Agree' or Disagree' heading. The total number of responses often exceeded the number of students who answered the question, because in many cases students gave more than one reason. The following are extracts from the tables addressing the role of women in science:

8.1a: Women scientists have a special role to play in science

	AGREE, because		DISAGREE, because
2	In the household women are able to control the diet of their families and help with primary health care	18	Don't be feminist! Everyone has a special role in science as long as they have the same goal in mind: to achieve whatever they work towards
4	Marie Curie for example!!	19	Women and men contribute equally..
6	Women can often have a different perspective and way of looking at something	21	The question of gender does not arise...

8.1b Women scientists do not have a special role to play in science

	AGREE, because		DISAGREE, because
		29	I consider men and women equal in this field<<<
		31	All are equal. Women are no different from male counterparts
		32	We do not need this debate as the Nobel Prize winners has been predominantly male<<<<<
		35	... they can come up with new developments
		37	.. scientists are scientists, black/ white/ male/ female....

There were altogether 17 reasons given in agreement and 11 in disagreement for the positive statement 8.1a, while for the negative statement 8.1b no reasons were given in agreement, but 19 reasons in disagreement. The reasons in disagreement with the negative statement in fact represent an agreement with the positive

statement. The above tabulation clearly shows the confusion often experienced with the double negative, and confirms the necessity of using both positive and negative statements to collect a wide range of responses and compare responses to the opposing statements.

2. Grouping of verbatim responses

Responses expressing similar reasons were grouped under a common topic. Ideally reasons in agreement with the positive statement and reasons in disagreement with the negative statement should fall into the same group, or vice versa. However, due to the misinterpretation of the double negative this was not always the case. Single responses which did not fall into any group were classified as “Unique”, while responses which were not understandable were classified as “X” and were eliminated. Table 3.5 represents the analysis of the above-mentioned example on the role of women in science. In this case there were no unique statements (U) and also no unclear and/ or unusable statements (X).

Group	Preliminary topics reflecting common reasons	No. of Responses from 8.1a	No. of Responses from 8.1b
A	Family and household	3	-
B	Novel scientific developments	4	2
C	Being an role model	3	4
D	More people oriented	4	3
E	Minority role of women	1	1
F	Male and female scientists are equal	9	9
G	Feminism	3	3
U	Unique statements	-	-
X	Unusable statements	-	-

Table 3.5 Analysis of open response questionnaire: statements 8.1a and 8.1b

3. Regrouping and reformulation of topics

The process of grouping responses and defining overall topics was repeated until between 6 and 8 topics per statement pair could be identified. Care was taken to avoid overlap or duplication of topics. At this stage reasons in agreement and reasons in disagreement with the positive statement generally started to emerge. For example in Table 3.5 topics A to D are in support of the overall positive statement, while topics E to G are in disagreement with it. These topics form the options in the multiple choice questionnaire of Phase 3. Topics were eliminated or combined in Phase 3 when descriptive multiple choice options were formulated.

The classification of the reasons for 3 of the 25 sets of opposite statements from the open response questionnaire was checked by an expert in this methodology. (Carspecken, 1996; McNiff, 1995.)

3.3.5.6 Conclusion

Phase 2 of the development of the instrument entails the formulation, testing and analysis of an open response questionnaire. For this purpose 25 pairs of opposite statements were formulated for the dimensions identified during the analysis of the interviews. The pilot test showed that the length of the questionnaire needed to be reduced. Sixteen different versions of the final questionnaire containing 16 different combinations of positive and negative statements were tested on a group of 71 students, of whom 22 responded. The analysis of the reasons provided in agreement or disagreement of the statements was done qualitatively by grouping and regrouping similar reasons and identifying representative topics.

3.3.6 PHASE 3: Fixed response questionnaire and analysis

3.3.6.1 Introduction

The third and final phase of the design of the instrument entails the formulation of a fixed response (or multiple choice) questionnaire, in which the reasons provided by respondents in the open response questionnaire of Phase 2 are used to formulate

the multiple choice options. In the following sections the formulation of the fixed response questionnaire is outlined. This is followed by details of its administration to a large group of students. The analysis of the data collected by means of the questionnaire and the compilation of an attitude profile complete Phase 3. (See also Figure 3.1.)

3.3.6.2 Formulation of the fixed response questionnaire

The selection of statements and reasons for the final questionnaire involved a series of steps represented in Figure 3.4 and detailed below:

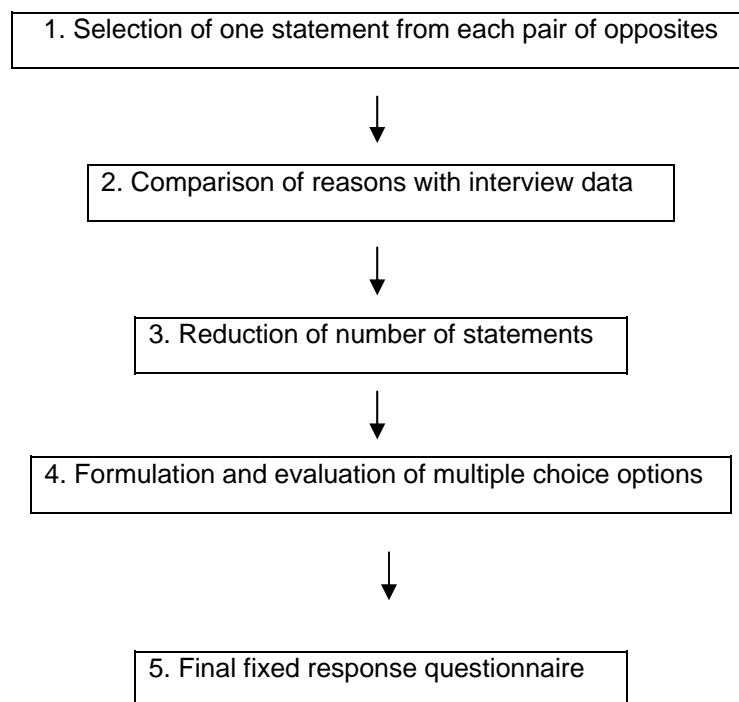


Figure 3.4 Flow diagram of formulation of fixed response questionnaire

1. Selection of one statement from each pair of opposites

The final instrument consists of one statement per dimension with a number of multiple choice options, each of which is preceded by either the phrase: 'agree with this statement because' or the phrase 'disagree with this statement because'. In answering the open response questionnaire, students experienced difficulties in expressing disagreement with the negative version of the pair of opposite statements. For this reason in all but one case the positive statement was selected for the final form of the fixed response questionnaire. The one exception was made for the statement:

'Scientists are not responsible for whatever use is made of their discoveries by industry'

because there was hardly any disagreement with the positive statement and it was therefore difficult to formulate disagreement options. In those pairs where one statement expressed an alternate view rather than a direct negative of the other, the statement which produced the clearest answers in Phase 2 was chosen (Aikenhead and Ryan, 1992).

2. Comparison of reasons with interview data

A summary was made of the 25 final questionnaire statements together with the groups of reasons from Phase 2. These groups were compared with the reasons which had been identified during the analysis of the interviews in Phase 1. In most cases, reasons offered in the open response questionnaire confirmed what had already transpired in the interviews. Reasons from the interviews were incorporated in cases where there were not enough topics in agreement or disagreement or where important issues had not been addressed by the students answering the open response questionnaire.

3. Reduction of number of statements

Having compiled all the reasons for all 25 statements, a critical analysis was done to assess the possibility of reducing the length of the final questionnaire:

Some of the reasons for statements 2.1 and 2.2 (refer to Appendix C) which both address responsibility for decision making coincided and it was therefore possible to eliminate statement 2.2. Statement 4.1 (*'Scientists should be the ones who educate the public in basic science'*) proved to be redundant, because some of the reasons coincided with reasons for statement 4.2 (*'All people should be educated in basic science'*). Furthermore, there was no clear distinction between 4.1 and 5.1 (*'Scientists should be the ones who communicate scientific information to the public'*) as well as considerable overlap in the reasons for the 3 statements concerning communication between scientists and society (5.1, 5.2 and 5.3), with the result that they could all be combined into one set of reasons for statement 5.3, eliminating 5.1 and 5.2. Finally, statement 6.6 (*'Scientists are the only ones who can save the world'*) was found to be addressed indirectly in statement 6.3 on the special responsibility of scientists, the reasons given for both being similar. The number of items in the final questionnaire was consequently reduced from 25 to 20.

4. Formulation and evaluation of multiple choice options

For each group of reasons several descriptive statements, based on the answers to the open response questionnaire and vivid statements from the interviews were formulated. This process was repeated until the most important agreements and disagreements were captured, clearly reflecting the language use of the student responses.

Attempts were also made at this stage to have an equal number of reasons in agreement as in disagreement, and to limit the total number of options to between 6 and 8. In cases where there were more responses in agreement or in disagreement, the ratio was approximately 2:1 in favour of the majority.

This selection of reason-statements for each of the 20 questionnaire statements was given to 4 science educators and 2 students for evaluation.

5. Final fixed response questionnaire

The feedback on the evaluation of the reason-statements with respect to clarity, use of language and preferential choice was incorporated into the compilation of the final form of the instrument.

The following example represents the format of each statement and multiple choice options. To facilitate the comparison of the various options for the reader, the key words were printed in bold. The X option at the end of each item made provision for respondents whose views were not reflected in any of the other options.

- 20. Women scientists have a special role to play in science**
- A.** I AGREE with this statement because
Women's scientific knowledge can **benefit family** and household
- B.** I AGREE with this statement because
Women can come up with **entirely different** scientific developments
- C.** I AGREE with this statement because
Women can act as **role models** to other aspiring women scientists
- D.** I AGREE with this statement because
Women are **people oriented**
- E.** I DISAGREE with this statement because
Women are in the **minority in science**
- F.** I DISAGREE with this statement because
There is **no difference between** male and female scientists
- G.** I DISAGREE with this statement because
Science is not about being male or female
- X:** None of the above statements reflects my view, which is
-
-

A total of 12 different versions of the questionnaire was compiled by varying the sequence of the statements, yet keeping statements which addressed similar issues (for example: education) together. The cover page of the open response questionnaire was used. An example of how respondents were expected to circle only one agree or disagree option of their choice was included. The final form of the instrument is contained in Appendix E. In this version the sequence of the statements is the same as for the original dimensions in Table 3.3, with the exception of 2.2, 3.5, 4.1, 5.1 and 5.2 which were eliminated.

3.3.6.3 Respondents

The first and second level practicals in November 2001 provided an opportunity for administering the final questionnaire to a large group of students. Students were addressed during one of their pre-practical talks on the general purpose of the questionnaire and on the value of their input in view of the important role scientists need to play in a developing country such as South Africa. As an incentive for students to answer the questionnaire and to provide their student number for analysis purposes, a book prize was announced. Due to time constraints during the practical sessions, students were given 3 days to return the questionnaire. After 2 days the researcher or a lecturer personally encouraged students at their work stations to complete the questionnaire.

Of the 150 first level students, 63 (42%) answered the questionnaire satisfactorily. The second level practicals were attended by 106 students, of which 41 students (39%) answered the questionnaire satisfactorily. Altogether only 10 questionnaires were unusable and had to be eliminated. In addition there were 6 third year students acting as student demonstrators who volunteered to complete the questionnaire. This latter minority was included into the second year student group for calculation purposes. Table 3.6 shows the distribution of the respondents by race and gender as compared to the classes as a whole and confirms the representivity of the sample.

	African female	African male	White female	White male	Asian female	Asian male	Total
Respondents 1st level	11 17%	12 19%	23 37%	13 21%	4 6%	0 0%	63
Class total 1st level	28 19%	39 26%	45 30%	25 17%	8 5%	5 3%	150
Respondents 2nd + 3rd level	14 30%	20 43%	4 8%	4 8%	1 2%	4 8%	47
Class total 2nd level	30 29%	37 36%	13 12%	12 11%	5 5%	7 7%	104
Respondents all levels	25 23%	32 29%	27 24%	17 15%	5 5%	4 4%	110
Class total all levels	58 23%	76 30%	58 23%	37 14%	13 5%	12 5%	254

	All levels	African	White	Asian
Race	Respondents total	52%	39%	9%
	Class total	53%	37%	10%

	All levels	Female	Male
Gender	Respondents total	52%	48%
	Class total	51%	49%

Table 3.6 Composition by race and gender of respondents and class total for fixed-response questionnaire

3.3.6.4 Data analysis of the multiple choice questionnaire

The VOSTS instrument was designed to investigate high school students' beliefs and views about science, technology and society (Aikenhead *et al.*, 1987). The authors calculated percentage responses for the multiple choice options and described and compared the results qualitatively within the context of the study (Aikenhead, 1987; Fleming, 1987; Ryan, 1987). Methods of statistical analysis performed by subsequent researchers as discussed in Paragraph 3.2.3, do not lend themselves to the investigative nature of the present study and the decision was made to follow the method used by Aikenhead and co-workers.

In selecting relevant data, only single responses to a question were used. All multiple responses were added to Group X which allowed for any other opinion not covered by the available choices. Ten (10) questionnaires were eliminated because respondents had not provided their student numbers and could therefore not be identified, or because more than half the questions had been left unanswered. The percentage total over all respondents, for each option, for each of the 20 questionnaire statements was calculated, tabulated and plotted as barcharts.

The research questions for this study also focus on whether gender and race differences could be detected in the views of students towards the social responsibility of scientists. Consequently a preliminary analysis of the data was done to distinguish the main responses according to race and gender. During this procedure a distinction was also made between 1st level and 2nd + 3rd level students merely because the demographic data on the 2 groups of students was separate. The results revealed tentative trends in some of the responses and thus the need for further exploration. The data was presented to a panel of statisticians for comment (Personal communication with Prof. R. Markham and Dr. S.M. Seeletse of the Department of Statistics, Unisa). A SPSS analysis with calculation of the Cramer's V and Standardized Residuals was recommended to determine whether any meaningful associations existed between chosen responses and race, gender, as well as academic year of study. The analysis was performed by the Department of Computer Services at Unisa.

3.3.6.5 Development of an attitude profile

In their research on students' views on the study of chemistry, Bennett and co-workers (2001) developed an instrument which draws on the methodology of the original VOSTS study. These authors argued that the percentage analysis of responses in the form of barcharts would not provide a comprehensive reflection of students' views and as such could not be used to implement remedial interventions. Consequently Thurstone type scales which are used in attitude inventories were developed for different aspects of attitudes towards the study of Chemistry. The multiple choice options of the fixed response questionnaire were individually scored on a seven point scale by members of a panel to designate degrees of positive or less positive attitudes towards the statement at hand. The scores were then compared and discussed in a group to reach consensus. These final scores were used to calculate mean scores for each student on the basis of chosen responses to

the questionnaire. Students' scores could be correlated with performance in the examinations. In a follow up study, profiles comprising specific sets of attitudes towards various aspects of the study of chemistry were compiled for positive and less positive students (Rollnick, 2001). Possible intervention strategies specifically for students with less positive profiles are suggested.

The present study appeared to lend itself to a similar approach. A scale which could measure science students' positive or negative attitudes towards social responsibility could be used predict and address actions and decision making skills and thereby prepare these students for careers in the scientific world. The two attempts which were made to compile an attitude profile are described below. The following flow diagram (Figure 3.5) gives an overview of the process.

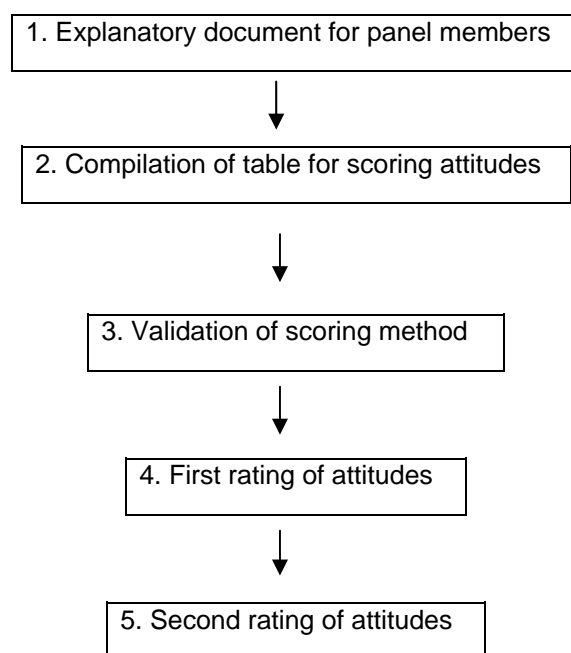


Figure 3.5 Flow diagram for the development of an attitude profile

1. Explanatory document for panel members

A short document (Appendix F) was drawn up with a summary of the background to the instrument, examples of perceived positive and negative attitudes towards the

social responsibility of scientists and an explanation of how values on a scale of 1 to 12 should be assigned to each of the multiple choice options of each question, with 12 being the most positive attitude. A larger scale than the one used by Bennett (2001) was applied in order to obtain a wider spread of attitudes. (Personal communication with Prof. M. Rollnick.)

2. Compilation of table for scoring attitudes

A table was designed to facilitate the scoring procedure by panel members and an example was provided of how the researcher had completed one of the questions. A 'Focus' column was included which could serve to assist in identifying the focus of the argument and direct the rationalisation process. A further column for additional remarks which could be of interest to the researcher was also provided. (See Appendix G.)

3. Validation of scoring method

The research topic strongly relates to value systems which have an ethical and philosophical dimension. It is for this reason that the questionnaire together with the explanatory document and the scoring table was submitted to the Philosophy Department of the University of South Africa for comment.

Feedback on the questionnaire included comments on the format and the formulation of some of the statements and multiple choice options, as well as the need for clearer distinction between the concepts of 'science' and 'knowledge'. With respect to the division of the topics of the questionnaire into the 9 strands, a suggestion was made to include additional aspects of the social responsibility of scientists such as ethics, morality and religion, and to address references to science and law and science and politics more explicitly. A different set of key concepts such as objectivity, falsity, truth, ethics and morality for the formulation of statements was

recommended. Finally valuable reference was made to historical examples in South Africa and World War II.

The researcher felt that at this stage it was not feasible to re-design the questionnaire. Some of the suggested aspects and concepts were also beyond the scope and methodology of this project and could not be included, while other aspects such as religion and politics were addressed more implicitly in the questionnaire in order to avoid preconceptions and limit the range of responses. The feedback on the questionnaire however forms a valuable basis for further research into the topic.

In a short interview some of the problem areas and limitations were explained by the researcher and an agreement was reached that the suggested procedure of developing an attitude profile could be followed. (Personal communication with Prof. M. B. Ramose.)

4. First rating of attitudes

A group of 8 science educators at the University of South Africa was approached to serve as panel members. The research project, the design of the questionnaire and the rating process were explained at an information session and each member was provided with the relevant documentation. A total of 5 responses were returned over a period of 3 weeks.

Respondents did not use the scoring table. They preferred to assign priorities directly next to the option on the questionnaire and thus did not give any indication of the reasons for their choice. Several comments were made on the difficulty, if not impossibility, of assigning scores to views in the multiple choice options. In several instances the same numerical score was assigned to various options or only one item was scored. Respondents also preferred to prioritize the options on a scale of 1 to 5 or 6, rather than assign specific scores from 1 to 12.

The scores of the respondents and of the researcher were tabulated. Values of 1 to 5 or 6 were normalized to values of 1 to 12. The averages per option were calculated, but were of no significance. In order to identify broader and more visual trends, scatter plots of score versus option were drawn for each of the 20 statements. Attempts were made to cluster those options which fell within a small range of scores. Except for clusters separating the agree- and the disagree-options, no further tendencies were apparent. Due to the fact that the results of this rating could not be utilized for developing an attitude profile, no individual or panel discussions as suggested by Bennett (2001) were held. The decision was made to approach a second group of panel members.

5. Second rating of attitudes

The explanatory documentation and questionnaire were sent to a selected group of 5 volunteers engaged in science education and research at the Technikon South Africa, with the specific request to score the options on a scale of 1 to 12. A panel meeting with the researcher was scheduled for a week later, with the objective of comparing scores and reaching agreements in cases where the differences were large.

Not all of the 4 panel members who attended the meeting had received their documents in advance. It was therefore necessary that time was made available for each statement to be studied as it came up for evaluation of the scores. This left less opportunity for in depth discussion. The individual scores were tabulated and compared with those of the researcher during the session. Notes were made of all comments.

Panel members did not allocate scores to more than 3 or 4 options, which they rated according to personal preference rather than the degree of social responsibility. The content of a large number of options was cast into doubt, preferential options were formulated and alternate definitions suggested. No agreement could be reached on scores or scales.

Due to 2 unsuccessful attempts to construct an attitude profile on the model suggested by Bennett (2001), this aspect of the data analysis was discontinued.

3.3.6.6 Conclusion

In Phase 3 the analysed responses from the open response questionnaire were formulated into 6 to 8 agree or disagree options for each question in the multiple choice questionnaire. By comparing responses to questions, the total number of questions could be reduced to 20. The formulated options were submitted to a group of science educators and students for editing and comments. The final multiple choice questionnaire was answered by 120 first, second and third level students. Response percentages were calculated and plotted as barcharts. A statistical SPSS analysis was done to assess differences in race, gender and academic level. The development of an attitude scale reflecting degrees of positivity and negativity towards the social responsibility of scientists was not successful.

3.4 SUMMARY

The in-depth development of a research instrument designed to assess the views of distance education science students on the social responsibility of scientists has been described. The development proceeds via three distinct phases, with each phase based on the views of respondents and each phase providing input for the following. The final fixed response or multiple choice questionnaire contains 20 statements on a variety of aspects of the social responsibility of scientists. The 6 to 8 response options associated with each statement reflect the reasoning offered by respondents in agreement or disagreement with the statement. The results will be presented and analysed in the following chapter.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 THE NATURE OF THE DATA

The fixed response questionnaire contains the diversity of views of South African distance education science students on the social responsibility of scientists. The uniqueness of this instrument lies therein that it reflects the views of students rather than most instruments which assume that the meaning which a researcher attaches to a question item is the same as that of the target group.

During the development of the instrument the main topics, questionnaire items and corresponding reasons were organized according to the broad categories shown in Table 3.3, Chapter 3. After a closer inspection of the literature on social responsibility the grouping of topics under the two main headings of: The Scientific Enterprise and Science, Technology and Society evolved. Within these two headings various sub-headings were discussed in the literature survey (Chapter 2, Figure 2.1). The questionnaire items were subsequently arranged in the same sequence as the topics in the literature survey, with the exception of the topics on the Scientist as Individual and Education. The overall importance of these two topics to this study was highlighted in the analysis of the data by treating the relevant questionnaire items under two separate main headings. Those aspects of social responsibility which were not included in the questionnaire statements are invariably contained in the reasons provided for the statements.

The data are tabulated separately for each statement. The response options (A – F or G or H) which portray the preferred reasons why students agreed or disagreed with the statement are arranged by percentage in descending order. The overall percentage in agreement and disagreement is also included.

Students were expected to select one option only and unusable responses were excluded. Prior to the analysis, 10 unusable questionnaires had been excluded. (See paragraphs 3.3.6.3 and 3.3.6.4). For the 110 usable questionnaires, the effective sample size per statement varied between 105 and 110. There were thus at most 5 responses per statement which were lacking or unusable. The percentages were calculated from the total number of single, unambiguous and relevant responses for each response option. The responses always included the option X into which students could add their own unique reasons if these were not represented among the available options. The sum of the percentages in agreement, disagreement and unique X responses adds up to 100%. The percentage X which varied between 2% and 14% is an indication of the comprehensiveness of the available options. A high percentage of X responses may however also be due to the fact that the questionnaire was developed over an extended period of time and with different target groups who were at different academic levels. The content of these responses was not analysed.

4.2 THE NATURE OF THE ANALYSIS

The questionnaire statements as well as the reasons in agreement or disagreement together compose an integrated picture of the range of students' views on the social responsibility of scientists. These are the prime objectives of the research and also reflect the choice of instrument design. The percentages for each response option reflect the preference of one view above another in the particular group of respondents, but should not deter from the broader picture. As was evident during the interviews it may well be that any one student can have more than one, or even conflicting, opinions. The different views as such can also not be seen as either correct or incorrect. In essence the results portray the spectrum of multiple opinions, attitudes and even concerns, some of which being more important than others. Consequently, the analysis must be seen as mainly qualitative with equal attention given to all reasons. From an educational point of view it may be precisely the secondary reasons and concerns which require explanation and discussion, as for example arguments concerning whistle blowing, financial considerations, or feminist and African perspectives of science.

The results were analysed by this researcher alone. The research situation precluded discussions with other researchers which could have lead to a broader picture. A comparison with other studies was equally not possible as there are no similar studies available nationally or internationally. The results were also not interpreted in terms of a theoretical framework. Such a framework would have to incorporate the philosophy, sociology and ethics of science, which is beyond the scope of this research. In addition, the positions of students are not grounded in fixed philosophical theories. They may even be a combination of different philosophies and religions as well as simplistic, naïve and conflicting world views, values and practical experiences. The interrelationship between beliefs, opinions, attitudes, values and behaviour is close and complex. In the measurement and description of views and attitudes this complexity must be borne in mind. It accounts for ambivalence and conflicting results. As a result, any comparison of the different options within a statement and options between statements was difficult and frequently lead to opposing conclusions. This may also be compounded by the wording, context and available response options of the statements.

The analysis of the data is highlighted by relevant quotations by students. These were extracted mainly from the interviews and to a lesser extent from the open response questionnaire. The quotations were corrected for language and grammar, and were condensed where there was repetition, interruption or re-phrasing of an argument. Reference numbers are included to indicate the interview number and line number in the verbatim interview transcripts, or the table and statement number in the open questionnaire summary. The quotations do not always match the response options absolutely, but nevertheless give an indication of the breadth and the liveliness of the arguments. The commitment, honesty and experience of the respondents are also evident from these.

As mentioned above, the analysis and results of the 20 statements are presented in accordance with the main topics in the literature study, and not as they were grouped during the design of the instrument where the original numbering of the statements was also done. In order to avoid confusion, these numbers were retained throughout. (They are also reflected in the copy of the final fixed response in Appendix D.) This

explains why the analysis of statements does not proceed consecutively. Table 4.1 below gives an overview of the analysis of the 20 statements in the questionnaire, indicating the literature study topics, (original) statement numbers and topics, and the respective paragraph numbers in this chapter.

Main topic and paragraph.	Statement number and paragraph	Statement topic
4.3 The scientific enterprise	4.3.1 Statement 10	Scientific freedom
	4.3.2 Statement 12	Scientists' special responsibility
	4.3.3 Statement 11	Research objectives
	4.3.4 Statement 6	The technological imperative
	4.3.5 Statement 8	Prediction
	4.3.6 Statement 14	Science in Africa
	4.3.7 Statement 17	Women in science
4.4 The scientist as individual	4.4.1 Statement 13	Honesty
	4.4.2 Statement 15	Whistle blowing: duty to inform
	4.4.3 Statement 16	Whistle blowing: personal decision
4.5 Science, technology and society	4.5.1 Statement 9	Moral implications of research
	4.5.2 Statement 20	Collaboration and communication
	4.5.3 Statement 19	Education of the public
	4.5.4 Statement 4	Decisions and implementation
	4.5.5 Statement 5	Monitoring and responsibility
	4.5.6 Statement 7	Consequences of science
4.6 Education	4.6.1 Statement 2	Science-related social issues
	4.6.2 Statement 1	Applied topics
	4.6.3 Statement 3	Value education
	4.6.4 Statement 18	Science students and society

Table 4.1: Overview of analysis of questionnaire statements

4.3 THE SCIENTIFIC ENTERPRISE

In this section the views of students on scientific freedom and the notion of the special responsibility of scientists are presented and analysed. This is followed by aspects of scientific research such as the nature of research objectives, the possibility of research and its applications reaching a stage beyond control, and questions surrounding the prediction of the outcomes of research. Students' positions on the viability of science in Africa and the role of women in science conclude this section.

4.3.1 Statement 10: Scientific freedom

Scientists should be free in their search for knowledge

Details of questionnaire analysis:

	No	Reason	%
Agree 65%	D	Intellectual freedom is a prerequisite for scientists to exercise their social responsibility and avert dangers	25
	B	Mankind always needs to gain a better understanding of man, nature and the universe	17
	A	Freedom is essential for meaningful research	12
	C	This will enable scientists to improve the conditions of mankind	11
Disagree 31%	E	There should be limitations to prevent scientists from infringing on the rights of others	18
	F	Scientists should be aware of their responsibility to society	13
X			4

This statement addresses scientific freedom which is regarded as the foundation for social responsibility.

Approximately 2/3 (65%) of the respondents agreed with this statement and the majority of these (D: 25%) understood that freedom is a prerequisite for responsible action. It is expressed very pertinently by one student as:

“otherwise science will be dead science” (6.1a: 2)

and by another as

“Nothing good can be accomplished when anyone is not free; otherwise lots of mistakes can be made which can result in a disaster in the community and the environment” (6.1a: 7).

The reasons A (12%) and B (17%) underscore the objective of science as the pursuit of knowledge and that freedom is necessary in order to achieve this. For 11% (C) the focus was on the improvement of social conditions. During interviews and in the open response questionnaire this was mainly seen as job creation and the alleviation of poverty and illness, and as such clearly expresses the expectations developing countries place in science. In Statement 11 (paragraph 4.3.3) 61% of the respondents supported the view that scientific research should benefit society.

Two responses, E and F, totalling 31%, disagree that scientists should be free in their search for knowledge. Response E (18%) demands that the right or privilege of scientific freedom be curtailed in order not to infringe on the rights of other citizens. The view of one student was that

“in their quest for knowledge scientists cannot cross certain boundaries, such as infringe upon the rights of individuals or bring cruelty to humans or animals” (6.1a: 14)

while another added

“if there are no legal limitations to, for example, cloning, it could be scary” (6.1a: 16).

Response F (13%) again focused on the needs of society, but here students expressed the opinion that these needs can only be met if scientific freedom makes room for the needs of society. Scientific freedom and simultaneously addressing the needs of society was regarded as not being compatible by these respondents, contrary to those who selected response C.

In summary, students largely recognized the importance of scientific freedom for the practice of science which should focus on creating benefits for society. There was a degree of concern or doubt that scientists will not honour their social commitment and a warning that scientists may act unethically.

4.3.2 Statement 12: Scientists' special responsibility.

As a scientist one has a special responsibility towards society

Details of questionnaire analysis:

	No	Reason	%
Agree 86%	B	Scientists must educate society on the risks and benefits of science and technology	39
	C	Scientists have a special responsibility to use their knowledge to improve the quality of life	37
	A	Scientists have specialized and powerful knowledge	8
	D	Scientists are able to predict the long term effects of scientific and technological innovations	2
Disagree 12%	F	All people have a responsibility towards society	12
	E	Scientists do not have the power to make a difference	0
X			2

This statement reflects the view that the production and implementation of a system of knowledge as powerful as natural science implicitly places a unique responsibility

on its originators and implementors. Although a total of 86% of respondents agreed with this statement, only 8% (A) regarded the specialized and powerful nature of scientific knowledge as the reason of priority.

For the dual majority of 39% (B) and 37% (C) the reason why scientists have a special responsibility again focussed more directly on the needs of society. While C looks at the general improvement of the quality of life for the man in the street, B is more explicit about scientists' responsibility to educate society in the risks and benefits which science offers in their daily lives. While discussing the radiation risks which miners faced underground, a Masters student in Chemistry had the following very strong views:

"There is a lack of consideration and a sense of irresponsibility among scientists. They are the people that know everything about the dangers and the benefits. The people who are working at the operations level know nothing and should be informed before they are exposed to dangerous situations. So, if scientists had some sense of responsibility they would make the environment safe for these people. I wouldn't blame the government. They rely on the scientists and they expect them to be responsible." (3: 4,6)

The view of the only 8% (A) of the respondents who understood the powerful nature of scientific knowledge was expressed by one interviewee as

"Because the scientist knows, his concern must be wider and not only personal". (5: 1, 2)

A further minority (D = 2%) selected the scientists' ability to predict the effects of science as the reason for their special responsibility. This aspect is explored in detail in Statement 8 (Paragraph 4.3.5).

The 12% of responses in disagreement with the statement were all represented by option F. This relatively small number of respondents did not believe that scientists should be shouldered with an extra responsibility towards society and argued that all citizens could equally be expected to fulfill their responsibility towards society.

Reason E was not chosen as an option in the final multiple choice questionnaire although this aspect was clearly addressed during the interviews as well as in the

open response questionnaire. During a discussion on the lack of intervention by scientists in the Aids debate, one student had the following to say:

“Scientists have powerful knowledge but they are not the powerful people to get it out”.

(8: 17)

The difference in target groups which participated during the various stages of the development of the final questionnaire may account for this discrepancy.

In summary, the power of scientific knowledge as an important reason for scientists' special responsibility towards society was mainly seen in terms of the application of science and technology towards improvement of quality of life and the ability to educate society.

4.3.3 Statement 11: Research objectives

In their research scientists must be motivated by the needs of society

Details of questionnaire analysis:

	No	Reason	%
Agree 65%	A	Scientific research should improve life	61
	B	Scientists are nurtured and supported by society	4
Disagree 25%	C	Society wants quick fix answers which are not always useful	7
	D	Scientists must decide for themselves how to focus their powerful knowledge	7
	E	The purpose of scientific research is to investigate the mysteries of nature	7
	F	Research depends on who provides the funding	4
X			9

This statement specifies the social objective of scientific research explicitly. A total of 65% agreed to this statement, while 25% disagreed.

There were only 2 options in agreement of the statement. The first one, A, stating the improvement of life, obtained the major response of 61%. One student explained this as follows in terms of progress:

“The reason why we are where we are is because the work scientists did. Scientists try to make our lives better by gaining more knowledge”. (3: 19)

This response referring to the improvement of life is also present in the previous Statements 10 and 12, where they received 11% (C) and 37% (C), respectively, of the responses. The target group clearly regarded this as an important aspect of scientists' social responsibility. The second reason, B, which states that scientific research should be motivated by the needs of society because society in turn supports scientists, only received the remaining 4% of the positive responses. Although the support of society is indispensable for scientists, students did not appear to be adequately aware of this important mutual relationship.

Three (C, D and E) of the four negative options to the statement received an equal number of responses, i.e. 7% each. The options however vary widely in the type of reason. Option C, stating that “society wants quick fix answers” represents a negative view of society. Referring back to the open response questionnaire, this view must be interpreted mainly as the prevalence of consumerism as well as a disinterest in science which may be based on fear or distrust of science. Option D regards scientific freedom as a priority for deciding what needs to be investigated and may be seen to relate closely to the views expressed in Statement 10 (Paragraph 4.3.1). Option E states more clearly that scientific research should solve the mysteries of nature which was also expressed by 17% in Statement 10. Thus for this group of respondents basic scientific research is a higher priority than the needs of society. Both these views are reminiscent of the opinion of a Physics student who was concerned about limitations on research in genetics and genetic engineering:

“This is the same as in the Dark Ages when people like Galileo said the earth revolves around the sun and the people called him blasphemous...It is the same ignorance that was exhibited a couple of hundred years ago”. (3: 8)

The last option, F, with 4% of the responses indicates that neither purely scientific objectives nor the needs of society are important where funding dictates what is required. Students were generally well aware of the power of money in the scientific enterprise, but regarded other aspects as having a greater priority.

In summary, the responsibility to improve the quality of life of society was regarded as the outstanding objective of scientific research, while there were concerns that scientific freedom to pursue pure and basic research could be limited.

4.3.4 Statement 6: The technological imperative.

We can rely on scientists that they will not let their research get out of control

Details of questionnaire analysis:

	No	Reason	%
Agree 21%	B	Scientists can be trusted to work in the interest of the public	11
	A	Scientists are in possession of all the relevant knowledge to regulate themselves	10
Disagree 72%	C	All scientists should adhere to formal ethical codes of practice	25
	F	Money often determines what decisions are made	17
	E	This would be a personal choice and everyone has individual values	13
	G	Scientists have to take risks in order to make progress	13
	D	The public should monitor what scientists do	4
X			7

This statement reflects the technological imperative which proposes that the effects of science and technology can reach a stage where they are beyond human control. It also indicates that in their search for knowledge for its own sake scientists may not be inclined to interrupt this search when the consequences may be doubtful. While the previous statements received 65 - 86% positive responses, this statement received 72% negative responses. One student articulated this distrust in scientists by stating:

"The scientist left alone is dangerous, because he can come up with anything and he forgets about ethics". (8.2: 3, 5)

The 21% of students who agreed that society can rely on scientists not to let their research get out of hand were equally divided among the available two options, i.e. that scientists are the ones who have the expertise to regulate and monitor research (A = 10%), and the fact that scientists are working in the interest of society will motivate them not to go beyond a point where there are unknown factors which could be harmful (B: 11%). This trust in scientists and the scientific process was articulated during a discussion on poisoned water as:

“Scientists know what they are doing and have not lost control”. (6.2: 17)

The majority (C: 25%) of the 72% of respondents who disagreed with the statement was in favour of ethical codes of practice to control or monitor scientific research. Option D (4%) complements this by stating that the public should monitor scientists. A further 17% (F) felt that there was the possibility that the financing of research programmes could drive research into unwanted directions. According to option E (13%) the choice to pursue a dangerous or unknown course of action was seen to lie in the hands of the individual and thus depended on personal values. Option G (13%), on the other hand, contends that science has to break the barriers of the unknown and even take risks in order to progress. It was expressed as:

“The helpful and the harmful go together”. (5.3: 17, 18)

Consequently the nature of science itself is seen as the cause that it can get out of control, and the morality of the individual scientist is no guarantee for preventing it.

In summary, the large negative sentiment towards the statement reveals doubt about the integrity and / or social concern of scientists. The reasons accompanying this statement show that students were aware of the complex questions of where to draw the line between calculated risk and dilemma and how to monitor the scientific process. The main solution which was offered was that scientists should be monitored either by the public or by an ethical code.

4.3.5 Statement 8: Prediction

Scientists should predict the long term effects of scientific and technological developments

Details of questionnaire analysis:

	No	Reason	%
Agree 81%	C	Scientists should not only use their knowledge to make discoveries but also to predict the long term effects of such discoveries	43
	A	Possible danger or harm could then be prevented	30
	B	Long term effects can be approximated	8
Disagree 16%	E	Scientific findings can change	6
	D	Scientific knowledge is not advanced enough to predict long term effects	5
	F	Nature is unpredictable	5
X			3

This statement is related to the previous one in that it indirectly addresses the contentious issue of risks and the prediction thereof. An 81% majority of students expressed the need for prediction, while only 16% believed that this was not possible within the existing scientific knowledge base.

The majority of positive respondents (C: 43%) argued that in the same manner that scientists used their knowledge and scientific techniques to pursue research into unknown aspects of nature, they could and should also employ this expertise in determining the long term consequences of their research. Option B which was selected by only 8% of the respondents is more specific about the use of scientific knowledge, implying that the expertise already exists which can enable scientists to approximate or project the long term effects of science and technology. The confidence in the ability of science to predict consequences was stated as:

“Prediction is possible to a certain extent because that is what we learn”. (5.3: 10)

The second most important reason (A: 30%) was the prevention of danger, thus portraying the importance of social responsibility above that of scientific progress.

The options selected by the 16% of respondents who disagreed with the statement were equally represented (D: 5%; E: 6%; F: 5%). They all refer to perceived characteristics of science (D and E) and of nature (F). Option D expresses doubt about the present potential of scientific knowledge to forecast consequences of science and technology, while option E refers to the tentative nature of science. Looking at the complexity of nature and of humanity, the respondents who selected option F contended that they are unpredictable and that science cannot possibly trace all variables in order to effectively forecast long term impacts.

In summary, a large majority confirmed scientists' responsibility to predict the effects of scientific and technological developments. The respondents' trust in the power of scientific knowledge and in its ability to prevent negative effects predominated. The contentious arguments in the literature whether or not prediction is possible were well represented in the reasons in agreement and disagreement of the statement.

4.3.6 Statement 14: Science in Africa

New science can come out of Africa

Details of questionnaire analysis:

	No	Reason	%
Agree 62%	A	There is a great potential for innovations/ new ideas	41
	B	Africa has come up with excellent scientific work already	21
Disagree 27%	F	People leave Africa because there are better possibilities elsewhere	9
	E	The resources are limited	6
	G	Scientific knowledge is internationally shared	5
	D	More people need to be interested in science	4
	C	We first need scientific role models on the continent	3
X			11

This question was included due to a special interest of the researcher in the topic. The statement in its existing form was not formulated from the interviews. Interviewees however referred to the negative and positive aspects during the interviews. The majority of students (62%) agreed that “new science can come out of Africa”, while 27% disagreed.

Option A which expresses the potential for scientific innovations and new ideas to emerge from the African continent received the largest percentage (41%) of the responses. To this may be added one student’s concern during the interviews that:

“Research funding should be directed to finding solutions specific to South African problems, because they can differ from those of other countries”. (3.4: 15)

A further 21% (B) of the students were aware of the valuable scientific research that had already been accomplished in the past. In the open response questionnaire

students referred both to indigenous knowledge such as the healing properties of herbs as well as Western scientific achievements such as the first heart transplant.

At this juncture an analysis of the ratios with respect to race for the two majority responses (A and B) to this statement is of interest. For the group of respondents to the fixed response questionnaire the ratio of Africans : Whites : Coloureds and Indians was 49% : 42% : 9%. (Indians and Coloureds were classified separately from black Africans because during the interviews the researcher observed that the attitudes and views of this group often differed from that of black Africans.) For option A in this statement, the ratio of responses was 43% : 47% : 9% respectively, while for option B the ratio changed significantly to 76% : 14% : 10% respectively. These results may indicate that, independent of race, students were confident that there was great potential for new ideas in Africa. Contrary to this, there appears to be a racial bias among students who preferred option B, meaning that considerably more Africans believed that Africa has produced excellent scientific work in the past. Caution must however be exercised in attaching too much significance to this result, because of the 105 usable responses to this statement only 21% selected option B, which may make the above mentioned ratio statistically not significant. This was also confirmed by members of the Department of Statistics.

In spite of the majority of positive responses to the topic, the negative responses afford an insight into the problems encountered by scientists in Africa. The wealth of responses to the open response questionnaire necessitated that five negative options were formulated, as a result of which the response percentage for each option was low. Option F (9%) which addresses the brain drain received the largest number of responses. Option E (6%) refers to the limited resources which constrain scientific progress, while D (4%) points out the low level of interest in science which causes a lack of public engagement in science as well as decreasing numbers of young people entering scientific careers. The need for African role models in science was of the lowest priority (C: 3%). In the experience of this researcher it is however highly important for science students to receive not only tuition in scientific subject matter, but advice on the internal ethos of scientific communities and institutions, especially because African students do not come from backgrounds where such

social intelligence has been established over generations. This was poignantly expressed by a Master's student without any prompting early during the interviews:

"As scientists in South Africa we don't trust ourselves ... and we believe that people who come from outside are better than us. -- At the moment we don't have role models."
(2:10)

A fellow student further explained this by referring to economic problems:

"We might have potential scientists here in South Africa or even the wider part of Africa who could be Nobel Prize winners ... but because of the economy here in Africa that is something far beyond our reach." (2:17)

Option G (5%) represents the only reason which directly denies the possibility of the emergence of innovative scientific knowledge from the African continent. This argument refers to the predominance and international nature of Western science which is seen by some to be the only correct and relevant one. The thoughts of one student deserve mention because they extend the argument unexpectedly:

"Science should not be changed to accommodate the understanding of the man in the street by means of traditional explanations. Science in Africa must not be inferior and should be able to compete globally and standards should not drop." (7.4: 11)

In summary, an approximately two-thirds majority confirmed that there was a possibility of new scientific developments originating in the African context, their conviction being based in the potential of the people of the continent and their past achievements. This conviction is however tempered by a clear awareness of problems such as resources and the lack of interest and role models facing scientific development in Africa.

4.3.7 Statement 17: Women in science

Women scientists have a special role to play in science

Details of questionnaire analysis:

	No	Reason	%
Agree 38%	C	Women can act as role models to other aspiring women scientists	13
	A	Women's scientific knowledge can benefit family and household	10
	B	Women can come up with entirely different scientific developments	10
	D	Women are people oriented	5
Disagree 48%	G	Science is not about being male or female	36
	F	There is no difference between male and female scientists	12
	E	Women are in the minority in science	0
X			14

This statement looks at the complex issues surrounding the role of women in science. Similar to the previous statement on science in Africa this matter was not addressed explicitly by the interviewees. The formulation of the statement for comments in the open response questionnaire was prompted by observations made by the researcher during the interviews, which showed that female students had a large degree of information, social commitment and dedication to their role as scientists. The wide range of responses offered in the open response questionnaire by male and female students alike was surprising in that it covered all the main topics in feminist literature. The positive (38%) and negative (48%) responses to this statement are in a ratio of approximately 4:5 thus indicating a slightly negative predominance.

An approximately equal number of responses was given to the first 3 positive options (A: 10%; B: 10% and C: 13%) while the last positive option (D) received 5%. Options A and D address the traditional role of women. Option A (10%) refers to the importance of women as homemakers and the fact that scientific knowledge about health, diet, risks and toxins can be beneficial in family care and the running of a household. Option D (5%) looks at the priority women attach to the welfare of people and in so doing they may succeed in humanizing science which has often been criticized as being too factual. For example:

“Perhaps a woman’s touch will help solve some of today’s scientific problems!” (8.1a: 7)

“This could be an advantage because they are more socially responsible and have better standpoints on moral and environmental issues”. (8.1a: 14, 15)

Options B and C pertain more directly to the practice of science. Option B (10%) acknowledges the important argument in feminist literature that female scientists can add new insights to male dominated Western science. One student was well aware that:

“Women can often have a different perspective and way of looking at something”. (8.1a: 6)

Option C (13%) which addresses the need for female scientists to act as role models to aspiring female scientists received the highest number of positive responses. This was clearly explained as follows:

“The number of women scientists is increasing and this is very important scientifically, socially and economically. This can boost the morale of other women to join the scientific environment since there was the idea that science is for males”. (8.1a: 8)

A larger percentage of respondents preferred the negative over the positive options, thus disagreeing with the statement that women have a special role to play in science. The overwhelming reason (G: 36%) which was offered was that sexist issues were irrelevant in the practice of science, which is about the search for knowledge. Option F (12%) corroborates this by referring to gender equality. In the context of this investigation male and female students regarded themselves as equals in their scientific aspirations. For them it was science that mattered. The

opinions provided in the open response questionnaire already eloquently described the fact that female students did not see themselves as disadvantaged or marginalized. Male and female students regarded themselves as equals and the pursuit of science was the predominant goal:

“The question of gender does not arise. In an envisaged non-sexist South African society women like men are just human beings with equal roles to play in any new groundbreaking activities”. (8.1a: 21, 27)

Although several respondents to the open questionnaire pointed out the minority status of women, the fact that none of the respondents in the fixed response questionnaire opted for reason E further supports the argument of gender equality and the focus on the pursuit of scientific knowledge.

As for the previous statement 14, an analysis was done by gender and race for the predominant response G. While the overall female : male ratio of the group of participants was 50% : 50%, the ratio for option G was slightly in favour of female respondents at 57% : 43%. This can be interpreted as female science students being less concerned about gender based biases than their male counterparts. With respect to race, the total African : White : Coloured plus Indian group ratio of 51% : 41% : 9% was changed to 40% : 49% : 11% for option G. This can indicate a slight predominance among White, Coloured and Indian science students in favour of non-sexism in science. As in the previous paragraph about science in Africa, it must however be remembered that the total number of respondents selecting option G was only 35, and consequently the result may not be statistically significant. In future such trends could however be explored further.

In summary, the results of this statement are unexpected in that current science education literature points to the under-representation of female science students and differences in their fields of interest and achievement. Contrary to most statements which received a clear majority of over 70% in favour of one response option, the 4/5 ratio in agreement to disagreement appears to indicate a certain degree of ambivalence about the role of women in science. The majority of respondents however did not see the role of women in science as special and/ or

different due to factors such as discrimination and differing fields of interest. The predominant reasons which were offered were based on gender equality, which is further corroborated by the observations of the researcher during the interviews as well as in her professional capacity during laboratory work and lecturing. The results thus appear to paint a positive picture of the role of female scientists, but may need to be limited to the distance education setting where students are generally more mature and experienced. There may also be a lack of awareness and empowerment about the potential which feminist perspectives can offer to science.

4.4 SCIENTIST AS INDIVIDUAL

The following 3 statements focus mainly on the personal role of individual scientists and the choices they can make to be socially responsible.

4.4.1 Statement 13: Honesty

Scientists should always make honest decisions in their work

Details of questionnaire analysis:

	No	Reason	%
Agree 80%	A	Honesty and integrity are necessary for all of us at all times	37
	B	When scientists are dishonest, the lives of innocent people can be affected	36
	C	Otherwise people would lose their confidence in science	7
Disagree 15%	D	Scientists are just normal people who have weaknesses and make mistakes in the same way as everyone else	7
	F	Scientists are only more truthful in their work because other scientists might try to verify their findings	7
	E	Honesty forms part of scientific practice	1
X			4

Personal honesty and objectivity are prerequisites for scientific observation and reporting and form the basis of the trustworthiness of the scientific process. Eighty percent of the respondents placed a high value on scientists' making honest choices in their work while 15% offered some reservations.

The largest percentage in favour of honesty (A: 37%) argued that honesty is required of all individuals, thus not regarding truthfulness for scientists anymore important than for non-scientists. Option B on the other hand received a comparable number of responses (36%), thus confirming that the consequences of dishonest practices in science can be more far reaching and damaging than dishonest actions by non-scientists. This choice indicates an awareness of the power of scientific knowledge and the potential for benefit as well as harm. In connection with the falsification of data one student argued:

"An honest choice must be made in advance, because you can't manipulate people. If you need to manipulate people, rather don't do research". (5.5: 12)

And another student added:

"If the wrong choice has been made in the beginning it is difficult to take responsibility if there are adverse effects". (5.5: 13)

Although option C only received 7% of the positive responses it points out the importance of public trust in science which could be lost if scientists are found to be dishonest or biased.

Only 15% of the respondents did not agree that scientists specifically should make honest choices in their work. Seven percent (D) contended that scientists were no different to any other person in making mistakes, or being allowed to make mistakes, while another 7% (F) argued that greater truthfulness was only achieved by virtue of the peer review system. Option E with only 1% of the responses confirms the trust in the scientific ethos which is aimed at regulating the scientific process and excluding personal weaknesses.

In summary, being the scientists of the future students placed a high premium on honesty and integrity in their scientific work. Although they argued that these values are required of all persons, they were equally aware of the special importance of such values to scientists where dishonest scientific work can have the potential to harm fellow citizens.

4.4.2 Statement 15: Whistle blowing: duty to inform

Scientists should inform the public when there is a possible danger from scientific practices

Details of questionnaire analysis:

	No	Reason	%
Agree 87%	B	People have a right to know what affects them in order to take the necessary action	50
	A	It is important for the safety of the public	30
	C	It is the right thing to do	7
Disagree 5%	E	Scientists should first inform their employer before going public	3
	D	The public could start to panic	2
	F	Scientists should first consult the law	0
X			8

The following two statements address whistle blowing which is an important aspect of scientists' social responsibility. The statements were circumscribed so as not to include the term "whistle blowing" in order to prevent subjective responses. Statement 15 asks whether it is in fact the duty of scientists to alert the public to potential danger or harmful effects of science and technology. Statement 16 extends the argument by questioning whether it is a matter of individual decision making which in essence is based on personal values and convictions.

For statement 15 a total of 87% of the respondents confirmed that scientists should inform the public of possible dangers arising from scientific and/ or technological practices, whereas only 5% disagreed with this. The main reason (B: 50%) in favour of the statement was that the public had a right to know in order to undertake whatever steps were necessary for their own protection, thus placing the responsibility to undertake action against harmful effects in the public domain. Option A which stated that it was the scientists' duty to consider public safety received another 30% of the responses. During a conversation on the dissemination of scientific facts about the drugs used in the treatment of AIDS the following transpired:

"Scientists always take the backseat and pretend they are not involved. In the case of AZT scientists who know the real issues regarding toxicity and cost don't come out. They should forget about money and jobs and become more involved and speak out. It's crucial to everybody's life". (8.4: 23, 24, 25)

The third reason (C: 7%) in agreement with the statement refers to personal moral values which would cause a scientist do what is right for the greater good. This in effect answers Statement 16 which appeals to individual morality.

Of the three options (D, E, F) providing reasons for disagreeing with the statement, only D and E received 2% and 3% of the responses respectively. Option D states that scientists should not blow the whistle in order to prevent public panic and option E prefers consultation with the employer. Option F suggesting that scientists should rather seek legal information or protection was not selected by the respondents to the multiple choice questionnaire, although it was a relevant reason provided in the open response questionnaire. This option is also expressed in the conversation among three students which is included in the analysis of the following statement (Paragraph 4.4.3).

In summary, except for a minority of 5%, students were fully committed to their responsibility as scientists to inform the public of potential dangers. It was argued that not only did the public have a right to know but that public safety was paramount.

4.4.3 Statement 16: Whistle blowing: personal decision

A scientist is responsible in his/ her individual capacity to alert the public to any possible dangers resulting from scientific activity in his/ her company

Details of questionnaire analysis:

	No	Reason	%
Agree 79%	B	The safety of the public comes first	30
	A	It is a moral duty	27
	C	Companies often do not address dangerous situations	19
	D	Scientists must protect themselves from legal action against themselves	3
Disagree 12%	E	The scientist should adhere to company policy	5
	F	Some facts must remain confidential	4
	G	The scientist could be victimized by the employer	3
X			9

This statement which professes that it is a scientist's personal responsibility to alert the public about potential dangers was confirmed by 79% of the respondents. It therefore expects a scientist to make a personal choice in order to protect uninformed citizens. The percentage positive responses is slightly lower than the 87% who reacted positively to the previous statement. One could speculate that the reason for this could be that some respondents retracted their commitment to blow the whistle on realizing that the decision to do so is usually an individual one with personal consequences. It is precisely for this reason that two statements on whistle blowing were included into the questionnaire.

The reasons which received the largest number of responses were A and B, with A at 27% pointing out that it was a scientist's moral duty to blow the whistle, and B at 30% putting public safety first. These two options reflect the tension between morality and duty. Option C (19%) addresses the fact that companies often do not publicize potentially hazardous situations and that it is therefore a scientist's duty to bring the facts to the attention of the public. A further small percentage of the responses (D: 3%) opted for the legal aspects of whistle blowing, indicating that scientists should rather blow the whistle than face legal action themselves for not doing so.

The 12% of respondents who argued that the scientist as lone individual should not be responsible for alerting the public of possible dangers is slightly higher than the total of 5% disagreeing with the previous statement 15 which asked whether or not scientists had the duty to alert the public. The 3 negative options to statement 16 each received 5% or less of the responses. Option E (5%) referred to loyalty and adherence to company policy. Option F (4%) stating that some facts should remain confidential is similar to option D in statement 15 which opted for the prevention of public panic. The last option G (3%) warned of possible victimization of the whistleblower for exposing the employer.

The following exchange of opinions by three participants (A, B, C) and this interviewer-researcher (I) during one of the interviews highlights the conflicting aspects of whistle blowing. It also reveals the sense of commitment and honesty portrayed by the students. The researcher (I) sketched a scenario where a scientist had detected that faulty rubber was used in the manufacture of tyres. The conversation then proceeded as follows:

- I: What would you do if you see things are going wrong?
C: I cannot afford to lose my job telling people that these things are not right...But, on the other hand, this can affect one of my family members.
I: Ja
B: So, you would keep quiet?
C: I think I'll keep quiet and warn my family members.
B: I think you can go to one of your advisors.

Later in the conversation B and A (the only female student in the group) had the following to add:

- B: I believe it depends on the individual, how he values life and his job.
A: You can tell the lawyer. If they then kill you, your lawyer knows. But (at least only) you die instead of hundred people. (1: 23)

In summary, respondents felt overwhelmingly responsible to act in a personal capacity when the need for whistle blowing arises. They argued that it was a moral duty and that public safety came before personal benefits or company policy.

4.5 SCIENCE, TECHNOLOGY AND SOCIETY

The following 6 statements address the relationship between science, technology and society. The statements progress from the inclusion of societal values, collaboration, communication and basic scientific literacy to decision making, implementation and consequences.

4.5.1 Statement 9: Moral implications of research

Scientists must consider the moral implications of their research

Details of questionnaire analysis:

	No	Reason	%
Agree 73%	A	Science and technology impact on people's lives and therefore morality and scientific knowledge cannot be kept separate	57
	B	Scientists have the knowledge to determine the consequences of their actions	16
Disagree 22%	C	Society determines how scientific discoveries will be used or abused	8
	G	There should be general codes of practice for all scientists	5
	F	There are always individual opinions on what is right or wrong	4
	E	Funding agencies and commercial interests determine what research is done and how it is implemented	3
	D	Scientific knowledge is neutral and therefore socially and morally value-free	2
X			5

While science is seen as objective and value free, it is precisely the concerns and moral values of society that have to be considered if scientists want to be socially responsible. This consideration therefore forms the foundation of interactions with society and the implementation of innovations. A total of 73% of the students agreed with this statement, while 22% disagreed.

The first positive option (A) which expresses the inseparability of scientific knowledge and social values when considering the impact of science and technology was acknowledged by 57% of the students in the target group. During a discussion

on the relocation of communities in order to build a dam or a power station, one student put this simply as:

“Wants, needs and feelings of people must be accommodated. You have to know what this place means to me before you are going to remove me.” (3.5: 23)

The second positive option (B) which states that scientific knowledge enables scientists to determine consequences and that this in itself enables them to act morally received another 16%. This argument appears to negate consultations between scientists and the public.

With a total of only 22%, the five negative options each received a relatively small percentage of the responses. Option C with the largest percentage (8%) placed the responsibility for the use or abuse of science onto society, thus indicating that the moral choices do not lie with science but rather with society. Option D with the lowest response rate of 2% reiterates this from the point of view of science being neutral and value free and thus unable to make pronouncements on moral issues. As with previous statements, a small percentage of respondents attached importance to the determining influence of funding agencies (E: 3%). Another group indicated that moral values differ from individual to individual and that it is therefore not feasible to argue that scientists should consider the moral implications of science. Possibly this dilemma could be solved by option G (5%) which called for codes of practice to regulate scientific activity.

In summary, although a clear majority of respondents realized the existence of value based implications of scientific research and that as such science was not value free, this awareness was lower than for whistle blowing. The reason for this may be that students have little or no experience or knowledge in evaluating conflicts on an ethical basis. This explanation is supported by students' clear desire to be educated in “values, attitudes and controversies related to science and society and the environment” as evident in Statement 3 (Paragraph 4.6.3).

4.5.2 Statement 20: Collaboration and communication

There should be better collaboration between scientists and the community

Details of questionnaire analysis:

	No	Reason	%
Agree 88%	A	Scientists could solve many problems in consultation with the communities	32
	D	The technical and scientific decisions by scientists should be balanced by social and ethical issues	21
	C	Scientists can convey a balanced and objective perspective on scientific development and its consequences	16
	B	The community has a right to know what scientists are doing	11
	E	Society will be more interested in science and supportive of science	8
Disagree 5%	F	The public will not understand the scientific facts correctly	3
	G	People who have better communication skills than scientists should liaise between scientists and the community	2
	H	Scientists have the responsibility of liaising and communicating with other scientists only	0
X			7

This statement which addresses collaboration also, and importantly, refers to communication between scientists and communities. It received a high positive score of 88%. Only 5% of the respondents favoured negative arguments.

Option A with 32% of the responses addresses the advantage of collaborative problem solving among scientists and communities. This was explained as follows:

“Not only the scientist, but all have to work together to find solutions to new developments”. (5.3: 17)

Option D with the second highest positive score (21%) focuses on the input which society can make by balancing scientific preferences with value based considerations, when, for example, decisions need to be made on scientific or technological projects. This was articulated as:

“You get someone who does not know about science but has beliefs. There are different opinions. If you have pressure from other groups we won’t fluctuate very much from the ideal”. (8.2: 5)

Option C (16%) focussed on the important contributions which scientists can make by communicating scientific information in a balanced and objective way. Option B with 11% was more assertive of the rights of communities to be informed, which was formulated during the interviews as follows:

“When scientists discover things, even if they are dangerous, we should know about them, even if it means that a lot of people are losing jobs.” (4.2: 6)

A relatively small percentage (E: 8%) of respondents recognized the view that the level of interest for and support of science among the general public would be improved if there was collaboration between scientists and the general public.

The three negative options, totalling only 5% of the responses, address the inability of the public to understand science (F: 3%) and, on the other hand, the inability of scientists to communicate intelligibly (G: 2%). Option H which contends that scientists are only expected to communicate among themselves received no responses in the multiple choice questionnaire.

Options F and G, although receiving a small number of responses in the fixed response questionnaire, were discussed extensively during the interviews. Students were concerned about the low level of scientific literacy among the population. They indicated that this was the cause for harmful practices and pollution, and also that:

“The public is misled by semi-scientific facts for marketing purposes”. (6.3: 19)

Students further contended that the communication of scientific facts about Aids by the scientists themselves would contribute to its containment:

“The message about Aids should be spread by scientists, because they have the details. The message fails if details are not given by scientists. Just to say: ‘Aids kills’ is not enough.” (4.5: 17)

But scientists’ responsibility extended beyond this. They should also

“Communicate positive and interesting facts, and not only negative ones, about science”. (5.7: 20)

This concern was also one of the reasons which induced African students to serve their communities by teaching primary and secondary level learners as well as adults. Statement 18 investigates this concern in more detail. Scientists’ inability as well as unwillingness to communicate with the public was also frequently criticized during the interviews:

“Scientists don’t have time and they also don’t know how to talk to people. They are always like nerds”. (5.7: 21)

On the other hand, the prevalent opinion was that journalists and the media in general failed to present an accurate picture of science and that they did not have the benefit of the people in mind:

“Journalists cannot be relied to inform the public, they are not worried about looking after people”. (5.7: 21)

“Journalists are not helpful because they don’t understand how everything fits together”. (8.4: 25)

In summary, the need for collaboration between scientists and the public and the concurrent need for communication was supported by one of the largest majority of

responses to the questionnaire. Consultation between scientists and society was seen as essential to the solution of problems thus achieving a working compromise between scientific and social issues and concerns. As is also evident from the verbatim excerpts from the group interviews, the problem of communication between scientists and society and the public understanding of science is such a multi-faceted topic that it was not adequately captured in this statement.

4.5.3 Statement 19: Education of the public

All people should be educated in basic science

Details of questionnaire analysis:

	No	Reason	%
Agree 83%	A	Almost everything revolves around science	36
	B	A scientifically educated public can make better choices regarding the use of science and technology	36
	D	The public will understand that science and technology do not have all the answers	7
	C	It will enable people to fulfil their roles in society more effectively	4
Disagree 12%	E	People should be able to choose what they want to learn	9
	F	Not everyone has the ability to understand science	3
X			4

This statement refers to making scientific knowledge available to the people through the educational sector, but also by means of public information campaigns and basic adult scientific literacy training. It however also implicitly refers to the elitist view of the exclusiveness of science which tends to alienate non-scientists from science.

The overall agreement of 83% to this statement reflects the degree of importance which students attached to the acquisition of basic scientific knowledge by the general public. Options A and B were regarded as equally important, each receiving 36% of the responses. Option A addresses the prevalence of science in modern life and thus the need to be knowledgeable about it. Option B looks at the possibility of improving public participation in scientific decision making by a scientifically literate public. A student described this view as follows:

“People should be educated enough to make their own choices. With sufficient knowledge they will be aware of the benefits and after-effects and able to weigh them up”. (3.5: 28)

Options C and D were seen as less important. Option D (7%) expresses the necessity of including social concerns and values in decision making. Option C (4%) in turn echoes option B that scientific literacy can enhance the role people play in society.

The 12% of negative responses illustrate the beliefs that not all people would have an interest in science and could thus not be expected to study it (E: 9%), or that not all persons have the mental capacity to understand science (F: 3%). One student argued that

“It may not be possible to educate the public”. (6.3: 20)

Other students however realized that scientific literacy of the public could be improved by explaining scientific facts in everyday language:

“The public does not always understand. Nothing is in laymen’s terms, so they choose not to hear.” (6.3: 22)

In summary, the concern and commitment which students already displayed during the interviews for educating their communities in the basic facts and principles of science, was confirmed by the majority responses to the statement. Students not only pointed out the importance of science in modern life, but were also aware that adequate information would enable citizens to exercise their democratic right in

decision making. As for the previous statement, the researcher feels that the wide and important field of public communication and public understanding of science could not be adequately explored by the choice of reasons.

4.5.4 Statement 4: Decisions and implementation

It should be left to scientists to decide on the implementation of their scientific discoveries.

Details of questionnaire analysis:

	No	Reason	%
Agree 23%	B	Implementation of scientific discoveries by non-scientists may have harmful consequences	14
	A	Scientists understand their discoveries best	9
Disagree 73%	C	Other bodies such as government, financial controllers, ethics committees and representatives of the public should be consulted	38
	D	If decisions are based on scientific facts only, the environment and social impacts might be ignored	23
	E	Non-scientists could come up with innovative applications of scientific discoveries	6
	F	Society will only support scientists if the values and concerns of society are addressed	6
X			4

The theme of this statement is whether decisions to implement scientific innovations should be reserved for the scientists who invented them. Only 23% of the respondents favoured sole decision making by scientists while 73% were in favour of participative decision making for a number of different reasons.

The reasons for favouring sole decision making by scientists were that scientists knew the relevant facts about their discoveries and could best interpret them (A: 9%) and that unscientific decisions could have harmful consequences (B: 14%). One

student tried to compromise by arguing that scientists should at least have the final say:

“The people need to have a choice in what is happening, but if the experts have a point the public must accept what they say.” (3.5: 22)

Of the 73% of the respondents who did not favour sole decision making by scientists, the majority (C: 38%) preferred participative processes in which government, financial advisors, experts who could address social and ethical aspects, and members of the public such as community leaders should be included. A further 23% (D) were more concerned with the consequences of unilateral decisions which may not consider environmental and social impacts. Option E (6%) indicates the belief that the application of scientific knowledge should not be reserved for scientists, as non-scientists can contribute in innovative ways. This was expressed by one student as follows:

“The public’s way of thinking is different to that of a scientist, and it is a good thing. Not everyone can be a scientist and it is good that there are non-scientists, because they can bring in other aspects”. (5.7: 23)

The last option (D: 6%) which disagrees with decision making by scientists alone looks at the much needed support by society for the scientific enterprise and that such support will only continue if society can add its values and concerns to the overall picture.

There was a degree of disillusionment among the interviewees which is not apparent in the questionnaire results. A discussion among students A, B and C on foreign financing of a dam and government decisions revealed the following opinions:

- C: There should be a group of scientists who should make scientific conclusions. The government will have to side with the US government because they need the finance. They will have to adhere to demands of the US even if it is not right.
- B: Although money talks, I believe you can’t ignore the people who are involved.
- A: It is important to hear what people have got to say, but the government will build the dam. They will just ignore it, they just do what they want. (1: 15, 23)

The impression which students have of the disempowerment of scientists and the public alike is evident.

In summary, this statement expressing the prerogative of scientists to decide on how scientific discoveries should be implemented, received a large negative response. Students believed that participative decision making was imperative so that societal and environmental concerns could be addressed.

4.5.5 Statement 5: Monitoring and responsibility

Scientists are not responsible for whatever use is made of their discoveries by industry

Details of questionnaire analysis:

	No	Reason	%
Agree 44%	A	Scientists cannot control how scientific information is used by industry, the military or anyone else	21
	B	The people who implement scientific discoveries should be responsible for the risks involved	13
	D	Funding agencies determine the type of research that is done and how it is implemented	7
	C	Scientists are employed to do research and not to implement it	3
Disagree 47%	F	Scientists must always follow up how their discoveries are used.	29
	E	Scientists must prevent that harmful information is made public	18
X			9

This statement is the only one which was formulated in the negative. It explicitly negates the responsibility of scientists for any application and implementation of their research findings in the long term, as well as the responsibility to issue warnings or

monitor development. Opinions on this rather controversial matter were divided approximately equally among the respondents: 47% argued for scientists' continued responsibility, while 54% argued against it.

The main reason (A: 21%) that scientists could not be held responsible for applications of their results was that these were difficult or even impossible to monitor. This confirms the arguments in Statement 8 (Paragraph 4.3.5) on the prediction of the impacts of science and technology. Thirteen percent (B) placed the responsibility for any adverse effects onto those who chose to utilize the information for their purposes. This was reiterated as follows:

"Scientists can carry no responsibility if something is used beyond the purpose for which it is tested". (6.5: 13, 14)

However students were also aware that

"Scientific information in the wrong hands, for example the military, could cause disasters". (6.5: 18)

The decisive role of funding in determining the objectives and applications of research was selected by 7% (option D), and for 3% (C) the isolation of scientists in research laboratories was reason enough that they need to have no concern about how the outside world utilized their discoveries.

Among those who argued for continued responsibility, the highest percentage of responses (F: 29%) was from students who felt strongly that scientists should follow up how the results of their research were applied. For a further 18% (E) the dissemination of scientific information on potential dangers or disadvantages could serve as an important preventive measure. One student argued as follows:

"If you design something, limit its use. If you know that it is used for harmful purposes, try to do something about it". (6.5: 14)

In summary, the complex decisions surrounding the extended application of scientific innovations were realized by the target group. This statement is one of three which

received an approximately equal percentage in agreement and disagreement. It is also the only one which was formulated in the negative mode, but it is unclear whether this influenced the range of responses. The main argument relieving scientists of their responsibility to monitor the long term application of their discoveries expressed scientists' lack of control in the face of powerful institutions such as industry and the military. A slightly larger percentage of respondents however countered this argument by urging scientists to accept responsibility on a long term basis. As is evident in the literature discourse among scholars there are no clear guidelines. Scientists will be faced increasingly with such dilemmas and science students need to receive skills on how to approach these.

4.5.6 Statement 7: Consequences of science

Scientists are responsible for damage, such as pollution, to the environment

Details of questionnaire analysis:

	No	Reason	%
Agree 14%	B	There will always be certain harmful side effects accompanying positive scientific advances	11
	A	Scientists are the ones who produce products which are harmful to the environment	3
Disagree 76%	D	Everyone is responsible for pollution	21
	C	Scientists do the basic research while industry applies it	17
	G	Consequences of research applications often appear at the end of a long process and all who are involved in it are responsible	16
	E	Scientists actually use their knowledge to control pollution	13
	F	It depends on the individual and you cannot generalize	9
X			9

This statement puts the question of responsibility for the consequences of scientific innovations to a wider audience than the previous statement and focuses on the actual state of affairs rather than the possible prevention of dangers as argued in the previous statement. Altogether 76% of the respondents disagreed with the statement that scientists are responsible for the degradation of the environment, while only 14% agreed.

The largest number of respondents (B: 11%) who agreed with the statement that scientists indeed bore the responsibility for environmental damage argued that negative side effects are always present with any scientific application. This argument is extended by the further 3% (A) who believed that scientists produced harmful products and consequently had to take the responsibility for their application. An interviewee put her viewpoint as follows:

“Scientists should accept the blame. People are affected by what you as a scientist do. So you need to clean up your mess”. (5: 4)

The majority of respondents who disagreed with the statement contended that everyone, scientists and the general public alike, shared the responsibility for environmental damage (D: 21%). Two similar arguments narrowed down the responsibility to organizations such as industries who utilize the basic scientific findings to develop technologies (C: 17%) and, alternately, to everyone who participates in the long line of research, applications and developments (G: 16%). Respondents who selected option E (13%) believed that scientists actually were the ones who seek to apply their knowledge in combating pollution and therefore cannot also be held responsible for it. A small percentage (F: 9%) felt that damage and neglect were a matter of personal choice and morality. These diverse responsibilities were described as:

“Not only scientists are involved. It’s not scientists that cause all the problems”. (5: 8)

In summary, it is of interest to note that while for Statement 4 (Paragraph 4.5.4) the general consensus was in favour of joint decision making, the present statement

similarly argues for joint responsibility for the consequences of science, with both statements having comparable majority responses. While joint decision making should take place via government bodies, financial auditors, ethics committees and public representatives, the responsibility for consequences of science such as pollution is seen to rest with each and everyone who utilizes its products.

4.6 EDUCATION

Authors do not generally include formal education of young scientists among the social responsibilities of scientists. Social responsibility is limited to public communication and the provision of specialist information to citizens. In the context of this research which was conducted among tertiary education students on campus, the awareness of the importance of education can be expected to be dominant. The conversations during the interviews tended naturally towards students' needs and questions surrounding their education and its applicability in becoming successful scientists. The statements on education address questions surrounding the objectives of higher science education, the balance between theory and application and the inclusion of values, philosophy and ethics. The conviction which science students portrayed of their responsibility towards their communities was an unexpected and unique aspect of the topic at hand. The threefold mission of the University of South Africa which is defined as teaching, research and community involvement is thus reflected in the students' thinking.

4.6.1 Statement 2: Science-related social issues

The purpose of science education is to produce scientists who can solve science-related social issues

Details of questionnaire analysis:

	No	Reason	%
Agree 41%	A	Scientists must be trained to assist in solving scientific problems in society	29
	B	Scientists must know about all aspects of science	9
	C	Science education should include a broad spectrum of social, ethical, practical and communication skills	3
Disagree 53%	D	Science education should focus on subject knowledge only	36
	F	Science education equips you with the knowledge to address any problem that might arise	13
	E	Scientists should specialize in their subject	4
X			6

This statement aims to determine whether and why students require that their education in science should equip them with the ability to respond to science related societal issues such as communication, decision making, determining impacts and assessing social values. Slightly less than half (41%) of the total number of students were in favour of a broad based education which enabled them to apply their knowledge to problems within society. The other 53% disagreed that this was an essential objective of science education.

A majority 29% (A) agreed that future scientists should know how to assist in the solution of science related societal issues. One interviewee explained her vision:

“They call me a scientist because I have a degree. They have taught me how to do differentiation and integration, but this will not solve the problems of our country. They

should teach me what is important about our communities, because we want to know how to develop our country". (2:13)

Among the remaining 12% of respondents who agreed with the statement, 9% (B) preferred that science should be taught holistically so that interrelationships between different disciplines could be understood. A further 3% (C) were more specific in stipulating the inclusion of social, ethical, practical and communication skills. This latter option complements option A and is further explored in Statement 3 below.

The main negative response D is diametrically opposite to the main positive response A. While 29% wished to be able to receive training in addressing social problems in A, 36% disagreed in D on the grounds that subject knowledge alone was essential. Another 13% (F) of the respondents felt that the basic scientific skills already equipped them with the ability to address any problem, and that therefore no additional training in problem solving for society was necessary. The remaining 4% disagreed by pointing out that the main aim of science education was to become a specialist.

In summary, this is the third statement receiving an approximately equal distribution of positive and negative responses. It clearly reflects the conflict which students experience between their desire to fulfil their role in society by being able to address science related social issues, and first and foremost to become highly trained specialists in their field.

4.6.2 Statement 1: Applied topics

Science education at university should include topics such as waste management and the effects of radiation

Details of questionnaire analysis:

	No	Reason	%
Agree 91%	A	This knowledge will help students to become more efficient and responsible in their future work in industry, research, teaching or management	60
	C	Scientists need this knowledge in order to protect the community	20
	B	Applied knowledge is important in understanding the corresponding theory	11
Disagree 5%	E	Such topics should be optional	4
	D	Science education at university should concentrate on the teaching of scientific theory only	1
X			3

Statement 1 addresses the balance between purely theoretical and applied knowledge. During the interviews strong opinions were expressed about applied knowledge in a South African context. Almost all students (91%) preferred applied knowledge in their syllabi; only 5% disagreed.

Of the 91% in favour of the statement, 60% (A) wanted to be better prepared for the job market. They indicated:

“In order to be prepared for the job market the Chemistry curriculum needs to contain information on industrial processes in South Africa, rather than examples from foreign textbooks”. (6.6: 29, 30)

This need for South African resources was further explained in another interview:

“It is necessary to sustain our knowledge and impart it to the next generation, and the development of resources forms part of recognizing local scientists’ ability”. (7.5: 15)

The additional 20% (C) of respondents who wanted to use applied knowledge in their service to the community compare with the 29% (A) in the previous Statement 2 who wished to be trained in social problem solving. Both reasons clearly reveal social commitment among the respondents. For example:

“This knowledge should make you aware how harmful chemicals are and what they can do to others. And, if you are more aware you can educate and help the public”. (5.6: 22)

Applied problems are generally included in science syllabi to elucidate the theoretical knowledge and this was recognized by 11% of the respondents (B).

The opinions of the small percentage (5%) of students who disagreed with the need for applied knowledge were divided among a desire for the teaching of theory only (D: 1%) and the demand for a choice between applied and theoretical subjects (E: 4%). From the interviews it is evident that this view represented the opinion that the teaching of applied knowledge was reserved for technical colleges. The 1% demand for theoretical knowledge only in this statement differs widely from the 36% (D) in the context of Statement 2 above.

In summary, the overwhelming majority of students called for more applied topics within the South African context in their science syllabi at university level. The main reason for this was that they wanted to be adequately trained for the job market. This may be seen to resonate with the group of respondents to the previous statement who wanted to become highly trained specialists in their field, rather than be educated in science related social issues.

4.6.3 Statement 3: Value education

University science education should create an awareness of values, attitudes and controversies related to science and society and the environment

Details of questionnaire analysis:

	No	Reason	%
Agree 89 %	B	Students will be more aware of the effect of science on society	34
	C	Scientific knowledge and human values cannot be separated	29
	A	This awareness would broaden the minds of science students	24
	D	Society will have a more positive attitude towards science	2
Disagree 6%	E	Students should be able to form their own judgements	4
	F	Science is all about knowledge and cannot be mixed with societal issues	2
X			5

This statement expresses the need for the inclusion of the philosophy and ethics of science into science curricula at tertiary level. A very large majority of 89% of the students agreed that knowledge of values, attitudes and societal issues was important; only 6% disagreed.

The reasons in favour of the statement fell mainly into 3 groups. The majority (B: 34%) of respondents wanted to enhance their awareness of the social impact of science. This confirms response A to Statement 2. The following are some thoughts of a science teacher from a rural area:

“We grew up with ubuntu. Ubuntu means caring for everyone around you...

Apart from science, education must instil morals....

Education must be inculcated into one's experience and must become a value system....

In terms of ubuntu, a scientist is first and foremost a person who regards his fellow persons and environment". (4: 15)

Another large group (C: 29%) was aware of the fact that knowledge brings responsibility and that there is thus a need for knowledge about values. This is in clear contrast to the view that science is neutral and value free. For a further 24% (A) additional knowledge about values, attitudes and controversies was seen as a way to broaden their knowledge base. Such knowledge could consequently enhance social awareness and lead to socially responsible conduct as expressed in Statement 2. For a minority of 2% the attitude of society towards science could be improved if scientists were more aware of its values, attitudes and fears about science. This is an important aspect of the public relations in science without which science cannot expect society's support for its ventures.

Of the only 6% who disagreed with the inclusion of value related aspects of science in the curriculum, 4% (E) did not wish to be indoctrinated, rather wanting to make their own value judgements, while 2% (F) felt that the two cultures, i.e. science and society, could not find common ground. Therefore only these 2% in option F were in direct opposition to the 29% in option C above who felt that increased knowledge should go hand in hand with an increased commitment to values.

In summary, it is of interest to note that, although the majority of students called for the inclusion of applied topics into their syllabi in the previous statement, this did not exclude the demand by an approximately equal percentage of students for inclusion of topics on the philosophy and ethics of science. The reasons for this are more varied than for the previous statements on education. They reflect an awareness of the inseparability of scientific knowledge and human values and the effects of science on society, as well as purely academic interest.

4.6.4 Statement 18: Science students and society

Interaction is necessary between science students and the community

Details of questionnaire analysis:

	No	Reason	%
Agree 87%	B	Science students could promote an interest in science among the community	39
	C	Science students can become aware of the needs of society	23
	A	Science students could inform the community on dangers of chemicals and how to handle them safely	22
	D	Science students need to give back to the community that nurtured them	3
Disagree 6%	E	It would not be easy to achieve in practice	3
	F	Science students do not have enough experience	3
X			7

The need for science students to be involved in their communities by offering tuition and advice was an unexpected outcome of this research on students' views on aspects of the social responsibility of scientists. As such it may be seen to reflect a unique African outlook. This was already evident during interviews when the black students related their experiences and efforts in their communities where they tried to explain relevant scientific issues such as water pollution and facts surrounding HIV / Aids. Many of the students were also engaged in teaching school children after hours. The final results of the fixed response questionnaire however showed that students of all races (87%) wanted to be involved in their communities, although only approximately half of the respondents were black.

The majority (B: 39%) of science students wanted to promote an interest in science in their communities, while 23% (C) thought that community involvement would enhance their awareness of the needs of society with respect to scientific matters. Another 22% saw an opportunity to inform their people about matters of specific concern such as the safe handling of hazardous household chemicals. For example:

“We can’t ignore the mothers. They are not aware of these things”. (7.6: 23, 24)

A small percentage of those who responded positively (D: 3%) expressed a need to offer their knowledge in return for the benefits they had received by being nurtured by their people. This is a reflection of the African community spirit of ubuntu.

Of the 6% of the respondents who did not agree with the necessity of science students being involved in their immediate society, 3% (E) were apprehensive of the practicalities involved and 3% (F) felt that as students they were lacking adequate experience.

A closer look at the choice of the three main reasons showed that for option A the ratio by race was similar to the racial composition of the target group. For option B responses by African students increased by 12% above the group percentage, while for option C responses by the white students increased by 11%. Bearing in mind that results are not be statistically significant, the following trends are nevertheless evident: while all respondents, independent of race, were committed to communicating scientific information to the public, the African students saw more clearly that there was a need to promote an interest in science, while the white students were more concerned about identifying the needs of society.

In summary, the inclusion of this statement into the questionnaire was motivated by the repeated reference by African interviewees to their passionate community involvement, thus utilizing their scientific knowledge to benefit of those in need thereof. This was substantiated by the large majority, representing all races, favouring this statement. It is evidence of most science students’ concern to create scientifically literate and interested communities, and in turn to obtain knowledge of the needs and concerns of society.

4.7 CONCLUSION

Although the analysis must be seen as mainly qualitative, incorporating all views and reasons more or less equally, the question may still be asked how a typical student would see the social responsibility of scientists. The following is an attempt to describe such an imaginary student with respect to her views, attitudes and sentiments on the four main topics, i.e. the scientific enterprise, the scientist as individual, the science-technology society interface and education.

It may be said that a typical science student may wish for scientific freedom in order to be creative, but will balance it with her main concern and objective of creating benefits for society. She may have some concern that scientists could abuse their scientific freedom by infringing on the rights of others. On the other hand, she is aware that scientific freedom should not be limited to the extent that pure and basic scientific research is restricted. She realizes the powerful nature of her scientific knowledge to the extent that it gives her a special opportunity as well as a special responsibility to benefit and educate society. She will utilize this knowledge to prevent scientific and technological innovations from reaching a dangerous stage beyond human control. In this she will attempt to act with integrity and adhere to ethical codes of practice so as not to jeopardize the trust society puts into its scientists. This young scientist is convinced that in her scientific work she will be able to assess and prevent potentially adverse consequences. Being of Africa she takes pride in the past achievements of her continent and its people. She however tends to be discouraged by the lack of resources and the lack of leadership and role models, and she realizes that much also depends on creating a greater interest in and understanding of science among all members of society. Being a woman, she sees herself first and foremost as a professional scientist and an equal among her male colleagues, and is also largely regarded by them as such, with all having a similar focus and vision of science. She believes that she can inspire aspiring female scientists and that her knowledge will also benefit her family and community.

As an individual in her role as scientist, honesty and integrity are part of her personal value system. She will however take special care not to compromise these in her

scientific work, being aware of the far reaching consequences of dishonest practices on the welfare of fellow citizens. Her personal values and her primary concern for public safety also extend into accepting her responsibility to blow the whistle and inform the public if she is aware of any potential danger, even if it is at the cost of personal security or company loyalty.

As a typical science student and young scientist in training, she has a clear understanding of the important aspects of social responsibility at the science-technology-society interface. She realizes that science and social values cannot be separated and that in her role as scientist she needs to consider the impact of scientific discoveries on the values and moral sentiments of society. There should be joint decision making between scientists and society on the implementation of scientific and technological innovations, with each group contributing its own concerns and expertise, and it should be facilitated by means of close collaboration between scientists and society. She is passionate about communication of scientific findings to the public and basic scientific literacy of all citizens. It is however difficult and conflicting for her to take responsibility for the long term monitoring of the application of scientific discoveries, especially in the face of powerful institutions such as industry and the military. On the other hand, while her responsibility as scientist is to prevent and predict adverse consequences of scientific discoveries by means of her scientific knowledge, she is comfortable with the idea that the responsibility for pollution and other harmful consequences of science rests with everyone who utilizes science and its products.

In her role as science student she experiences the dual need for more applied science topics in a South African context and for subject content on the philosophy and ethics of science. She requires the former to become a specialist in her field and enable her to enter the job market. Her education has left her with little or no experience or training in evaluating value based aspects of the effects of science on society, and she recognizes the moral implications of scientific innovations. She may well need to venture opinions and make decisions on such matters in her career and community engagement. There is a measure of ambivalence about the inclusion of science-related social issues such as communication, problem solving and decision making into the science syllabus. This may prevent her from obtaining optimal

scientific training, and she may argue that the inclusion of applied topics and topics on ethics and philosophy will equip her adequately. Her service in her community, even as a student, by teaching and creating an interest in science also is seen to prepare her for her role as socially responsible scientist.

4.8 IMPROVEMENTS TO THE STUDY

An overall analysis of trends in the questionnaire responses showed that in 5 of the 20 statements, the first option (A) was selected, in a further 3 statements options A and B received an equal number of responses, and in 4 statements option B was selected. Thus, in 12 of the 20 statements the first 2 options (in agreement) were chosen. This trend may indicate a certain bias, with respondents not paying equal attention to all options. This bias could be prevented by shuffling the options and compiling several questionnaires with different option sequences as was done for the open response questionnaire. It may further be added that, in compiling the multiple choice questionnaire the sequence of the response options was randomly arranged, and did not depend on any prior student preferences in the interviews and open response questionnaire.

The analysis of trends in the questionnaire further revealed that in 14 of the 20 statements there was a clear majority of over 70% (9 of which were above 80%) in favour of socially responsible views, attitudes and conduct. In the remaining 6 statements the ratio between agreement and disagreement varied between approximately 65% : 30% for 3 statements and approximately 40% : 50% for a further 3 statements. This trend towards a clear majority of views may have its cause in respondents predominantly and indiscriminately selecting the first 2 options as explained above. However, judging from the original interviews, it was already then apparent that there were unequivocal trends and preferences among the interviewees, and that, generally, there was a high degree of social awareness and commitment.

The instrument was developed in three distinct phases, i.e interviews, an open response questionnaire and a fixed response questionnaire (See Figure 3.1). For

each phase a different target group was involved due to the fact that the distance education students were only available when they attended their practical examinations. The result of this less than ideal situation was that 3rd level and postgraduate students were interviewed, while 1st level and to a lesser degree 2nd level students answered both questionnaires. The different target groups as well as the extended period over which the research was conducted may account for the rather high percentage of additional (X) responses to some statements as well as the fact that some reasons which were developed in the open response questionnaire received 0% in the fixed response questionnaire. Research done over 1 year among a fixed cohort of students might improve this discrepancy.

Due to time constraints and the lack of volunteers it was not possible to conduct adequate pilot interviews nor do pre-tests on the formulation of the open and fixed response questionnaires. These could have eliminated duplication and lack of clarity especially in the fixed response questionnaire.

The research is based on the interpretation by this researcher alone. Input by other researchers on the interpretation of the interviews, the grouping and coding of the open responses and the final analysis would have contributed to an improved formulation of the questionnaires and to greater reliability of results.

The qualitative analysis of interviews alone is labour intensive and does not make allowance for a large number of respondents. The inclusion of paraphrased student quotations in the foregoing analysis of the questionnaire results however demonstrated that in the formulation of the questionnaire statements and reasons a large amount of specific information was lost. A refinement of the statements and reasons may succeed in capturing the essence of the students' views to a larger degree.

4.9 SUMMARY

The results of 20 fixed response questionnaire statements were analysed individually. The analysis is based on the main aspects of the social responsibility of

scientists which were discussed in the literature review. The results represent the breadth of students' awareness of the topic. Where possible comparisons among statements were made and similarities or differences indicated. The discussion of the response options was underscored by relevant quotations by students. The final chapter will attempt to synthesize the wealth of information and offer recommendations.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 INTRODUCTION

The analysis of the individual questionnaire statements allows for integrated conclusions to be drawn on how distance education science students viewed the social responsibility of scientists. Although the final fixed response questionnaire was limited to twenty statements with a choice of six to eight response options each, they demonstrate a wide spectrum of students' views, positions and attitudes. The conclusions reflect students' priorities and focus areas in the comprehensive spectrum, addressing not only what is expected of scientists in order to fulfil their social responsibility but also their concerns and recommendations. Overall, the awareness of students of the impact of science on society and of the role of scientists was unexpected. Their dedicated commitment to apply scientific knowledge in the service of society was experienced as nothing less than refreshing and encouraging.

The following paragraphs provide comprehensive answers to the two research questions which inquired, firstly, on the range of views of distance education science students pertaining to the social responsibility of scientists and, secondly, on the reasoning which students proffered in defence of their views. An answer to the third research question on racial and gender differences was not quantifiable, although subjectively differences were noted in attitude and argument. The design of the instrument which formed an additional objective of this study was covered in Chapter 3.

5.2 FINDINGS

An important feature of the questionnaire is that it determines the views of students together with their associated reasons in agreement or disagreement with these views. In answer to the research questions, the results of the fixed response questionnaire can be translated into a number of clearly defined views of distance education students on the social responsibility of scientists and the major and minor reasons for such. The following paragraphs each reflect a specific aspect of the spectrum of views which is supported by a summary of the respondents' associated reasoning. Only the main percentages of usable responses are included. The paragraphs are arranged in the same sequence as the questionnaire statements discussed in Chapter 4. (Also see Table 4.1.)

5.2.1 Scientific freedom and social responsibility

The generation of scientific knowledge rests on scientific freedom, and 65% of the respondents to the fixed response questionnaire recognized this important prerequisite. The majority (36%) argued in favour of social responsibility by referring to the need to avert dangers and improve the conditions of mankind. For 29% scientific freedom was seen in terms of the acquisition of pure scientific knowledge by means of meaningful research into the secrets of nature. Negative responses (31%) reflected a degree of concern that scientists would not honour their social commitment by being granted scientific freedom (13%) and that they might infringe on the rights of others (18%).

5.2.2 Scientists' special social responsibility

The powerful nature of scientific knowledge with its ability to transform, places a unique responsibility on scientists who develop and implement it. A large majority of 86% realized that as a scientist one indeed had a special responsibility towards society, with only 12% negating this view on the basis that all members of society

bore an equal responsibility. Reasons offered by the majority again focussed mainly on society, with 39% seeing scientists' special responsibility in terms of the need to educate society on the risks and benefits of science and technology, and 37% to improve the quality of life of society. The inherent nature of scientific knowledge which confers power on its originators and applicants and a concomitant enhanced responsibility was only realized by 8% of the respondents. A minority of 2% regarded the ability to predict the long term effects of scientific and technological innovations as significant.

5.2.3 The responsibility to focus scientific research on the needs of society.

The social objective of scientific research was supported by 65% of the students, the majority (61%) argued in favour of improving the quality of life of members of society. A minority of 4% was aware of the fact that society supports science, and that scientists should in turn respond to the needs of society. The 25% who disagreed with the social objective of scientific research focused on the autonomy of science (7%) and the main purpose of science to investigate the mysteries of nature (7%). A further 11% were aware of the influence of market forces and financial incentives.

5.2.4 The responsibility to prevent scientific research from escalating

A total of 72% of science students were cautious about relying on scientists to contain scientific research and prevent it from reaching a slippery slope. Only 21% had sufficient trust in scientists' commitment to the interests of society and to utilize their knowledge to regulate research and its applications. Among the 72%, a large percentage (29%) opted for monitoring scientists and controlling them by means of ethical codes of conduct. A further 30% cautioned that individual values or financial considerations could influence scientists' sense of responsibility towards society not to let their research get out of control. Thirteen percent (13%) were aware that the nature of scientific progress often demanded that certain risks may need to be taken.

5.2.5 The responsibility to predict the long term effects of scientific and technological developments.

The view of the majority of students, 81%, was that scientists had the responsibility to predict long term effects of scientific and technological developments, with 16% arguing that the unpredictability of nature and the limitations of scientific knowledge did not allow for this. While 30% in favour of prediction considered the prevention of harm and protection of society, 51% portrayed their belief in the power of scientific knowledge and the responsibility to focus equally on development and prediction.

5.2.6 The responsibility with respect to scientific developments in Africa

The belief by 41% of respondents in the potential and need for scientific innovations in Africa was supported by the awareness of a further 21% of the past advancements in Western and indigenous science on the continent. Constraints on scientific development in Africa were recognized by 22%. These were listed as the loss of manpower to other countries, limited resources, lack of scientific interest and the need for role models. A minority view of 5% saw Western science, which is internationally shared, as the only correct and relevant one.

5.2.7 The responsibility with respect to women in science

The notion that women could perform a special role in science was only supported by 38% of the cohort, while 48% disagreed with this notion. Among the latter, 36% believed that the focus of the scientific enterprise was on knowledge production and that gender influences were irrelevant, while the remaining 12% were convinced of gender equality among scientists. The special role of women in science was seen by 15% in terms of the traditional role and people oriented nature of women. Thirteen percent (13%) were aware of the need for acting as role models to aspiring female

scientists, and 10% realized that women could indeed contribute new perspectives to science.

5.2.8 The responsibility for honesty in scientific work

Honest and objective data accumulation and reporting form the basis of the trustworthiness of scientific knowledge production and dissemination. A large majority of 80% of science students supported the need for scientists to consistently make honest decisions in their work, but many (37%) did not regard this as an exclusive attribute of scientists alone. However, an equal number (36%) were aware of the fact that dishonesty and lack of integrity in science had a greater potential to affect the lives of innocent people than in other professions, while the remaining 7% were concerned about the loss of confidence by the public in science. The 15% who disagreed with the special call for scientists to make honest decisions in their work, argued similarly to the above 37% and added that honesty was enforced by external verification.

5.2.9 The responsibility to inform the public of possible dangers arising from scientific practices

A total of 87% of students were in favour of scientists' responsibility to blow the whistle. The majority (50%) supported this with the argument that the public had a right to know what affects them in order to protect themselves, while 30% regarded public safety as a priority and 7% referred to personal ethics. Only 5% were not in favour of whistle blowing, pointing out company loyalty and the prevention of public panic.

5.2.10 The personal responsibility for whistle blowing

Whistle blowing frequently requires a personal choice at a personal cost. Nevertheless, 79% of the science students regarded it as an important responsibility of scientists. They realized that companies did not always address harmful situations (19%). They further argued that public safety was paramount (30%), that it was a moral duty to protect the public (27%) and that there may be a need to indemnify themselves (3%). The 12% who were not willing to make the personal decision to blow the whistle referred to company loyalty, the need for confidentiality about sensitive information and a concern about personal victimization.

5.2.11 The responsibility to consider the moral implications of research

A total of 73% of respondents were aware of the need to take into account the moral concerns and values of society before implementing scientific and technological innovations. The main reason which was offered was that scientific knowledge and morality cannot be separated (57%), with a further 12% being concerned about the consequences of such innovations. The 22% who disagreed with the above premise offered a variety of reasons ranging from the view that society is responsible for the use or abuse of scientific discoveries, to a call for regulating scientists by means of codes of practice, to individual accountability and the determining influence of funding. Only 2% regarded science as neutral and value free, thus contradicting the 57% above who regarded science and values as inseparable.

5.2.12 The responsibility for improved collaboration and communication with society

A large majority of 88%, with only 5% disagreeing, realized that the enactment of scientists' social responsibility depends on enhanced collaboration and communication between scientists and society. The main reasons were based on

joint problem solving and thus the balancing of scientific knowledge with social and ethical concerns (69%). A small percentage pointed out the right of society to be informed (11%) and the fact that society will be more interested in and supportive of science if there was improved communication and collaboration (8%). The minority of 5% who disagreed, argued that society was unable to understand scientific information and that the liaison between scientists and society should be done by specialized science communicators.

5.2.13 The responsibility to educate the public in basic science

The improvement of scientific literacy among the public was supported by 83%, reasoning that science and technology permeate all spheres of modern life (36%), and that a clearer understanding would enable individuals to make better choices and become fully functioning and effective members of society (47%). The 12% who did not support the call for improved scientific literacy argued, as before, that some members of society would be unable to understand scientific information and that everyone should be given a choice of what to learn.

5.2.14 The responsibility to engage in decision making on the implementation of scientific discoveries

In its original form this statement proposed that scientists alone should be responsible for decisions on the implementation of scientific discoveries. This was confirmed by 23% who contended that scientific information can be misunderstood or misused by lay persons with harmful consequences. A total of 73% of respondents however were in favour of participative decision making because a variety of stakeholders could be involved (38%) and because societal, environmental and other innovative aspects could be incorporated into the scientific viewpoint (29%). A small percentage (6%) was aware of the importance of public support for science which could be improved by means of participation in decision making processes.

5.2.15 The responsibility to monitor the long term applications of scientific research

This statement was formulated as a negative, proposing that scientists are not responsible for the long term applications of their research by industry. It received a mixed response with 44% in favour of the argument and 47% against it. Thus it can be argued that a slight majority of respondents nevertheless required scientists to accept responsibility in this respect, suggesting the importance of monitoring applications and preventing potentially harmful information from being abused. The 44% who felt that scientists could not be held responsible for the utilization of their discoveries based this on the facts that this was beyond the control of scientists (24%), and that control and responsibility rest with funding agencies and industry (20%).

5.2.16 The responsibility for the consequences of scientific innovations.

Congruent with their view that scientists and society should jointly decide on the implementation of scientific innovation, respondents also reasoned that those who utilize such innovations are responsible for collateral consequences such as pollution and environmental degradation (76%). In this respect respondents placed the responsibility to varying degrees on all members of the public (21%), on industry and technology (33%) and on individuals (9%), with 13% relieving scientists of any responsibility because scientists were in fact attempting to control and remediate the negative side effects. Fourteen percent (14%), on the other hand, placed the responsibility solely on science which was seen to always have negative side effects and on scientists who invent these products.

5.2.17 The responsibility to educate science students to solve science-related social issues

The education in science-related social issues covers aspects such as communication, decision making, determining impacts and assessing social values. Only 41% regarded this type of education and training as a necessity on the basis that it would enable them to solve scientific problems in society (29%) and that it would broaden their knowledge base (12%). The 53% who did not see this as an essential requirement of their scientific education were more concerned about obtaining adequate and specialized subject knowledge (40%) and were confident that their scientific approach would enable them to address problems in society (13%). The latter is in direct opposition to the 29% who saw the need for such training.

5.2.18 The responsibility to include relevant applied topics into science syllabi

The necessity to include applied topics such as waste management and the effects of radiation into science syllabi was regarded as a priority by 91% of the science students. The majority (60%) wanted to be prepared for their future careers and 20% wanted to be able to apply this knowledge in their communities. The remaining 11% saw it as a means of improving their theoretical understanding. A 5% minority was in favour of being offered the option to choose between theoretical and applied syllabi.

5.2.19 The responsibility to create an awareness of values, attitudes and controversies related to science, society and the environment in the education of young scientists

Similar to the above requirement to include applied topics into science syllabi, 89% saw the need for the inclusion of subjects or topics which are based on the philosophy, ethics and sociology of science into the science curriculum. By means of

this, 34% wanted to improve their awareness of the impact of science on society, 29% realized that science and human values cannot be separated and 24% felt the need for a larger knowledge base. As previously, a small minority (2%) was aware of the attitude of society towards science and felt that a broader awareness of scientists would improve society's attitude towards science. The 6% who were not in favour of the inclusion of above topics wished to form their own judgments and felt, contrary to the above 29%, that science and society had no common ground.

5.2.20 The responsibility of science students to interact with their communities

The commitment of 87% of respondents to be engaged in their communities while still being involved in their studies was an unexpected and unique aspect of respondents' views of the social responsibility of scientists. While most respondents (39%) were motivated by the need to promote an interest in science, others (22%) wanted to offer important information such as chemical safety. A further 23% saw their engagement in their communities as a means of learning about the needs and problems of society, and a small percentage (3%) saw it as community service. Only 6% of the respondents were not inclined to become engaged in their communities due to practical difficulties and inexperience.

5.3 DISCUSSION

The views and corresponding reasons as outlined above form an integrated picture of students' thoughts and expectations with respect to scientists' social responsibility. A detailed look reveals that certain themes feature in a number of statements and associated reasons, which re-affirms the holistic, integrated nature of social responsibility where one aspect weaves into another. What follows is an attempt to discuss the common themes across statements and reasons. It is argued here that

this will provide an insight into the research question which interrogates the reasons which students offered for their views on the social responsibility of science.

The leading theme which permeated all aspects of social responsibility was the view that scientific research and applications should be aimed almost exclusively at the improvement of social conditions and to the equal benefit of individuals and mankind as a whole. During the initial interviews it was clear that scientific research and applications were regarded chiefly in terms of health and medicine, energy and water supply, environmental degradation, toxic chemicals and risk assessment and prevention. The questionnaire statements also elicited special reference to the protection of society by means of scientific prediction of the effects of scientific and technological innovations. Public safety was the main motivation for whistle blowing. Scientific freedom and the power of scientific knowledge were similarly focused more on the improvement of the quality of life than on the creation of pure scientific insights and applications. In their studies science students appealed for relevant applied topics which they could utilize not only for being better prepared for the job market but also to serve and protect their communities. These illustrations of students' concern for the welfare of society can be seen to have their foundation in their understanding that factual knowledge and human values cannot be separated.

Views which pertained more directly to the reliance on scientific knowledge and the pursuit of theoretical knowledge to the exclusion of social values and concerns generally received a lower priority, thus reflecting a developed sense of social commitment among the respondents. In this respect respondents may not have adequately recognized the significance of basic research in building a knowledge base and a scientific culture, as was evident during the interviews. The necessity for scientific freedom for the creation of new insights into man, nature and the universe was acknowledged to a similar degree as its necessity for the improvement of the conditions of mankind. The value and power of pure scientific knowledge was espoused by approximately one quarter of the respondents who argued that scientists alone should be responsible for decisions on the implementation of scientific innovations. An even smaller percentage acknowledged the concomitant responsibility of scientists for the consequences of scientific innovations. Confidence

was expressed in the ability of scientific knowledge to predict the effects of innovations and that this knowledge would enable scientists to prevent harmful consequences and forestall the possibility of scientific innovations from escalating beyond control. A relatively small number of respondents pointed out that scientific progress implied that a certain amount of risk may need to be taken to expand the frontiers of science, and a minority expressed the opinion that nature was unpredictable and scientific knowledge tentative and not advanced enough. The power of scientific knowledge was similarly acknowledged in warnings that it may be misused by scientists and non-scientists, thus supporting the need for the long term monitoring of applications of scientific findings and for sole decision making by scientists. A certain measure of scientific isolationism and elitism was apparent in arguments referring to the notion that science and society do not have a common ground, that science was neutral and value free and that the public would not be able to understand scientific information.

There were conflicting views among students simultaneously indicating confidence in the ability of scientific knowledge to impact positively on society and a lack of confidence in scientists' commitment to society. Respondents for example expressed a high degree of confidence in the ability of science to predict and prevent harmful consequences and thus enabling scientists to meet their responsibility. On the other hand, they portrayed a pronounced lack of confidence in scientists' intention and/ or integrity to prevent the application and effects of scientific knowledge from reaching a state beyond control or repair. In this respect, scientists were seen to be socially irresponsible by more than two-thirds of the respondents. Contradictions such as the foregoing may also signify a lack of understanding of the philosophical foundations of science as well as attitudes and decisions which are not grounded in sound ethical argumentation.

In contrast to the foregoing paragraphs which focussed on aspects of scientists' responsibility to social welfare and to the scientific enterprise, there were also a small number of respondents who argued that responsibilities rested with society alone. This in effect supports the argument for the separation of science and society into two worlds. The view of respondents, although in a minority, was for example

that society was responsible for the implementation of scientific innovations. Consequently they also argued that society was responsible for the impacts of science and technology on the environment, while scientists were in fact attempting to remediate and control them. Science students' views that society was using and abusing science and was caught in a spiral of consumerism to the detriment of pure science are also relevant in this context.

Judging qualitatively from interviews and the number of statements and reasons in the questionnaire, public communication and education was seen by students as a major social responsibility of scientists. It included a call for commitment by scientists to engage more actively in the public arena and to become more adept in promoting the public understanding of science and technology. The view was that all members of society should acquire an understanding of basic scientific facts. The majority of respondents even regarded the education of society as a special responsibility of scientists, and as such it was regarded as slightly more important than the improvement of social conditions. The importance of communication was also underscored by science students' who wanted to inform their communities on basic scientific hazards and promote an interest in science. Science education was seen to empower individuals to make better decisions in modern life which is permeated by science and technology, and to enable community members to participate constructively in joint decision making with scientists and other stakeholders. Adequate collaboration with scientists was seen to depend on objective scientific information communicated by scientists rather than by journalists in clearly understandable terminology. Science education and public communication of science were however not only regarded as a necessity but as a public right to information. This was for example pointed out by half of the respondents as the reason why scientists had the duty to blow the whistle on detrimental practices.

The repeated reference to the responsibility of scientists to participate in the Aids debate and bring scientific facts and findings to the attention of the public deserves special mention. Such understanding, brought about by the authoritative and respected voice of scientists, would motivate and empower people to contain or overcome the disease. Students' vision was further that public communication would

enable scientists to become intimately involved with the public, informing them of innovations, addressing their concerns and also becoming aware of communities' values and expectations. Ultimately, however, communication and public education should not be limited to the risks and dangers of science and the solution of imminent problems. Positive communication of the benefits and beauty of science could improve public sentiment towards science, allay fears and concerns, and motivate and inspire the younger generation favourably towards science. The fundamental value of communication and collaboration among scientists and society was seen to lie in the achievement of a balance between scientific facts and social value-based priorities. This would place joint decision making and the joint acceptance of responsibility for the impacts of science on a sound foundation. The minority argument with respect to the achievement of general scientific literacy and public understanding of science was that not all members of the public would be able to understand or be interested in science. The lack of public interest, which would result in fewer students enrolling for science subjects, was also seen as a constraint to the promotion of innovative science in Africa. In addition there were repeated references, especially during the interviews, to scientists' voluntary isolation and lack of social and communication skills.

A further essential aspect of students' views of the social responsibility was scientists' participation in decision making processes involving the implementation of science and technology. Well-considered decisions were seen to depend on a scientifically literate society and effective communication between scientists and society. Respondents' opinions were unequivocal that decisions needed to be based on the equal consideration of scientific and human factors, involving experts and a variety of private and public bodies. It is of interest to note, however, that approximately equal minorities claimed that scientific information in the hands of non-scientists could inherently lead to harmful outcomes, while the contrary opinion was that non-scientists could come up with innovative ideas and applications. The evaluation of students' views further clearly shows that in accordance with the vision of participative decision making the majority was also in favour of joint responsibility for the consequences of scientific and technological innovations. In effect, the position of the target group can be summarized as: a scientifically literate society

could engage effectively in well balanced decisions to the greater benefit of all, and both scientists and society would be empowered to accept responsibility for the implementation, maintenance and/ or discontinuation of innovations. As stated above, a significant quarter of the respondents were however in favour of sole decision making by scientists while a smaller number felt that scientists alone bore the responsibility for deleterious effects of scientific progress such as pollution.

Two premises, scientific freedom and the awareness of the power of scientific knowledge, which determine how scientists execute their social responsibility, were less unequivocally argued. The central role which scientific freedom plays as a prerequisite and foundation of responsible scientific activity was recognized by a two-thirds majority. This was tempered by concern that scientific freedom could be abused, resulting in socially irresponsible research and implementations at the expense of society, thus indicating a lack of trust in scientists' commitment towards society. The critical and essential awareness of the inherent power of scientific knowledge as expressed by Robert Oppenheimer on the event of the detonation of the atomic bomb was lacking among the target group. Participants did not recognize that the very nature of the knowledge about the natural world and the ability of scientists to utilize this knowledge in order to manipulate the natural world gives them almost unlimited power and therefore a concomitant greatly enhanced social responsibility. The power of scientific knowledge was mainly seen in terms of scientists' ability to fulfil their responsibility in improving social conditions as well as educating society. The lack of recognition of the power of scientific knowledge may partially be due to minority views about scientists' lack of power, the belief in the neutrality and isolation of science, and even the conviction that the power of decision making and control rests with the public or, alternately, with each individual. A further reason which was not directly addressed in the questionnaire could be the respondents' lack of experience of the scientific enterprise, as very few were employed by research institutions where they work closely with research scientists.

Whistle blowing is an important aspect of social responsibility which is gaining prominence in institutions as well as in public perception. The protection of the public even at the cost of personal disadvantage or disloyalty to the employer was regarded

as a prime responsibility of scientists towards society as well as the right of the public to information. It was also seen as a decision which a scientist would have to make on her or his own, being solely dependent on moral convictions or personal values. Scientists' private life was therefore not separated from their responsibility as scientists. A minority adhered to a notion that sensitive information should not be disseminated and public alarm prevented. Students' views were however also clear that scientists required legal and corporate support, and / or personal and professional advice in order to fulfil their responsibilities and protect themselves from victimization or prosecution.

Personal morality, the need for honesty and integrity both in a professional and private capacity, as well as a consideration of the ethical implication of research areas or scientific implementations, were identified as important factors contributing to the protection and elevation of society. The far reaching effects of attitudes to the contrary, especially in the practice of science, were recognized, as well as the fact that dishonesty, plagiarism and data manipulation impaired public trust in the scientific enterprise as a whole. The majority of the target group did not consider science as neutral, value free and objective, and were aware of the inseparability of scientific and ethical conduct. Among respondents there was however also a distinct tendency to be aware of the tenuous role which personal judgements could play, and, equally, to acknowledge the right of an individual to make choices and decide whether or not to accept responsibility. Thus, in this respect all members of society were regarded as equal. Adherence to the scientific ethos, validation of scientific knowledge, the introduction of professional codes of practice and public monitoring were offered as means to preclude individual accountability.

Opinions on minority groups and minority science varied over a wide spectrum. By drawing on a healthy confidence in the untapped abilities of its people as well as a measure of pride in the achievements of the past, students supported the view that there was potential for scientific innovations which could include indigenous science on the African continent. Constraining factors such as the economy and its consequent loss of manpower, as well as a lack of interest in science and the lack of

inspiring role models were seen to prevent scientists from fulfilling this area of their responsibility.

The responsibility of scientists to promote women and female-oriented science as well as the special responsibilities of women scientists evoked divergent and unexpected reasoning among this target group. The support of the socially oriented and traditional role of women was contrasted with strong views on non-sexism in the scientific environment. The responsibility of female scientists to serve as role models for younger generations was highlighted. The potential – and potential responsibility - for women to add new focus areas and interpretations to science as it is practiced at present was acknowledged. In the opinion of this researcher the prevalent traditional and non-sexist views may however reduce such visionary projects to compliance with the current Western male orientation of science.

Although they were in a minority, a number of respondents supported reasons for socially responsible conduct which referred to the liaison between science and society and the importance of public support for science. The improvement of public interest in and the understanding of the limits of science by means of better communication and education were regarded as important responsibilities. Less tangible but equally significant may be the reason that society would be more inclined to support science if societal values were seen to be incorporated into decision making processes. Of equal interest is the notion that society would have a more positive attitude towards science if an awareness of values, attitudes and controversies related to science, society and the environment formed part of the education of young scientists. Statements which referred to the desire to offer society something in return equally point to respondents' awareness of society's indispensable support for its scientists.

Respondents identified a number of constraints which prevented scientists from exercising their social responsibility. Apart from a lack of trust in scientists' social commitment, constraints were identified in the areas of communication and decision making. Scientists' inability and/ or disinterest to communicate with the public was repeatedly voiced as an important concern, especially during the interviews.

Students were also disillusioned in the actual power which scientists had in order to influence decision making processes and execute their special professional responsibility. They felt that the concerns of the public and scientific facts and objectives were disregarded in favour of political and/ or economical considerations. Public communication, education, decisions and collaboration were also seen to be restricted by a lack of public interest. Personal preferences and values as well as financial considerations could equally impact on an individual's sense of social responsibility. The need for legal and institutional support as well as professional advice, role models and mentors was highlighted. The important function of professional bodies and codes of practice to support, monitor and regulate the scientific disciplines and thus facilitate the execution of scientists' social responsibility was recommended by respondents with respect to the utilization of scientific freedom, the containment of scientific progress and the acknowledgement the moral implications of scientific innovations.

Students' views on needs and changes in tertiary science education may be seen to reflect their desire to be equipped with the necessary skills and knowledge to fulfil their roles as future scientists who have a mandate for effectively executing their responsibility towards society. These views however can also be seen as the students' call on their institution of higher learning to train socially aware and responsible scientists. Alterations and additions to syllabi and curricula focussed on relevant applications of theory as well as knowledge of the fields of ethics and social and environmental science. Generally there was a pronounced desire for a comprehensive and stimulating education, covering a variety of topics and skills, with a holistic integration of knowledge and values. A minority opted for theoretical knowledge. To a lesser degree students required skills in addressing scientific problems arising within societies, in spite of the fact that there was an acute awareness of the inability and hesitance among scientists to engage with the public. In this respect a considerable number of respondents felt that their subject knowledge and scientific training was adequate for the resolution of science related social problems. Students' commitment to social responsibility was also eminently evident in their desire to be involved in their communities by teaching and promoting science and simultaneously increasing their own awareness of the needs of

societies. Such engagement can be seen as a valuable training ground for students' future role as socially responsible scientists.

The foregoing overview of the results and the discussion of students' reasoning are summarized below as answers to the research questions.

Answer to the research question:

What is the range of views pertaining to the social responsibility addressed by the students?

The range of science students' views on the social responsibility of science extends from factors surrounding the scientific enterprise and the generation and utilization of scientific knowledge to the role of scientists in their individual capacity, the science-technology-society interface and education. Social responsibility within the scientific enterprise addresses the use of scientific freedom, scientists' special responsibility with respect to the powerful nature of scientific knowledge, research objectives and the responsibility to predict the long term effects of scientific and technological developments and to prevent research from reaching a point beyond control. Responsibilities with respect to scientific developments in Africa and the role of women in science were addressed mainly in terms of new developments and gender equality as well as traditional knowledge and traditional roles. The social responsibility of scientists in their individual capacity is based on their personal value systems, and is defined by their honesty, objectivity and adherence to the scientific ethos as well as their personal commitment to inform the public of potential dangers. At the science-technology-society interface social responsibility was identified as the need to consider the moral implications of scientific research, collaboration and communication with the public, and the promotion of basic science education among all members of society. Added to this are joint consultative decision making and joint responsibility for the consequences of scientific and technological innovations, as well as monitoring of the long term applications of scientific research. Social responsibility in the field of education covers the teaching of science-related social issues, applied topics and aspects of the ethics, philosophy and sociology of

science. Science students' engagement in their communities was seen as an additional aspect of scientists' social responsibility.

Answer to the research question:

What reasons do students give for their views on the social responsibility of scientists?

The reasons which students gave for their views on the social responsibility of scientists were closely interwoven with the views as such. The main reason refers consistently to the welfare, advancement and protection of society, as well as society's right and need for scientific information. The inseparability of knowledge and values and a balance between scientific facts and social value-based priorities were emphasized. The importance of a personal commitment to moral and honest conduct together with the adherence to scientific ethos was recognized. The preservation of public trust, liaison with the public and public support of the scientific enterprise further motivated socially responsible practice. The potential of new focus areas such as indigenous knowledge systems and the support of opportunities for women scientists were underscored. A sense of separation between the two worlds of science and society as well the belief that science is neutral and value motivated by the exclusive pursuit of theoretical knowledge without concern for social applications and values. A lack of public interest in science, the misuse and abuse of scientific knowledge and consumerist tendencies supported this inclination to scientific isolation. Constraints on the implementation of socially responsible science were cited as scientists' lack of commitment to social engagement as well as their lack of power in social and political processes. Political and economical priorities in scientific policies and objectives were also recognized as determining factors. The need for institutional and legal support of scientists in instances such as whistle blowing was indicated. Professional bodies and codes conduct could fulfill the dual role of supporting and monitoring scientists. Science education should prepare scientists adequately for their professional engagement with society, and recognized role models could further the cause of science.

Answer to the research question:

Do students from different racial and gender groups have different views on the social responsibility of scientists?

Statistically significant results in support of this research question could not be obtained. Qualitatively there were indications that African students were more aware of past scientific achievements on the continent, while there was confidence across all racial groups that there was great potential for scientific developments in Africa. In spite of the overall perception of gender equality and the non-sexist nature of science by male and female students alike, there were indications of a slight predominance among female and White, Coloured and Indian students favouring these views.

5.4 RECOMMENDATIONS

At the outset of this research the premise was that the complex demands which are placed on scientists to exercise their responsibility towards society required specialized skills and knowledge. The in-depth insight which was gathered by this research into the views, attitudes and concepts of students on the social responsibility of scientists can inform recommendations for the training and education of future cohorts of science students in a distance education context.

The research results reveal uncertainties, conflicts, strengths, weaknesses, doubts, concerns, distrust, the need for support and for skills and knowledge within the wide scope of scientists' social responsibility. More directly, the results indicate a need for role models and expert mentors, for support structures and for theoretical and applied knowledge, philosophical models for integrating an understanding of the inherent nature of science, as well as communication skills and a foundation in ethical decision making. However, to this researcher, the research results reveal even more so an unexpected commitment to ethical behaviour and the practice of

socially responsible science. These, together with the youthful idealism of students are the foundation upon which educational interventions can and should be laid.

The Theory of Situated Learning and Legitimate Peripheral Participation emphasizes the important function of role models, experts and mentors. It is by their explicit guidance and example that young scientists learn from them and aspire to be like them. Through participation and engagement learners acquire responsible conduct and attitudes. A large portion of learning however also takes place implicitly through informal interaction and observation. The ambience pervading a laboratory or tutoring session may be intangible and subjective, but it communicates a message about the institutional culture and the attitudes, hidden values and priorities of its people. Similarly the overt actions of tutors can have a significant impact by virtue of their non-verbal communication and implication. Questions such as the following could be asked: “What am I communicating by discarding hazardous waste down the laboratory drain?” or “Am I giving marks for correct results only and possibly encouraging dishonest laboratory practices?”. Graduate students at tertiary institutions are seen to have the singular opportunity to acquire the “languages of research and scholarship, the norms of university and research lives, and the traditions and histories of their field, at the same time they are building human bonds with their colleagues” (Damarin, 1994). It is here that a high level of commitment to socially responsible conduct can be assimilated.

More directly and explicitly, the measure of experiential and theoretical knowledge on socially responsible practice which key figures can contribute on a continual basis is decisive. Such innovations are best initiated gradually at school level as suggested by the SAQA Critical and Developmental Outcomes. At a tertiary education institution inputs on socially responsible practice may appear inapplicable to a purely scientific topic. However, it is the function of institutions of higher learning to create the knowledge base of a nation and educate leaders in every field and profession. The insights of this research can inform science educators and provide a starting point for discussions and for syllabus and curriculum change.

According to the Theory of Situated Learning meaningful knowledge is created by means social participation and it is facilitated by situating activities in societal contexts. In the distance education context this could be achieved by including relevant information into study guides, tutorial matter, practical manuals and during practical sessions. Exploratory and stimulating notes or short discussions could prepare the ground for new approaches and course materials. Addressing the idea of scientific freedom or the power of scientific knowledge could start to create an awareness among students of the philosophical basis of what they are studying and practicing. Questions and discussions on how scientific concepts and findings could be communicated to a less scientifically literate public would not only enhance students' personal understanding but improve communication skills which they may well require in a work situation. Questions and discussions on current scientific issues such as the impending building of a Pebble Bed Modular Reactor will stimulate students to think about which scientific and societal factors need to be taken into account, and would simultaneously introduce them to ethical principles. Contributions by external specialists can enhance such excursions into the field of social responsibility. Industry and the corporate structures are generally more aware of the requirements such as the King Report pertaining to social responsibility (King Report on Corporate Governance for South Africa, 2002).

Students were clear about their demands for more relevant and more applied information which could inform scientific practice while simultaneously meeting social and environmental responsibilities. Relevant topics pertain to the South African or African context in distinction to the current examples from foreign textbooks. These should enable learners to relate to the specific industrial processes and environmental and social problems, needs, characteristics of the continent as well as obtain a more holistic view of the interrelatedness of various scientific disciplines and of science with society. Applied information should include legal aspects such as the Acts on Hazardous Substances, Environmental Conservation, Water, Environmental Management, Occupational Health and Safety. These could be available in the form of reference material attached to practical guides. Knowledge of the basic principles of toxicity, decontamination and disposal of chemicals should form an integral part of students' laboratory experience and research practice. The above serve to create an

awareness of needs and responsibilities, as well as a measure of knowledge on how to address them.

Attitudes and values are inspired by role models and mentors, but need to be grounded in theory when scientists are faced with conflicting decisions. This was recognized by respondents in articulating their demand for an awareness of values, attitudes and controversies related to science, society and the environment. The content of science needs to be contextualised within the philosophical and cultural perspectives of scientific concepts, laws and models, and different knowledge systems need to be balanced, especially in non-Western countries. Internationally the teaching of research ethics and the history and philosophy of science is highly recommended, either by means of separate courses or by including relevant aspects into pure science syllabi. The Green Chemistry approach developed by the International Union of Pure and Applied Chemistry is one such example (Gaie, 2002). For the student and scientist in Africa the inclusion of aspects of African philosophy is essential in order to make science and values more relevant to continent. The Africanization of science curricula needs to be grounded in the philosophy and ethics of Africa; mere African examples and applications will not change the face of science in Africa (Msila, 2005). Equally, feminist theories could inspire young female and male scientists alike to develop a science which is more people oriented and could serve the disadvantaged and neglected of society. In the distance education context with an already overloaded syllabus such additions may be difficult to achieve. In the short term these may take the form of lunch time, evening or weekend lectures during practical examinations, or additional or optional articles for reading. In the long term the inclusion of formal courses cannot be avoided and should become a priority.

Support structures such as professional societies could play an important role. Respondents pointed out that scientific conduct should be monitored either by professional codes of conduct or by society at large. An awareness of such codes could inspire and ground the scientific practice not only of professional scientists but of students at all levels. Professional societies host special student conferences. Discussions on professional ethics and social responsibility could well be included.

Professional societies could then be regarded as a professional home which not only monitors and controls but also supports and inspires its members.

Support, according to the concept of Legitimate Peripheral Participation, is also achieved by means of free and increasing access to resources, information, instrumentation and the equitable acceptance of novices into the profession at an early stage. Such access and participation however is seen to not only provide support, but also to reduce the dominance of gender, race, class, knowledge systems, cultures and communities. Accordingly, learners and their teachers are regarded as members of the scientific community as well as of other communities with which they are associated and whose values and traditions they share. This allows for an exchange and enhancement of knowledge and the subsequent transformation of all communities. Requirements of socially responsible conduct such as the acquisition of scientific literacy and knowledge of communities' needs and values is hereby achieved. Increased access and participation is further seen to promote what Streibel (1993) describes as "responsible freedom" which encompasses justice and equality, and empowers learners to engage in the transformation of the scientific and other communities, as well as in their own professional growth.

Feedback provided by participants in the interviews for this research project indicated that they were stimulated by it and would like to continue such discourse. Student engagement in questions surrounding social responsibility could well continue in student science societies or forums such as "Student Pugwash", which could serve as an excellent example upon which student support on the African continent could be based. Its mission is: "to increase awareness of the ethical dilemmas created by the interaction of science, technology, and medicine in contemporary society. Our interdisciplinary perspective intends to bridge the gap between academia and activism in such areas as biotechnology, computers in society, management of technology, national security and nuclear weapons, energy, technology transfer and the environment" (Simonelli, 1989). The movement combines the voices of science and humanities students and leaders in government, academia and industry worldwide in order to arrive at "decisions that respond to both

technological opportunity and societal need” (Simonelli, 1989). A forum at national level similar to Student Pugwash could offer students an opportunity to channel their undoubted passion for social commitment, voice their concerns, exchange opinions with specialists and realize their ideals. National forums can subsequently join international movements and facilitate a wider exchange of ideas as well as a better understanding of less developed worlds and Africa in particular.

Science students' voluntary commitment to service in their communities could be structured and formalized by involving them in basic adult education and training initiatives and / or community service such as the Community-Higher Education-Service Partnerships (Chesp – Community Higher Education Service Partnerships, 2005; Lazarus, 2000). The latter involves university students and faculties countrywide in the promotion of civic participation, the building of community capacity and the improvement of education. In this manner students can engage in community service, improve levels of scientific literacy and obtain experience themselves in science communication and the scientific and technological problems in societies.

5.5 CONCLUSION

In summary, it is evident that education and training in social responsibility not only places new challenges on student, but also demands incisive changes to curricula and syllabi, as well as to the attitudes and commitment of experts, teachers, mentors and role models. The collaboration of support structures such as professional societies and youth forums would have to be summoned.

All participants may have to interrogate their own position with respect to social responsibility and become more sensitized and informed. In this respect future research into the views on social responsibility of researchers, lecturers and technologists would be informative and would place transformation on a sound foundation.

And as a final remark: Bertrand Russell and Albert Einstein's warning and encouragement published in their Manifesto in 1956 is still pertinent, and reminiscent of the African spirit of ubuntu:

"We have to learn to think in a new way... There lies before us, if we choose, continual progress in happiness, knowledge and wisdom. Shall we, instead, choose death..? We appeal, as human beings to human beings: Remember your humanity, and forget the rest".

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APPENDIX A.1

Miners 'fried' by radiation (Janine Stephen, Mail & Guardian, March 1999)

MAIL & GUARDIAN
February 26 to March 4 1999

Miners 'fried' by radiation

Janine Stephen reports on a scrap in Parliament over who should control nuclear safety in the mines

In shock reports presented at a parliamentary public hearing this week, the National Union of Mineworkers (NUM) disclosed that large numbers of mineworkers are being exposed to dangerous radiation levels.

An inspection carried out by the Council for Nuclear Safety in May to August last year showed more than 1 000 workers in Harmony Gold Mines in the Free State have received an annual radiation dose five times higher than it should be.

"Essentially, these workers were being fried," said a council source. "They are not provided with protective clothing or even instruments that would allow them to measure radiation levels and withdraw from an area if these are too high."

The mine safety manager at Harmony Mines, Rob Gilmour, confirmed that an inspection by the council had indicated "radiation levels over the maximum" allowed.

An investigation by the council at the Nigel Gold Mining Company in September last year showed levels of radiation due to radioactive radon gas, released by uranium deposits in the shafts, were dangerously high.

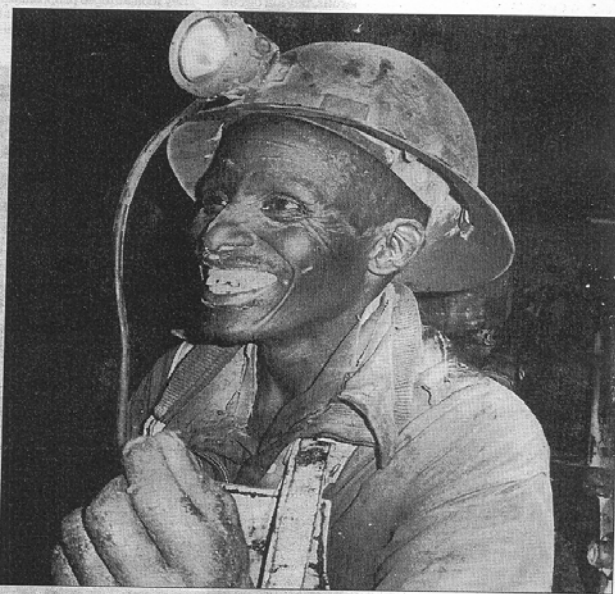
These facts were presented during two day public hearings on the draft nuclear energy and national nuclear regulator Bills. The Council for Nuclear Safety is a watchdog that advises the government on nuclear safety.

Relations between the representatives of the Department of Minerals and Energy and mining companies on the one hand, and the council and NUM on the other, were at times acrimonious during the hearings. The unions accused the Chamber of Mines of being "bullyboys", and the chamber retaliated by calling the council "draconian".

The acrimony arose largely out of perceptions about the process of drafting the Bills — most of the input came from the minerals and energy department and the Chamber of Mines — as well as a controversial proposal to transfer responsibility for regulating radioactivity in the mining industry from the council to the department.

NUM representative Sazi Jonas said the eagerness to remove mining from the council's regulation "is driven by a desire to protect profits and lower mine safety standards". He also accused the department of being "unduly influenced by mining industry employers".

Chamber of Mines representative John Stewart denied any accusations of collusion



Exposed: An inspection at a gold mine last year showed that miners had received an annual radiation dose five times higher than the maximum level allowed

with the department. He said Minister of Minerals and Energy Penuell Maduna had agreed the Mine Health and Safety Act should govern mining radiation hazards.

"The activities at a gold mine do not have the same radiation risks as those of a nuclear power station ... therefore there are no nuclear safety risks at a typical gold mine that need regulation by the Council for Nuclear Safety," said AngloGold representative Johan Botha.

"Mining has a social benefit and we can't make it so costly that workers' jobs are at risk. So perhaps you say radiation will kill you, but no jobs will also kill you."

Council representative Thomas Aufdehyde countered that the Mine Health and Safety Act "does not provide for the unique nature of radiation damage on mines".

He expressed concern about the ability of the chief inspectorate of mines to take over regulatory responsibility. If the proposed schedule laying out allowed levels of radioactivity

was passed, "some [workers' and public] exposure to radiation may be higher than before".

Environmental groups, the Chemical Workers Industrial Union and the South African National Civic Organisation objected to the transferral of regulatory responsibility to the chief inspectorate of mines.

They raised concerns about the lack of independence of the regulator, and lack of consultation when the Bills were drafted.

"The drafting has been a closed shop," said Stephen Law of the Environmental Monitoring Group.

"There has been no attempt by the department to consult beyond its own ranks."

The new Bills are meant to separate the functions of nuclear safety from the development of nuclear technology, lumped together in the old Act. But the result has been to strip the council of power or influence in the mines, and to leave control in the hands of those sympathetic to the mine owners.

APPENDIX A.2

- Iscor 'poisoned our water' (Brummer, Mail & Guardian, May 2000)
- US environmentalists visit Durban hotspots (Kirk, Mail & Guardian, May 2000)

Iscor 'poisoned our water'

In a move reminiscent of the film *Erin Brockovich*, a poor West Rand community of plot-owners is taking Iscor to court, alleging that the company knowingly polluted their properties

Stefans Brümmer

In what is being hailed as South Africa's biggest environmental case yet, steel giant Iscor will be in the dock next week over allegations that it knowingly caused high levels of dangerous water pollution around its Vanderbijlpark plant.

The case, which is expected to run a week, could seriously embarrass the former minister of water affairs and forestry, Kader Asmal, who will be accused of knowingly tolerating the company's alleged criminal behaviour.

In the application a poor West Rand community of plot-owners will ask the Johannesburg High Court for an interdict forcing Iscor to eradicate all sources of pollution in three months, and to clean the water and soil of adjacent neighbourhoods in six months — a gargantuan task the applicants estimate will cost more than R1-billion and could stop the plant from operating.

The soil in Steel Valley, Syferpan, Rietkuil, Lourens and Lindokim — all suburbs bordering the Vanderbijlpark steel works — sweats a salty white substance. Residents, many of whom rely on small-scale agriculture, say this is but one sign of how their groundwater, their land and their livelihoods have been poisoned by pollutants Iscor releases.

It is a bleak and scarred landscape. Iscor has long publicly denied liability, yet recently started trucking drinking water to selected residents, many of whom relied exclusively on borehole water before.

Since February Iscor has bought out more than 140 property owners — at least half the land — to "better manage" the area. Eighty-plus homes on these plots are being demolished and more than 400 residents have joined an exodus in search of greener pastures.

The area is dying a slow residential death. The Iscor saga seems almost a copy of the film *Erin Brockovich*, in which Julia Roberts plays a legal clerk who uncovers serious water pollution by a large United States company. In the film, based on a true story, the company tried to hide the damage by buying out affected homeowners. A judge awarded hundreds of millions of dollars damages to residents, many of whom suffered life-threatening ailments.

Unlike its public stance, Iscor does accept a degree of liability in its court affidavits, but argues that the interdict is unnecessary as it has a suitable strategy to stop all pollution by 2005 and take remedial action. Iscor declined to comment this week, saying the matter is "sub judice".

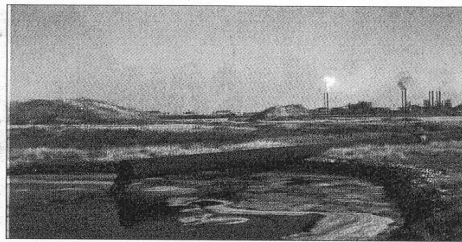
For Iscor the stakes are undeniably high. Not only is the R1-billion or more it may be forced to spend the equivalent of the Vanderbijlpark flat steel plant's annual turnover, but the applicants say the interdict could be a stepping stone to a huge damages claim for devaluation of property, loss of income and health problems allegedly associated with the pollution.

Then there is the embarrassment factor: the court is to be presented with evidence — taken from internal Iscor reports — revealing that the company knew 25 years ago that it had a serious environmental problem on its hands, yet did very little about it.

"I hope that justice is just, since if it turns out not to be, I am not going to walk the way of justice either... I am not going to leave Iscor alone for the rest of my life"

The applicants — community organisations the Vaalhoeve Baskermingsgroep, the Vaal Renaissance Association and community leader Johnny Horne — append to their court papers copies of Iscor's own internal reports spanning the years, which show management knowledge of a large "plume" of groundwater and surface pollution spreading westwards of the plant, as well as contamination of the Vaal River, where much effluent is ultimately discharged.

Asmal, who is now the minister of education, could be similarly shamed. From papers filed with the court it is clear that Asmal's department knew Iscor was contravening the Water Act — a criminal offence — but that the department went softly-softly rather than enforce the law. Asmal personally dealt with the dispute in 1997 and 1998. A May 1997 departmental briefing to him makes damning references, including that Iscor "never realised their commitments to comply with



Not fit for consumption: An Iscor pipeline discharges effluent into a pond at the steel giant's Vanderbijlpark plant. PHOTOGRAPH: STEFANS BRÜMMER

the specified effluent standards".

Marius Koe, water quality management deputy director in Gauteng, this week acknowledged that between 1985 and 1989 Iscor operated without any effluent discharge permit, which would have allowed pollution within limits. He said the Department of Water Affairs "could have taken Iscor to court" but that it preferred negotiating with Iscor and residents.

The department finally granted Iscor a permit last September allowing specified amounts of pollution, but it is alleged the company is exceeding even those limits — still a criminal offence. In their papers the applicants present figures, again culled from Iscor's own research, which seems to show that this year Iscor has consistently and significantly exceeded the permit quotas of several pollutants.

In the Iscor saga the person perhaps most closely resembling heroine Erin Brockovich is Duard Barnard, a Pretoria lawyer-turned-environmental consultant. Barnard, like Brockovich, found a large part of his ammunition when he unearthed reports that the company itself had commissioned and submitted to the water affairs department.

The main sources of pollution include a "slag dump" — a 110ha mountain of metal and other wastes dumped by Iscor on part of its property which contaminates water that percolates through it. A 1987 Iscor report says: "Although no accurate records were kept of the types and volumes of material dumped here, a wide variety of material, including potentially hazardous waste, has been disposed of over the past four decades. The base of the dump has not been lined nor has any rehabilitation taken place through the years."

Other sources of pollution include evaporation and maturation ponds — lakes of oily and acid water containing high concentrations of chlorides, sulphates and ammonia,

much of which seeps into the soil. In 1975 already a report commissioned by Iscor drew management's attention to the fact that some 400m³ a day was disappearing from the ponds.

A 1988 consultant's report details how pollutants progressively spread into the groundwater of Steel Valley, while another report from the same year states: "This was considered a sensitive issue as numerous small holdings with pumping boreholes are located to the west of the works... and could potentially draw of the polluted groundwater."

In their affidavits, community members list what they say are the effects of the pollution, including poisoned water, dying vegetation, diminished agricultural production and a drop in property values.

Privately some of the applicants say animals are dying or born misshapen, while community members suffer what they believe to be high incidences of strokes and other ailments. They acknowledge a causal link is hard to prove.

Barnard said this week that the interdict, if granted, could pave the way for further legal action.

A victory here will make it easier for these people to institute damages claims: loss of income, devaluation of property and, if it comes to that, even damage to health.

Barnard, who is working on a contingency basis with instructing attorney Anton van Aswegen, said hundreds of thousands of rands had already been advanced by community members to fight Iscor.

Horne, the community leader listed as one of the applicants, who operates a garage in the shadow of Iscor's slag dumps, said this week: "I hope that justice is just, since if it turns out not to be, I am not going to walk the way of justice either... I am not going to leave Iscor alone for the rest of my life."

US environmentalists visit Durban's toxic hot spots

Paul Kirk

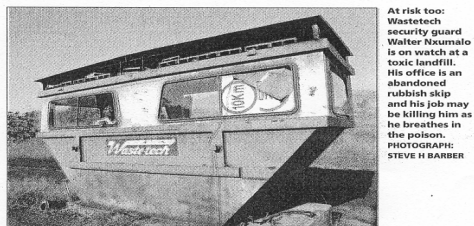
It was tourism with a difference this week as two visiting United States pollution experts were given a toxic tour of Durban.

The environmentalists — who were in town to teach Durban residents how to monitor pollution levels — were treated to, among other things, an arsenic-laced landfill near a school, and a beach where fishermen catch the family meal in water polluted with industrial poisons.

The Americans, Shira Bansal and Denny Larson, were accompanied by Bobby Peek, a well-known environmental campaigner in Durban who grew up in the heavily polluted area.

Unlike the US, where the Environmental Protection Agency carries a big stick to deal with polluters, South Africa relies on self-regulation by big business. Which meant the American duo were in for a few shocks.

First port of call on the tour was the Strelitzia Primary School in Isipingo. Two weeks ago more than a hundred pupils of the tiny school had to be treated for inhaling potentially lethal chlorine gas that escaped from the Polfin factory owned by AECI. The only warning teachers and pupils had was a siren that sounded to warn Polfin workers of the danger:



Larson brought along equipment that can be used by communities to take air samples themselves — he planned to run courses on how to manufacture and use the equipment in the coming weeks. The idea, Peek said, is that communities take the air samples and

send them back to the US for testing, as similar South African facilities are not considered up to international standards.

The school could have benefited from the equipment were it available two weeks ago, but their pollution problem is over.

At risk too: Wastetech security guard Walter Nxumalo is on watch at a toxic landfill. His office is an abandoned rubbish skip and his job may be killing him as he breathes in the poison. PHOTOGRAPH: STEVE H BARBER

The closed landfill site in suburban Umhlati is another story though. Nobody knows exactly what was dumped in the site as no one bothered to keep records.

To the shock of the Americans Peek tells the small group that he has documentary evidence that arsenic was dumped on the site. Birds and any other form of life are conspicuous in their absence. Larson holds the tour up for a few minutes to take an air sample.

Next the tour moves to a site in Isipingo where a canal flushes untreated sewage and industrial effluent into the sea. Here fishermen can be seen catching their supper.

From the view site above the beach the group is treated to a spectacular vista of refineries, factories and minor uncontrolled landfill sites stretching as far as the eye can see. But there is little time for reflection.

The last stop of the tour is a playground in Wentworth. In 1994 a chemical company owned by Engen shut down operations in Wentworth and abandoned their plant along with barrels filled with Lindane — a lethal poison. Children from Wentworth found their way into the factory and opened the barrels, poisoning their playground next door. A very toxic end to a very toxic tour.

APPENDIX A.3

The heat is on in the Arctic (Arlidge, Mail & Guardian, August 1999)

MAIL & GUARDIAN
August 6 to 12 1999

WORLD 19

The heat is on in the Arctic

Global warming is destroying the Arctic. Soon the whole world will be feeling the heat. **John Arlidge** reports from on board the *Arctic Sunrise* in the Chukchi Sea

Kilometres off the Alaskan coast a speck appears on the vast polar horizon. It is barely a dot, glistening orange in the sun's midnight rays. The *Arctic Sunrise*, a lone ice-breaker sailing through the icy wastes towards the North Pole, sets a course for it. The crew train their binoculars on the shape as it floats towards the bow, rising and falling in the dark swell. Is it a seal? An Inuit fishing boat?

The ship steams ahead at full throttle until a voice from the bridge rises above the noise of the funnel. "It's moving. It's a bear, a polar bear."

The crew watch in horror as a lone, emaciated bear paddles towards the boat. "It's so weak it can hardly swim," says the first mate. Attracted by the smell of sausages cooking in the galley, the giant male paddles forward, begging for scraps.

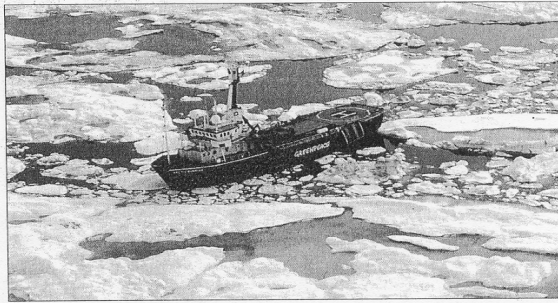
"I've never heard of a bear swimming so close to a ship," says Melanie Duchin, an environmental researcher. "Look, it's so pathetic, so hungry."

The bear paws limply at the waves and looks up at the crowd of faces on deck. As the Arctic night turns to dawn, its head sinks beneath the swell and disappears.

The *Arctic Sunrise* is just hours into its journey to the ice edge. The crew are shocked by the sight of the dying bear, but they are not surprised. For years scientists have warned that the melting polar ice cap will decimate once vast populations of the world's best-loved animals, including bears, whales and seals. The bear is proof that they are not crying wolf. The world should take notice.

Amid warnings of a potential environmental disaster that could have disastrous consequences for humanity, I joined a team of American and Russian scientists on board the *Arctic Sunrise* heading towards the North Pole.

As we sailed into Siberian waters, the captain was in the crew's nest, charting a safe route through a slushy sea. An icy mist had closed in and the temperature was -30°C.



Meltdown: The Arctic Sunrise adrift in a world turning to sludge. PHOTOGRAPH DANIEL BELTRA

It seems a miracle that anything can survive in this hostile environment. But the Arctic's ice, snow, tundra and permafrost are home to polar bears, walrus, seals, caribou, collared lemmings, Arctic foxes, wolves and musk oxen. It is also a breeding ground for migratory birds — 15% of all the world's species mate north of the Arctic Circle.

The still waters and ice floes of the Arctic may seem a natural haven, but they hide a secret. The coldest place on Earth is getting warmer, thawing out the giant ice pack that blankets the North Pole. In Alaska, northern Canada, Greenland, northern Scandinavia, Siberia and the vast Arctic Ocean, temperatures have increased by more than 1.5°C since 1965 — five times faster than anywhere else on the planet.

A slight increase in temperature may not seem to matter much in a place where winter winds force the thermometer as low as -75°C. But the Arctic meltdown threatens an environmental and human catastrophe.

Almost every living creature in the Arctic Ocean depends on ice. Humans and polar bears hunt the whales, walrus and seals which feed around it, walrus and seals live off the shellfish and Arctic cod which eat the algae that grows under it.

Now, as the floes thin and retreat north, the delicate food chain is unravelling. Lori Quakenbush, an Arctic researcher, explains: "It is cold and

dark out here for much of the year and survival is hard. Every species depends on a short food chain. Each link in that chain is vital as there are no food substitutes. If anything changes, the consequences are huge. Melting threatens everything."

Quakenbush and a group of climate change researchers have been surveying the animal population to see whether numbers are falling and the worst predictions of global warming are coming true.

Their sighting sheets make grim reading. There are not enough pups on the ice nursery. "We have seen plenty of males, but the female-to-young ratio is lower than we would like to see," said Dr Brendan Kelly of the School of Fisheries and Ocean Sciences at Alaska University. "It has gone as low as 5% of adult females, when we should be seeing around 38%. The number of one- and two-year-olds is also lower."

He concedes that there is "too much noise in the system" to be clear about the exact causes of wildlife decline, but still points the finger at global warming. "You can't pump the amount of carbon dioxide the world is pouring into the atmosphere and not have an effect. There is warming. The question is whether it's a blip or a trend."

"If it turns out to be a trend, then some models show the effect cascading through the ecosystem, melting ice

very rapidly. Animals here depend on the ice. If it disappears, so will they."

This is scant surprise to the environmentalists. Duchin, who visits the area every year, says each time it gets harder to find the animals. "The ice is much further from the shore and it is directly affecting wildlife."

As the floes retreat north, animals find it harder to breed and raise their young. Warm snaps melt bear and walrus ice dens, crushing the suckling mothers and their cubs.

Even if the young do survive, adult animals cannot always feed them because the further the ice retreats, the deeper the water and the harder it is to dive to the bottom where shellfish and Arctic cod live. Some animals can even find themselves trapped on land because the ice has retreated so far they can no longer swim to it.

Scientists predict that, if the floes go on thinning, many species — including polar bears — could become extinct within 20 years.

It is not just marine wildlife which is at risk. On land, grizzly bears, caribou, Arctic foxes and wolves have finely tuned their migration habits over millions of years to coincide with the growing season of grass, moss and lichen so that they can mate and feed their young.

But as spring arrives earlier and the tundra dries out, herds are finding it difficult to travel from wintering areas in time to feed.

About 10 000 reindeer died of starvation on Russia's Chukotka peninsula two years ago and Alaska's Peary caribou face extinction.

If the natural world is under threat in the most hostile place on Earth, the people who depend on it to survive are quick to suffer. For centuries Inuit fishermen on the Alaskan coast and at Savonoga and Gambell on St Lawrence Island have hunted whales, walrus and seals. Food used to be so plentiful that when one village landed a whale it shared the meat and blubber with other communities. Now they cannot even find enough to feed their families.

Inuits know little about the science of global warming. But they are convinced their environment is changing. Birds and insects are getting bigger. Fruits and berries they have never seen are beginning to grow. March used to mark the start of spring, but now the February sun melts the floes, stragglers the currents that sweep the ice edge further and further away from the coast.

Industrial countries spewing out carbon dioxide and other greenhouse gases through the burning of fossil fuels, including coal, oil and gas, are the prime cause of global warming. The gases trap the sun's radiation at low levels, causing temperatures to rise. As they nose-to-tail their way to work every day, few Westerners think about climate change or the Arctic. Soon, though, they might be forced to.

The region's icy waters are the world's temperature gauge. The annual summer melting and winter freezing drive the vast ocean currents that regulate the climate thousands of kilometres away.

The threat global warming poses in the Arctic and beyond was acknowledged by nearly all countries when they gathered in the Japanese city of Kyoto two years ago to draw up a comprehensive climate change treaty. Industrial nations agreed to reduce the emissions of six greenhouse gases by an average of 6% from 1990 levels, and to complete the reductions between 2008 and 2012. In most countries releases are still rising.

"Look at this sea, this ice, this sun," says Duchin. "It is one of the last places on Earth where natural conditions still prevail. That's what draws me back every year. There is no industry, no cars, few planes flying overhead, and very little pollution. But day by day, year after year, the world's leaders and fossil-fuel dinosaurs are trashing it."

For the world's last great wilderness, and the rest of humanity, the heat is on.

APPENDIX A.4

Dammed if you do, dammed if you don't (Matlou, Mail & Guardian, March 2000)

irrelevant, but delegates at an international water conference took a longer-term view

MAIL & GUARDIAN March 24 to 30 2000 29

South Africa's rural roads in a bad state

Barry Streek

The roads in South Africa's rural areas are so bad that more than half of them have to be reconstructed — and that's official.

Minister of Transport Abdullah Omar says that "over 60% of rural roads in this country are now classified as being in a poor condition".

This follows his disclosure earlier this month that the cost of the accrued backlog for the upgrading, maintenance and repair of South Africa's national roads was estimated at R3-billion at the start of the 1999/2000 financial year.

The crisis about the state of South Africa's roads, particularly for the poorest of the poor in the rural areas of the former homelands, was underlined when Omar replied to a question last week, tabled in the National Assembly by Gregory Schneemann (ANC).

He said the absence of sustainable funding mechanisms for transport infrastructure "remains a matter of serious concern".

His department and the Department of Finance has formed a joint technical committee, known as the Transport 4x4, to develop an appropriate funding approach to transport infrastructure funding.

"This process has thus far identified the trend of diverting road infrastructure budgets to fund shortfalls in government consumption expenditure in other line functions, as being a matter of great concern." Money meant to be used for the building and repair of roads is being diverted for the government's running costs.

Omar continued: "The delaying of infrastructure maintenance as a means of funding shortfalls elsewhere can only be sustained for short periods of time before infrastructure conditions deteriorate to a point where more expensive rehabilitation or rebuilding has to be done."

His department, together with the provincial and local authorities, is therefore developing "a fundamentally new approach for dedicated transport funding to be drawn from the 'fiscus' (that is, government funds)" and the government is considering charging fees for using the roads.

"I am very concerned about the continuing decline of South Africa's transport infrastructure which can only hamper the country's economic development. I will continue to argue for a comprehensive infrastructural development programme backed up by a dedicated funding mechanism."

Dammed if you do, dammed if you don't

Jubie Matlou

A compromise is on the cards between developers and environmental activists on the protracted and highly charged debate over dams and water storage.

The unfolding rapport between the two antagonistic sides emerged during a special session of the Cape Town-based World Commission on Dams (WCD) at the Second World Water Security Forum.

Developers, consisting of governments and private sector companies, are increasingly considering the impact of their bulk infrastructure projects on the surrounding communities and the environment.

It is becoming routine for many developers to adopt a set of ethics, of consulting with affected communities, providing alternative and viable resettlement options and to strive for the least possible damage to the fauna and flora in the vicinity where a dam is under construction.

Environmental activists, on the other hand, have come to accept that there are currently no viable and secure methods of water storage that could replace the multipurpose deliverables provided by dams. Many dams are the source of energy, water and sanitation, industrial production, flood control and irrigation.

The emerging spirit of compromise is best summed up by Peter Rogers, a Harvard University professor, and a panelist during the WCD session: "Diamonds are forever, but dams are time" — as a reference to the fact that some old dams in the United States have been pulled down.

The WCD was established two years ago following deliberations in a workshop hosted by the World Bank and the World Conservation Union that sought to debate the future of dams.

The commission's mandate was to solicit dialogue among all stakeholders, through consultation, input and studies.

Larshmi Jain, the WCD vice-chair, told the *Mail & Guardian* that dam construction is beset by two problems: "Firstly, the lack of consultation and proper explanation to the people and how they are to be affected by the dam and what kind of benefits would accrue."

"Secondly, the social and environmental price that has to be paid for the building of a dam."

"It's a question of equity. In many cases, people who pay the price through relocation and resettlement, for example, usually do not get benefits," Jain said.

He said it is important for people to be afforded the opportunity to choose what is good for them as a community in development projects such as dam construction.

Dr Christopher Gordon of the Centre for African Wetlands told a session of the WCD that the creation of the Akosombo Dam on the Volta River in Ghana resulted in the displacement of over 85 000 people.

"The construction of the dam unleashed negative consequences downstream."

"There was little water left for domestic use and irrigation of crops. There was also a drastic reduction in river life, leading to increased poverty as many communities relied on fishing for a living, either for domestic consumption or for selling on the market," he said.

The disturbed flow pattern of the Volta River has led to an increase in disease, particularly bilharzia, as well as water weeds and an increased acidity of the soil, making it impossible for communities to cultivate the land.

To date the most vocal objections to the construction of dams came from India's environmental groups.

The Free Narmada Campaign seeks to stop one of the most ambitious river valley projects along the Narmada River in India. The \$10-billion project plans to build 3 200 dams that would affect about 25-million people who live in the valley and reconstitute the Narmada and her 41 tributaries.

Construction work on the Sardar Sarovar Dam began in 1980, but was suspended seven years later following a successful application by the campaign to the Indian Supreme Court.

A published article by novelist Arundhati Roy states that although construction was stopped, "forests slated for submergence continued to be cut down, forcing people who depend on them to move out."

"Huge deposits of silt have developed upstream and construction has cut off access to the river, thereby forcing women carrying water pots to walk long distances to find a negotiable entry point."

Meanwhile, the WCD has commissioned 17 thematic reviews to gain an understanding of the conflict-ridden debate that characterises planning and decision-making over large dams and their alternatives.

These themes cover social impacts, environmental impacts, economic and financial issues, assessments of dams and non-dam options in providing services as well as institutional capacity and decision-making processes.

The reviews would also be informed by a cross-check analysis of 150 large dams in 40 countries, out of a total of 430 000 dams built around the world.

It is apparently this high number of dams, and their impact, that prompted Patrick McCully of the International Rivers Network to pen *Dammed Rivers* — regarded as the most authoritative work on the subject.

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APPENDIX A.5

Deadly day of sun and onions (Bowcott, Mail & Guardian, March 1999)

24 WORLD

MAIL & GUARDIAN
March 5 to 11 1999

Deadly day of sun and onions

Saddam Hussein's chemical attack on Kurds 10 years ago is still claiming victims.
Owen Bowcott
reports from Halabjah

The faint smell of gas was like freshly cut onions, Neheat Kerim remembers. It was a bright spring day, but most of the town's inhabitants were sheltering in cellars from Iraqi air raids. The bombs that mid-afternoon landed with duller explosions. The first people affected became hysterical, laughing and dancing in the streets before they dropped down dead.

More than a decade after the nerve-agent attacks that devastated Halabjah, northern Iraq, the after-effects are still claiming victims. British-backed medical studies are only now beginning to expose the extent of the casualties.

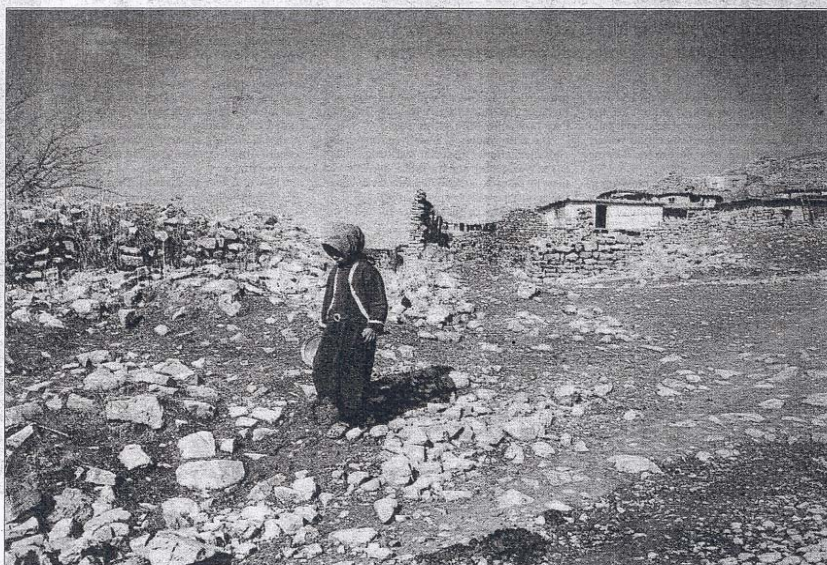
Halabjah's political significance has also endured. The use of nerve gas, on a rebellious but predominantly civilian Kurdish population, branded Saddam Hussein a mass murderer in the eyes of the international community.

The atrocity — on March 16 1988 — came in the final stages of the Iran-Iraq war. The town was controlled by Kurdish guerrillas and Iranian revolutionary guards. Halabjah is today controlled by the Islamic Movement in Kurdistan (IMK). The movement's activists carry Kalashnikovs and sport long beards in the Iranian style, without moustaches; many women cover their faces.

The events of that day, which left between 4 000 and 7 000 dead, have not been forgotten. On one roundabout, a statue portrays a father lying down, spreading a protective arm over his only son. Both were victims of the gas.

Kerim (30) thought her life was finished. "I smelled something like fresh onions, then lost my vision," she recalled. "I couldn't see anything. Some people became crazy and hysterical. I was blind for three days but recovered after being taken to Iran and given atropine injections."

Her husband Adil (30) is the med-



Fatal blow: A child plays near Anab. Many died when deadly gas blew their way as they fled to the village. PHOTOGRAPH: OWEN BOWCOTT

ical director of Halabjah's hospital. His work is dedicated to understanding the medical consequences of the attack. "The chemicals — some of the blister agents burnt through to the bone — were heavier than air," he said. "The high casualty figures were partly due to the fact that most people were in underground shelters."

"In one shelter we found more than 300 bodies. The Iraqis also used VX and other nerve agents which caused suffocation and violent spasms."

But it is the long-term after-effects that occupy him. "The first things we noticed were increases in malignant carcinomas, leukaemia, infertility in women, respiratory difficulties, miscarriages and congenital abnormalities."

Halabjah still lives with poisonous residues. When old earth houses are destroyed, workers complain of itchy skin and burning eyes. Adil Kerim has seen at least 10 cases of deformities of the spinal cord among babies, as well as cleft lips and palates.

He has been working closely with Professor Christine Gosden, a medical geneticist at Liverpool University, who visited Halabjah last year to help assess the level of illness caused by the gas attack.

Although supported by the British government, the two doctors have been frustrated by lack of equipment. The compilations of precise figures for the increase in birth defects has also been complicated by the number of refugees who have dispersed to other villages.

"We are trying to raise more funds," Gosden said. "Dr Kerim works by candlelight every night. There are no body scanners, for example, in the whole of northern Iraq. There are kidney machines but no solutions to run them; anyone who goes into renal failure is going to die."

"This is the first time anyone has tried to establish a medical assessment programme for a civilian population that has been gassed. Most studies before now have been of military men aged 18 to 25."

"There are people blinded by mustard gas burns and we don't know whether corneal transplants or special medical contact lenses will most help them," Gosden said.

"Mustard gas changes the genes. It also creates rare cancers of the head and larynx. There are victims

with long-term bronchitis, who wheeze terribly. They are not getting the drugs they need."

Everyone in Halabjah today lost some friend or relative in the attack. Wreha Brakhas (53) lost his brother.

Brakhas fled from Halabjah towards the village of Anab, but the wind blew the gas his way. "I still don't see too well," he said. "When I went back there were piles of bodies, some as though they were sleeping in their cars. The smell, some said, was like apples, others said onions."

"My brother Mansour was 65. His house was in the centre of town. He was huddled in a foetal position on the floor."

"It was like a dream, a film, seeing those men, women and children lying along the roadside, their faces turning black. How can you forget?"

APPENDIX A.6

Challenge to the AIDS dissidents (Davison, Mail & Guardian, 2000)

MONITOR

A BAROMETER OF GOVERNANCE AND DEVELOPMENT

Challenge to the Aids dissidents

The controversial stance of Aids dissidents is negated by the spread of the disease in Africa, a scientist argues

Sean Davison

Throughout history the geniuses in our midst, who have profound insight beyond most people's comprehension, have been ridiculed.

When Galileo proposed, in the 16th century, that the Earth revolved around the Sun, he was ridiculed by the public and the scientific community. We must now ask ourselves, with an open mind, whether the claims by dissenting scientists, that HIV does not cause Aids, is of a genius being ignored.

The scientific process by its very nature allows scientists to come forward with any theory, no matter how ridiculous it may seem on the surface, and put it to rigorous scientific testing and peer review. By doing this the theory can be accepted or rejected on the basis of that testing.

This indeed has been the process over the past two decades in proving the link between HIV and Aids.

President Thabo Mbeki, in launching the presidential advisory council on Aids, has chosen to ignore the vast volume of scientific data gathered by the international scientific community on the HIV/Aids relationship. The alternative view is proposed by the so-called "Aids dissidents", represented by a tiny minority of scientists.

Their viewpoint has been most frequently espoused by Professor Peter Duesberg, the international Aids dissident.

Duesberg has published widely on the subject and has impeccable credentials; these are exemplified by his election to the United States Academy of Sciences in 1986, for his work on retroviruses (the family of viruses that cause Aids).

Duesberg's seemingly most convincing argument is that he has found, in published literature, accounts of 4 621 cases of individuals with Aids diseases who show no symptoms of having been infected by HIV. He then speculates that something else must be causing Aids in these cases and suggests that this "something else" is in fact causing Aids in all the other cases.

To counter this argument one must only consider the millions of Aids cases that have been positively linked to HIV infection. The total number of cases worldwide has reached more than 20 million.

The rest of Duesberg's arguments are essentially based on his personal opinions and his criticisms of scientific research that has been through repeated testing. For example, he suggests that the presence of the antibodies to HIV and the rarity of the actual virus indicate that the immune system has mounted a successful defence against HIV.

If there are so many antibodies to the virus, Duesberg questions how the virus could possibly lead to the

collapse of the patient's immune system cells. This opinion totally ignores the huge body of scientific evidence from independent laboratories that indicates the presence of HIV at all stages of the viral infection and have shown that as the virus infection progresses, the amount of viral particles increases.

Some of the most convincing evidence for the causal relationship between HIV and Aids comes from blood transfusion studies, which show that people who receive HIV-positive blood eventually get Aids.

Duesberg has a conspiracy theory for why HIV is being sold by scientists as the cause of Aids. He suggests that it came along at the right time to prop up the research and funding interests of virological research establishments. The discovery of HIV led to vast amounts of United States federal money pouring into research to find a magic bullet cure.

Even more astonishingly, Duesberg says that if HIV really were the cause of Aids it must fit Robert Koch's postulates; he claims it does not. Developed in the 19th century Koch's postulates are used for proving the causal relationship between a micro-organism and a disease. These are:

- A micro-organism must be present in every case of the disease but absent from healthy organisms;
- The suspected organism must be isolated and grown in pure culture;
- The same disease must result when the isolated micro-organism is inoculated into a healthy host;
- The same micro-organism must be isolated again from the diseased host.

Research has shown that HIV fulfils these criteria as the cause of Aids. Researchers have documented the presence of cell-associated proviral

HIV in virtually all patients with Aids. In addition, all four of Koch's postulates have been fulfilled in three laboratory workers, who have developed Aids after accidental exposure to concentrated HIV in the laboratory.

Duesberg and his fellow dissenters to the role of HIV in Aids further cloud the issue by using meaningless data. They describe an experiment where 150 chimpanzees were infected with HIV. These chimps developed flu-like symptoms just as humans do, but then their immune systems rallied. These animals then went on to live out the rest of their lives without the characteristic ravages of Aids.

Duesberg attempts to discount African Aids as a new name for a lot of old afflictions

The dissenters relate this response to cases of known HIV-positive people who have been living for more than 10 years after being diagnosed as HIV-positive.

A more meaningful use of animal studies would have been to note that HIV is species-specific and does not cause a lethal infection in monkeys. These examples illustrate that the selective use of animal studies to illustrate scientific arguments can be very deceptive.

Having used speculation and sensation to refute the claim that HIV causes Aids, Duesberg offers his own theory that recreational drugs and the drugs used to treat Aids are causing Aids. He claims that this accounts for the high-risk status of intravenous drug users and homosexuals whose use of the muscle relaxant, amyl nitrite, has led to Kaposi's sarcoma. As for hemophiliacs and other recipients of blood transfusions, Duesberg argues that AZT, a powerful cell-killing drug developed

as a cancer treatment, is responsible for their developing Aids.

This theory is easily refuted simply because the risk factors have been around for a long time, whereas Aids was only recently identified. The use of recreational drugs has been widespread in the US since the mid-19th century.

Studies have shown that people who engage in high-risk activities such as the sharing of needles that are not contaminated with HIV do not get Aids. Therefore it is the HIV and not the risk factors that are causing Aids.

The case against AZT is even more tenuous. The evidence that AZT is beneficial to HIV-positive patients in slowing down the course of the disease is overwhelming. To date there is no evidence to suggest that the use of AZT increases the HIV disease progression or mortality. In the African context, AZT has not been used routinely in the treatment of HIV-positive patients, yet there are many cases of Aids. This clearly refutes the argument that AZT causes Aids.

Since Duesberg has based many of his theories on US cases of Aids he has ignored Africa, where Aids is believed to have originated and where the incidence of Aids is highest. Duesberg attempts to discount African Aids as simply a new name for a lot of old afflictions.

He claims Aids is diagnosed when a patient suffering from one or more of these afflictions (for example, TB, leukaemia and dementia) has also tested positive for HIV antibodies.

However, recent studies have shown that individuals testing positive for HIV antibodies have a greatly increased chance of dying in the subsequent two years than those testing negative for HIV antibodies.

In South Africa the Aids epidemic is firmly established in the heterosexual community. In 1994 it was estimated that there were 658 000 HIV-infected

females and 400 000 HIV-infected males in this country. This type of pattern cannot be put down to the use of recreational drugs or AZT.

Duesberg's claims, which have influenced the South African government's assessment of the Aids epidemic, are emotionally convincing. Although his claims fly in the face of virtually the entire scientific community, his claims are seriously undermining the education campaign to minimise the spread of Aids. Until a cure or a vaccine is available, education is the best means of preventing the spread of HIV. The damage caused to this education campaign by Duesberg's claims is immeasurable.

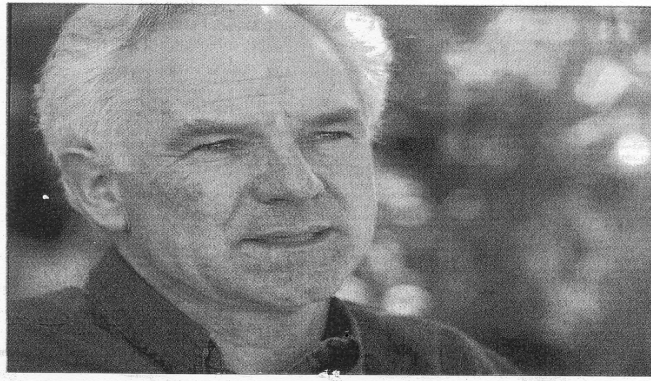
Not only does his argument excuse unprotected sex, but it may encourage HIV-positive people to neglect to seek treatment for the disease. This will be particularly unfortunate for HIV-infected pregnant women who may increase the risk of transmitting HIV to their infants by foregoing anti-HIV treatment.

If Duesberg is so convinced of his theories, I wonder whether he is prepared to put them to a scientific test by sharing a needle with a patient who is HIV-positive. I would willingly put his drug theory to the test by accepting a treatment of a non-hallucinogenic drug such as amyl nitrite. The scientific evidence clearly indicates that Duesberg would have a very high chance of contracting Aids in such an experiment, while I would not, since I would not be exposed to HIV.

One cannot help but suspect that Duesberg will not accept this challenge because he is making his claims simply for the sensational impact they will cause, and the fortune he will make from the sales of his book.

Sean Davison is a virologist and head of microbiology at the University of the Western Cape

Difference of opinion: Professor Peter Duesberg has come under fire for his theory that there is no link between HIV and Aids. PHOTOGRAPH: AP



tion Rispel, there are broader issues relating to

APPENDIX A.7

- Mixed messages from government (Mail & Guardian reporters, March 2000)
- Politicians unwilling to accept stubborn science (Le Page, Mail & Guardian, March 2000)
- Irrational AIDS debate rides rough-shod over patients (ka-Mankazana, Mail & Guardian, March 2000)

32 MAIL & GUARDIAN March 10 to 16 2000

The opportunity to institute a constructive policy to deal with the HIV/AIDS epidemic is slipping

The majority consensus

Mail & Guardian reporters

The vast majority of clinicians the world over reject the view that HIV and AIDS are not causally linked and that AIDS does not exist. The National Institutes of Health in the United States, drawing on research from around the world, issued a rebuttal of the dissident view. This rebuttal has the full support of the Southern African HIV Clinicians Society.

• HIV and AIDS have been repeatedly linked in time, place and population group; the appearance of HIV in the blood has preceded or coincided with the occurrence of AIDS in every country and region where AIDS has been noted.

• Among individuals without HIV, AIDS-like symptoms are extraordinarily rare, even in populations with many AIDS cases.

• Individuals as different as homosexual men, elderly transfusion recipients, heterosexual women, drug-using heterosexual men and infants have all developed AIDS with only one common denominator: infection with HIV.

• Laboratory workers accidentally exposed to highly concentrated HIV and health care workers exposed to HIV-infected blood have developed immunosuppression and AIDS with no other risk factor for immune dysfunction.

• Scientists have found HIV in virtually every patient with AIDS and showed that HIV is present in large and increasing amounts even in the pre-AIDS stages of HIV disease.

• Researchers also have demonstrated a correlation between the amount of HIV in the body and progression of the aberrant immune and metabolic processes seen in people with AIDS. Despite this plethora of evidence, the notion that HIV does not cause AIDS continues to find a wide audience in the popular press, with potential negative impact on HIV-infected individuals and public health efforts to control the epidemic. HIV-infected individuals may be convinced to forego anti-HIV treatments that can forestall the onset of the serious infections and malignancies of AIDS. Pregnant HIV-infected women may dismiss the option of taking AZT, which can reduce the likelihood of transmission of HIV from mother to infant. People may be dissuaded from being tested for HIV, thereby missing the opportunity for counselling as well as treatment. Such prophylactic measures prolong survival.

• Most troubling is the prospect that individuals will discount the threat of HIV and continue to engage in risky sexual behaviour and needle sharing. If public health messages on AIDS prevention are diluted by the misconception that HIV is not responsible for AIDS, otherwise preventable cases of infection may occur, adding to the global tragedy of the epidemic.

Mail & Guardian reporters

Minister of Health Manto Tshabalala-Msimang confirmed last week that her department is busy setting up a panel of approximately 30 local and international experts "to explore all aspects of the challenge of developing prevention and treatment strategies for HIV/AIDS that are appropriate to the African reality".

The announcement of names of panel members is eagerly awaited, in the context of widespread scepticism about the government's motives in setting it up.

Tshabalala-Msimang's statement followed an earlier report, based on an interview given by her special adviser, Dr Ian Roberts. The report, from Sipu, speculated that the panel would be asked to evaluate the claim by California biochemist Peter Duesberg and other AIDS dissidents that HIV is not the cause of AIDS.

The minister dodged the question of whether Duesberg had been approached to serve on the panel, but commented that her "personal view is that those with more extreme views are unlikely to participate because we are looking for a consensus view". She also stated that she would welcome suggestions for panelists.

She said the panel would convene as soon as possible to agree on their terms of reference in consultation with her department. They would be encouraged to publish their views, which would be available on the Internet, over a period of six to eight weeks. There would then be an attempt to "thrash out a consensus recommendation to the department".

Some of the issues which she would encourage the panel to review included the treatment of HIV/AIDS and opportunistic infections; general prevention of the disease; prevention of mother-to-child infections; prevention of HIV infection following rape or "needle-

stick" injuries; and local evidence regarding the causes and diagnosis of AIDS and opportunistic infections.

On whether the government would revisit its refusal to supply anti-retroviral drugs to pregnant women with HIV/AIDS, Tshabalala-Msimang replied that if the panel came to a different conclusion, she would give it serious consideration — although an ingenious solution to the funding challenges would be required.

But she defended the government's decision, saying that it had been taken "in the light of the best available evidence and the special social and economic circumstances in our country".

"I still think it's the right decision", she said. Asked whether the panel would be free to come to its own conclusions, Tshabalala-Msimang replied: "I can't imagine that top scientists will accept anything else."

She added, however, that it was the prerogative of the government to make a final

Politicians unwilling to accept

David Le Page

AIDS has attacked the intellectual resources of sections of the body politic as successfully as it has assaulted the immune systems of many South Africans.

The heart of the problem appears to be a profound misunderstanding on the part of the president, successive health ministers and their immediate advisers of the nature of science, how it advances and how to make use of its insights.

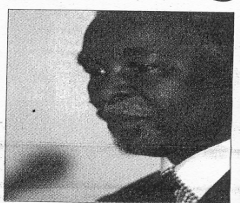
Several debacles reflect these misunderstandings, the first being the Virodene affair. A Pretoria company invented this so-called treatment based on a dry-cleaning solvent. Exhilarated by a presentation to the Cabinet on the drug's purported wonders, then deputy president Thabo Mbeki and then health minister Nkosazana Dlamini-Zuma threw their weight behind the researchers.

When the Medicines Control Council (MCC), which regulates trials of new and untested drugs, rejected the proposals for Virodene trials, Mbeki attacked it furiously. He accused the body of denying AIDS sufferers "mercy treatment". The African National Congress accused the MCC of "censoring" research and protecting vested pharmaceutical interests.

The affair culminated in Dlamini-Zuma's dismissal of two of the MCC's top officials, both later reinstated by the Commission for Conciliation, Mediation and Arbitration.

Another continuing controversy is the Department of Health's refusal to fund the anti-retroviral drug AZT for pregnant women in an effort to stem mother-to-child transmission.

As long as the argument against using AZT was couched in terms of how best to make use of existing resources, it left science unscathed.



Thabo Mbeki: Supported Virodene but appears to question the HIV-AIDS link



Nkosazana Dlamini-Zuma: First health minister to reject anti-retroviral therapy

But forced on to the defensive by attacks on the policy, the government has turned to attacking the very science behind AZT. In November, Mbeki declared that AZT is dangerous. His health minister, Manto Tshabalala-Msimang, said that AZT produces congenital defects in babies.

These notions are at odds not just with international knowledge and practice but with local experience.

Researchers at the UNAIDS programme in Geneva, and at Chris Hani Baragwanath and King Edwards hospitals, to name but a few, have plentiful evidence suggesting that AZT is the state of the art in preventing mother-to-child transmission, with benefits outweighing known risks.

What are the scientific missteps and mistakes demonstrated by these events?

There is a lack of an adequate information management system to intervene appropriately. The good suggestion that people should be tested for HIV anonymously, which could be applied to all target age groups to show what drives the epidemic, was slow in coming.

Are there any "bridging communities" that have been overlooked which are pivotal in driving the epidemic in some geographical areas?

There is a tendency for over-reliance on antenatal HIV testing to assess the size of the problem rather than as a monitor of the effectiveness of intervention measures. Combating AIDS/HIV has come to be seen as an eclectic area.

The politicians and the scientists are now seen as the only people with enough wisdom to make things happen. What about inputs from the social

sciences, religious groups, the lay members of the community (*izakha muzi*) and the like? What is their role in fighting this enemy at their door?

The existing approach is not in keeping with the presidential statement on this issue delivered on October 9 1998 that our aim was "to defeat the spread of HIV/AIDS lies in our partnership, woman, worker, religion, parent, teacher, student, leader, farmer, young and old, rich and poor hands as partners against AIDS."

The kind of questions the public out there are asking are: What areas of intervention are now operative? How well are we doing in these areas (strengths and weaknesses)? What then are the gaps in our intervention strategy in South Africa?

To start a dialogue about these questions, one has to divide the AIDS/HIV scenario into three areas. One is the biological features of HIV, the

'Irrational AIDS debate rides rough-shod

Mxolisi ka-Mankazana

South Africa is falling in its fight against HIV/AIDS at a time when other countries that have less economic, political and scientific clout than we do, such as Uganda and Tanzania, are gaining ground against it.

This is despite the appointment by the previous health minister of a special director to deal with the epidemic, and although we have seen high profile publicity by the president which involved a train ride from Pretoria to Cape Town.

There has been the realisation that all is not well with the Department of Health's strategy to combat the epidemic, resulting in the president appointing a national council. This will, hopefully, lead to the appointment of a task force as a strategy to orchestrate and collate all aspects of a total onslaught against AIDS.

The government has shown ambivalence in fighting the epidemic. On the one hand it has pushed for Virodene, despite its serious side effects, while on the other it has rejected AZT therapy for pregnant women because of serious side effects.

There appears to be a rift between the politicians and scientists on the ground regarding prophylactic therapy for pregnant mothers. The minister of health has rejected two reports from the Medicines Control Council about the efficacy of anti-retroviral treatments like AZT. The government is also sitting on the reports of two research projects by the Medical Research Council in favour of the use of anti-retroviral agents.

There is irrationality in the content of the debate around the fight against the epidemic, and the issue is becoming merely a political football. This poses the danger that the powers that be

might ride rough-shod over doctors who are passionate about the plight of AIDS/HIV victims.

There is a lack of an adequate information management system to intervene appropriately. The good suggestion that people should be tested for HIV anonymously, which could be applied to all target age groups to show what drives the epidemic, was slow in coming.

Are there any "bridging communities" that have been overlooked which are pivotal in driving the epidemic in some geographical areas?

There is a tendency for over-reliance on antenatal HIV testing to assess the size of the problem rather than as a monitor of the effectiveness of intervention measures. Combating AIDS/HIV has come to be seen as an eclectic area.

The politicians and the scientists are now seen as the only people with enough wisdom to make things happen. What about inputs from the social

sciences, religious groups, the lay members of the community (*izakha muzi*) and the like? What is their role in fighting this enemy at their door?

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APPENDIX A.7 (Continued)

out of reach as politicians and scientists argue over who knows best

government

decision about their recommendations. Tshabalala-Msimang denied accusations by the Treatment Action Campaign (TAC), following Roberts' initial announcement about the panel, that it was "a justification for the immoral, unscientific and unlawful decision to withhold AZT or Nuvirapine from pregnant women".

"I hope that the work of the panel will demonstrate that we have no hidden agendas", she countered.

It is difficult to see how the government could benefit from any further advice on the issue of using anti-retroviral drugs to prevent mother-to-child transmission of HIV. It has rejected two reports from the Medicines Control Council, and has not yet officially reacted to a third report from the same body — none of which it is prepared to make public.

It also has in its possession additional reports from the Medical Research Council and the World Health Organisation. All of these re-

ports are believed to support treatment using anti-retroviral drugs, but they are based upon the premise that HIV causes Aids.

The TAC also challenged both the minister of health and Roberts to state whether or not they support the Duesberg claim that HIV is not the cause of Aids, noting that it has been discredited by the international scientific community. Roberts has subsequently issued a statement confirming that he does not support the dissident view but, interestingly, Tshabalala-Msimang appears to have ignored this challenge.

She is known to have met prominent Aids dissident Charles Goshaker of California State University, during a visit he made to South Africa in December.

According to Sapa, yet another prominent Aids dissident, David Rasnick, claims to have been contacted by President Thabo Mbeki in January for advice. Mbeki's office has refused to verify or deny this claim.

stubborn science



Manto Tshabalala-Msimang: Still thinks withholding AZT is 'the right decision'

intention to form a new committee of "international experts", reportedly for the purpose of re-evaluating the evidence that HIV causes Aids. Mbeki is said to be about to lobby everyone from Bill Clinton to Tony Blair for "a new look" at Aids science.

The implied suggestion that scientists are not, as an international community continually re-examining and assessing Aids treatments, biology and theories, risks making South Africa seem the scientific equivalent of the North Korean polity.

According to David Sapiro, a Wits academic who teaches the philosophy of science, "the operation of a committee in science can be either good or bad or indifferent."

But scientific committees do not establish

scientific truth. "Certainly, they couldn't sit down and take a vote on the issue," said Sapiro.

At the most, they could establish a research group, which could then come up with its own conclusions. Even then, those conclusions would be subject to peer review.

"If the purpose [of the committee] is to reassess the science of Aids, it's the last thing we need in South Africa at the moment," says Mark Heywood of the Aids Law Project.

Heywood argues that scientists should rather be enlisted to assist with leveraging existing Aids know-how. "We're probably acting on 5% of our knowledge of Aids. We don't need to be creating new academic discourses. Why isn't anybody objectively sifting the results that we have, in order to formulate a sensible policy?"

"If they appoint the accepted leaders in HIV research, what do they expect them to do? Do their research all over again?" asks Sapiro.

The disregard for science and scientists appeared yet again at the end of January when a national Aids council was appointed — without including any conventional medical experts (though two traditional healers made the grade).

Sapiro points out that if the government's new scientific committee conducted its own research, it "might not get the answer it wants".

"They're looking for shortcuts, and therefore willing to rubbish the views of the scientific community. With AZT they're once again trying to create a red herring, trying to get away from the costs," says Heywood.

This is the heart of the problem: the government wants particular answers to the Aids problem. Accustomed to political answers that can be negotiated and economic answers that can be argued till the cows come home, it is affronted when science cannot play ball.

over patients'

second the epidemiological pattern/s, and the third intervention components of the epidemic.

Biological scientists need to tell us: What is the up-to-date scientific knowledge about this virus? Do the scientists know all that needs to be known to intervene? What are the gaps in our knowledge base regarding this virus? Do vaccines hold any favourable future for us, or will their contribution be marginal, just as the tuberculosis vaccine has been? How far are we in producing the vaccine in terms of stage of production and availability for clinical use?

Epidemiologists who deal with the factors that drive and perpetuate the epidemic must tell us: What are the critical demographic factors? Are there any "bridging groups" we have not yet identified that drive the epidemic? What are the various sexual behavioural patterns that spread the epidemic to different geographical locations?

What is the role of the socio-economic status in the likelihood of infection? What are the salient socio-cultural factors — for example, circumcision, indigenous value systems, religious influences on moral behaviour — in the spread of the disease. Are there any cultural no-go areas of a kind that cannot be included in the dialogue?

The intervention strategy must be multifaceted. It must be everybody's business. We must identify clear roles for politicians, biological scientists, epidemiologists, clinicians, all age groups, civic organisations, religious organisations and each one of us. We must empower people to make informed decisions for themselves and their communities so that we can all play our role against the common enemy.

Mxolisi ka-Mankozana is director of the Health Development Institute



Impassioned plea: 'We must empower people to make informed decisions for themselves and their communities so that we can all play our role against the common enemy'

The dissident view

Anita Allen

The idea that a virus, HIV, causes Aids remains merely a hypothesis until it is proven true. There is, as yet, no such proof. Moreover, HIV tests are non-specific and tend to cross-react, yielding false positives.

The definition of the syndrome (the "s" in Aids) has been changed over the years. Originally a few uncommon and rare illnesses, such as *Pneumocystis carinii* pneumonia and Kaposi's sarcoma (a type of cancer) were classified under the syndrome.

Now, however, more than 30 diseases, none of them new to the people of Africa, have been so classified. If you test HIV-positive, and have any of these diseases, say tuberculosis, then you are said to have Aids. If you test HIV-negative, then you are said to have tuberculosis.

In Africa if you present yourself at a clinic with a cough, or fever, or chronic diarrhoea, or weight loss, you may not be tested at all and still be classified as having Aids — and you could be sent home without treatment.

All of these conditions can be far better explained on a continent where half the people do not have access to drinkable water, adequate food or shelter and public health systems — a continent which, moreover, harbours a range of tropical diseases, parasites and other microbes unknown in colder climates.

African sexuality is said to explain the spread of HIV/Aids in Africa. Like it or not, sexual transmission of HIV is no more than anecdotal. So, too, is the view that health care workers are infected through needle injuries. As it stands, there is not a single published paper demonstrating either of these propositions. But several papers indicate that sexual transmission of HIV, if indeed it exists, is improbable.

It is precisely because there is no clarity about what is meant by HIV or Aids that they are lumped together as one thing — and used interchangeably. If one has HIV, then one is said to have Aids, and vice versa.

The problem, however, is that many

HIV-positive people remain perfectly healthy. This would, ordinarily, be considered a falsification of the HIV/Aids hypothesis. Instead, however, it merely led to the hypothesis being amended to incorporate the suggestion that the virus could have a period of latency of 20 years or more.

If at any stage an HIV-positive person dies of some ailment, then they are said to have died of Aids. Many people who have Aids-indicator diseases are, however, HIV-negative. Some seroconvert to HIV-positive months after being diagnosed with Aids. In that case, effect has preceded cause. How can that be? Others diagnosed with Aids have remained HIV-negative to the end. So, we have the effect, but the proposed cause is entirely absent.

In the United States, in the early 1980s, modelling of viral infections predicted rampant spread of HIV and Aids to heterosexuals. But this did not occur. Apparently HIV is able to distinguish not only sex but sexual inclination.

So the definition of Aids was changed to include more indicator diseases. When anomalies appeared, however, especially in Africa, where HIV infection is estimated to be evenly distributed between males and females, unlike in the US where it is mainly among males, the definition was changed again. So HIV can also apparently distinguish which continent one is on.

The conclusion is unavoidable: however varied and complicated the observed conditions, HIV/Aids proponents are determined to explain them on the basis of the interaction of the causal virus. If the preconditions don't work, they change the definition, and make the Aids net larger. If no two experiments show the identical virus, this is said to be because it mutates too quickly. New factors are always shoehorned into the point where there is virtually no disease to which HIV cannot be causally linked.

South Africa needs open and vigorous debate on these issues.

Anita Allen is a freelance science journalist

APPENDIX A.8

TV station seeks Bezwoda patients (Magardie, Mail & Guardian, March 2000)

TV station seeks Bezwoda patients

Khadija Magardie

The leading United States television news network, ABC, has drafted advertisements for the South African press seeking patients who were part of Dr Werner Bezwoda's discredited clinical trials into breast cancer treatment.

The advert calls on women who were part of Bezwoda's breast cancer trials at Johannesburg hospital to come forward to tell their stories, according to ABC.

The channel's popular current affairs programme 20/20 will be airing the first of its two-part programme this week. The first programme will focus on the ethical issues relating to Bezwoda's research, and how it has dealt a severe blow to advocates of bone marrow transplants for the treatment of advanced breast cancer.

The continued interest by the US media in one of South Africa's biggest-ever medical scandals comes as the University of the Witwatersrand wraps up its disciplinary hearing into Bezwoda.

The disgraced academic and researcher was due to stand on Friday before a panel comprising the university's ethics committee and industrial relations representatives.

The American Society for Clinical Oncology (ASCO), whose investigations prompted Bezwoda to admit he fiddled his cancer trials, will have representatives present as observers. It is believed that the team from ASCO may be called as witnesses. The provincial health authority also has two observers at the hearing.

The probe is two-fold because Bezwoda was employed as a researcher by the university and as a professional oncologist at Johannesburg hospital, but the hearing is primarily concerned with Bezwoda's alleged violation of the university's disciplinary code.

The provincial Department of Health has compiled its own "charge sheet" against Bezwoda, which it has referred to the Health Professions Council, a regulatory body that has the power to censure medical professionals found guilty of misconduct.

According to the Gauteng chief director of hospital services, Dr Lantitia Rispel, there are broader issues relating to ethics and prospective preventative measures which necessitate the intervention of the Health Professions Council.

The council has the power to institute various disciplinary procedures, ranging from a warning, to fines, to striking professionals off the medical register. This effectively bars

them from practicing elsewhere for either a limited amount of time, or indefinitely.

Rispel says that Bezwoda's actions had "both ethical and resource implications", because he used state resources to treat state patients.

The departmental "charge sheet" accuses Bezwoda of "unbecoming conduct", in terms of the public-sector code for health professionals. It also accuses him of "fraud pertaining to the use of patient names and hospital file numbers". Bezwoda

was unable to furnish records of over half the women he claimed to have treated. Doctors believe Bezwoda either merely used the details of standard patients, who were not in fact part of any clinical trial, or made up patients.

Because Bezwoda's trials were conducted as far back as 1991, Rispel says it has been difficult to track down any of the patients.

Hospitals are legally required to keep records for only up to seven years. Most of the women had

advanced-stage breast cancer, and may be long dead.

Bezwoda, an internationally renowned oncologist, admitted formally last month to faking the results of clinical trials he conducted into the treatment of high-risk breast cancer.

At a conference in the US last year, Bezwoda presented his findings to an international gathering of experts, showing that breast cancer could be effectively treated by high doses of chemotherapy, followed by

bone marrow transplants.

Because his results dramatically contradicted those of other researchers, a group of scientists were sent to study Bezwoda's techniques.

They discovered that not only had Bezwoda misrepresented the names of the drugs used in his trials, but that he had sidestepped the university's ethics committee in getting approval for his research. He also failed to get signed consent from the indigent black women who participated in his study.

You destroyed a career

Congratulations on destroying yet another brilliant career. Have you nothing better to write about? For 22 years I have been a patient at the oncology (cancer) clinic. I have yet to see anybody with the same dedication as Professor Werner Bezwoda. You crucified a good kind, soft person that had enough silent sorrow to bear.

Who are you to judge? I am a patient of Bezwoda's, and your reporters may one day join us in striving for life. Where we lived on borrowed time. — Cornelio Smir

More letters on PAGE 24

Write to: Letters, PO Box 91667, Auckland Park, 2006.
Fax: (011) 727-7111.
E-mail: letters@mg.co.za (Please include your name and address).
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APPENDIX A.9

Human organs made to order (Bullen, Mail & Guardian, March 2000)

Human organs made to order

MAIL & GUARDIAN **Science 2000** March 24 to 30 2000 **5**

Sarah Bullen

Movies have enjoyed a long love affair with the idea of cloning. Indeed the fantastical promise that scientists can exactly replicate a human seems more suited to a flickering image on a screen than reality.

But while movies have focused on creating clones from human parts, science is looking at the reversal of that notion — creating a part of a human through cloning. Human organs, made to order and grown in laboratories by scientists, could be on the agenda.

The possibility of cloning humans has led to vociferous ethical debate, which rose to a crescendo following the 1996 birth of Dolly, the cloned Poll Dorset sheep.

In the four years since Dolly was born, not only have mice and cows been added to the clone list, but also a sheep with a human gene added into its make-up has been born.

So rapid has been the advance of cloning techniques, and the increased possibility of human cloning, that ethical watchdogs have been left struggling in the wake of science.

The focus has now shifted to the use of cloning techniques in providing therapeutic value for humans, especially with respect to growing organs.

Organ transplantation currently presents the patient with two serious hurdles: a shortage of donors coupled with the chance that the body will reject the donor body part.

Even if a new organ is successfully transplanted the patient has to take strong immune system suppressing drugs for the rest of her life to inhibit her body from rejecting the new organ.

Techniques developed in cloning present the possibility of being able to grow organs from the actual cells of the patient. Originating in



Man-made: Dolly, the controversial clone, and her baby, Bonny

the patient's body, such transplanted organ parts would be accepted by the immune system.

Human development begins when a sperm fertilises an egg and creates a single cell. Progressive cell division and specialisation result in a foetus and then a baby.

But as the embryonic cells divide and specialise, they lose the ability to generate an entire organism. Instead they develop into stem cells that are able to recreate specialised types of cells. Specialised stem cells found circulating in the blood and bone marrow are already being used to restore the blood and immune systems of pa-

tients, but only embryonic stem cells have the potential to create organs.

Take the quest to grow a pancreas. There are several approaches to solve this from a scientific process, all fraught with ethical minefields.

One method would be to take a cell from the patient and inject the nucleus of the cell into a donor egg that has had its nucleus removed.

This type of cloning is called somatic cell nuclear transfer (SCNT). Scientists could — did legislation not prohibit it — then introduce a gene in the egg that counteracted the pancreas dysfunction of the patient. The egg could then be implanted in a woman's uterus in the same way as current methods for in vitro fertilisation. The child produced this way would be the identical twin, a clone, of the donor. A sample of the clone's pancreas could then be transplanted to save the patient's life.

Equally controversial, however, are proposals to abort the foetus and remove and use the embryonic organs for transplantation. It is conceivable that, in the future, scientists would be able to create an artificial uterus, overcoming the need for inhibiting and then terminating pregnancies. Presently research is restricted to using cells derived from human embryos taken from in vitro fertilisation clinics. But even here ethics and science collide.

In order to get around the raging debate sparked by the use of embryos, scientists have turned to methods of growing embryonic stem cells in a laboratory.

This process relies on SCNT. Sue Kilsdonk, an associate professor in the department of anatomy and cell biology at the University of Cape Town, uses the example of a patient suffering from muscular dystrophy.

Using SCNT, the nucleus of any somatic cell from the adult patient could be fused with a donor egg from which the nucleus has been re-

moved. In a laboratory the cell would develop into an embryonic structure called a blastocyst. Cells in the middle of the blastocyst are embryonic stem cells.

These cells can then be isolated and given a stimulus to develop into muscle cells. "As the cells specialise you can actually see them contract (like muscles) in the dish," said Kilsdonk.

The cells could be transplanted into the muscles of the patient with the hope that they will interact with existing cells, reproducing to stop the degeneration of the muscle.

These types of experiments are currently being tested in mice in various parts of the world and recently a scientist in California reported the successful growth of human embryonic stem cells. However, the tissues grown this way are by no means normal organs yet, says Kilsdonk.

Another, less controversial approach is to stimulate the body to regrow its own lost or diseased organs. Some parts of the body are able to regenerate, but others seem to have lost the ability. For example if you chop off the leg of a newt, the limb will regrow, but human limbs seem to have lost this facility.

Scientists currently think that somehow, in parts, the cells of the limb stump wake up and begin to grow as though they are in an embryo. But this does not happen in the cells of a human, or any other mammal.

Scientists have long been searching for the signal to nurse cells in the nerves, muscles, kidneys, heart and even limbs so that new organs can grow. But in the absence of finding this trigger, science will waste no time in experimenting with growing and harvesting new organs.

Professor Sue Kilsdonk will be lecturing on Saturday, April 1, in the Monument Olive Schreiner Hall at UCT.

APPENDIX A.10

A gene scientist who are remarking human life (Porter, Mail & Guardian, May 1999)

28 INSIDE SCIENCE

An elite band of thinkers is shaping our destiny. **Henry P.**

The gene scientists who a

It all started in the mid-1980s when an excited gleam appeared in the eyes of a number of molecular biologists and biochemists.

This was the outward sign of a dream that one day the entire human genome (the 70 to 100 000 genes that add up to a blueprint for a complete human) would be sequenced — laid out in a kind of vast map — then filled, divided up and analysed. It was a big ambition and only they fully appreciated its magnitude. To the rest of us, perhaps the project seemed bafflingly

expensive (more than \$3 billion) and irrelevant to ordinary life.

But now — just half a century after James Watson and Francis Crick discovered the double helix structure of DNA and effectively invented modern genetics — we are approaching a big moment in humanity's understanding of itself. But while this revolution is about understanding, it is also about a powerful technology that we will use to wrest control from the randomness of nature.

The publicly funded Human Genome

Project should produce a rough draft of the great map within a year. Some 20 organisms have been sequenced, the largest of which is a worm called *C. elegans*, with 19 000 genes, just completed by the Sanger Centre in Cambridge in the United Kingdom.

The average human has about 80 000 genes, which consist of three billion bits of information. The function of most of these genes is unknown and years of research lie ahead to figure out which particular genes are responsible for the traits, talents and flaws of mankind — athleti-

The maverick

Name: Kary Mullis
Institution: Independent
Field: Invented polymerase chain reaction

Only rarely can you say of a scientist that, without him or her, the world would be a different place. But it is true of Kary Mullis, who is an integral part of the history of the genetic revolution. Mullis is an unlikely member of the biologist's team, because he is a chemist, and one with leanings towards mathematics and physics. He has an animated curiosity and a mind that roams over many areas of science. He has invented a plastic which changes colour when exposed to ultra-violet light; he dabbles in astrology, talks about "astral planes" and LSD, and has some original ideas about Aids he believes that the disease is not caused by HIV.

I met him at a friend's house in a small town near his roots in North Carolina. He arrived awkwardly smiling and leaking energy like an adolescent. He is polite in the Southern way, and has the accent of his childhood, although his speech has been influenced by West Coast surfers.

He doesn't look at you much, except when he concentrates on a question; then his eyes have an open, hypnotic quality which makes you want to look away. He likes to drink and sip from a large glass of red wine. His face occasionally breaks into a broad smile, as if he is touched by the pleasure of his own ideas.

Back in April 1983, Mullis had applied his brilliant, unbound mind to the problems chemists think about when they are bored. He was driving up to his cabin in Anderson Valley, California, where the redwoods grow. He began to think about a particular problem. Suddenly, he experienced a rush of thought that was to change biology and open up great possibilities, although he had no idea of its impact at the time.

This is how he describes it in his book, *Dancing Naked in the Mind Field*: "My little silver Honda's front tyres pulled us through the mountains. My mind drifted back into the lab. DNA chains coiled and floated. Lured blue and pink images of electric molecules injected themselves somewhere between the mountain and my eyes."

The problem was how to find a chemical process to target specific lengths of DNA in billions of base pairs of genetic code. How could he get a usable quantity of this fragile, tangled material?

That to arrange a series of chemical reactions, the result of which would stretch the DNA," he writes. His mind ran through a series of reactions that would define and isolate the target. Then he realised that one of the reactions, involving polymerase, a naturally occurring enzyme that takes part in forming DNA, would double the target sequence. That's its job — copying DNA naturally. And it would repeat and repeat.

He stopped the car, found a pencil stub and paper, and began to calculate. What he was contemplating was a chain reaction and it was clear that, if it worked, it could generate a huge number of copies of the target DNA very quickly. Today PCR (polymerase chain reaction) machines can produce 100 billion copies of a targeted sequence in an afternoon.

The process is hard to understand if you are not a scientist, but to Mullis it seemed shockingly simple, so simple that he assumed it must have been already invented. Not so. All the constituent parts of PCR were known for 15 years and waiting to be put together.

It took a while for Cetus Lab, where Mullis worked, to make PCR a reality, and it subsequently challenged Mullis's authorship, saying that it had contributed as much to the development of the process as he had. At length, when another company, the multinational giant Du Pont, tried to claim that PCR had been developed 10 years before in its laboratories, Cetus employees had to back Mullis's account of the invention in court.

He was subsequently awarded a Nobel prize, but was only given a \$10 000 bonus by Cetus. It is fair to say that relations between Mullis and his former colleagues are still sour.

I asked him whether PCR and its contribution to the efforts to map the human genome bothered him.

It was PCR that allowed the rapid identification and amplification of parts of the human genome which will be analysed and used to change humanity.

"I am basically an optimist about having control of future generations. A lot of people don't think about this, but when I am choosing a wife I am basically choosing some traits I would like my children to have. You don't just randomly mate with a female, you study her traits and make a selection."

"We have been breeding selectively for all time. You would like everyone to be funnier, wouldn't you? Be smarter, happier, more successful, better at sports, have a better intellect, wouldn't you? Those kinds of options will be available to future parents and it doesn't bother me."

Mullis is in his fifties, but there is a lot of the boy prodigy about him and he used to have a reputation for hell raising. Scientific conferences all over the world were enlivened by his behaviour.

Mullis's mind is often in a state of free association, but this doesn't seem to stop him making important connections.

"It is interesting that biochemistry developed alongside computers. If computers had not come along at about the same time as the structure of DNA was discovered, there would be no biochemistry. You always needed the computer to process the information. Without it we would have



Kary Mullis: "We have been breeding selectively for all time"

rooms and rooms full of monks writing out the sequences."

You could say the same about PCR. Life without PCR would be very different. It is used in police investigations to identify fragments of DNA to prove a suspect's presence at a crime scene. It has become an essential part of medical diagnostics, and in archaeology it has opened enormous possibilities.

To the Human Genome Project, Mullis has contributed one of three important elements (computing and the sequencing method being the other two).

Now he has plunged into another project, a still secret method of diagnosing illness by machine. In *Star Trek*, he points out, they have a doctor who is a hologram, and not human. "That makes sense to me."

APPENDIX A.10 (Continued)

A gene scientist who are remarking human life (Porter, Mail & Guardian, May 1999)

Porter spoke to the scientists who are manipulating human genes are remaking human life

claim, a weak heart, a pug nose. Beyond this there are goals of almost unimaginable computation — how the genes that come together in one person interact and combine to produce the unique individual. The combination of genes that is formed when two humans mate successfully must have an almost incalculable potential.

If, for example, it had been possible to present scientists with the two relatively ordinary genetic profiles of a couple living in 16th-century Warwickshire, it seems unlikely that they could have predicted that the baby born on April 23 1564, would have the genius of William Shakespeare. Who knows, maybe when the third or fourth generation of DNA computers are in action, such a prediction will be possible.

In the next 25 to 35 years we can expect to see genetic manipulation of human embryos as routine practice. We will be able to eliminate inherited diseases, and solve many problems about aging. Tissue engineers will use genes they have located in the human genome to grow body parts:

skin and cartilage have already been made. There will be elaborate gene therapies that will discreetly reprogramme organs without the need for invasive surgery. In the United States, a scientist has modified the Aids virus to carry instructions to the nucleus of cells; another uses the temporary deployment of an adapted cold virus to create new blood vessels in a damaged heart.

A period of huge discovery is under way and it will alter countless areas of our culture and our history. This came home

The prophet

Name: Lee Silver
Institution: University of Princeton
Field: Genes and the brain

Lee Silver works with mice. He investigates the genes that predispose mice to certain behaviours. Some mice are social, others aggressive or predisposed to alcoholism, anxiety, curiosity, easy affiliation and even, in one tantalising discovery, autism. Each characteristic is inherited because of a particular gene which dominates and determines the temperament of a mouse for its entire life. In rodents, nature wins hands down over nurture.

But this is not true for humans, where conscious decisions can be made to resist patterns of behaviour. Humans may resist vulnerability to addiction or bad temper. And genes indicating certain behaviours in a person will be expressed differently according to environment.

"In one culture, people with aggressive genes are going to be just a little more assertive," said Silver. "But people growing up in the ghetto are likely to explode with violence. The same genes have totally different effects in different cultures."

Silver stresses the mouse-human difference to encourage us to resist the determinism of modern genetics. We are about to acquire enormous amounts of information about our own, and each other's, inheritances, and Silver believes we must understand that we are not, like the mouse, prisoners of our instincts.

But there are exceptions that make a belief in free will difficult to sustain. There is a family living in Holland with a severe gene mutation causing the men to be violent. "They are born with this — a rare mutation which results in an imbalance in brain chemistry."

This raises extremely difficult issues. What information should people be allowed about the genetic inheritance of individuals?

"In the future, we are going to be able to say about people that, because of the chemical imbalance in the neurotransmitters of their brain, children from this family will have a hundred-fold increase in the probability of being violent, or being a rapist."

He stresses that, in most cases, there will only be an increased probability — not a certainty — that such a gene would dominate the child's behaviour.

"Here is my ethical dilemma. If this child is a boy living near you, and you have a daughter, should you be allowed this information? It could lead you to discriminate against the boy who may not express the trait, and yet you should have the right to know, in order that you can move away from the area."

And there is the question of how much we should be able to change the genome of an embryo. The genomics industry is rushing

to release data that will eventually allow us to pinpoint characteristics and modify embryos accordingly.

For years, studies have been carried out on fruit flies or *Drosophila* which show direct correlations between mutant genes and the behaviour of the nervous system. Every genetics textbook has persuasive descriptions of how genes determine each fly's brief life. *Drosophila* has been categorised as the *Sluggish* and the *Cautious*, the *Dunce*, the *Prokred Out*, the *Comet*, the *Interruptus*. Though humans are vastly more complex than flies, the determinist culture of science will mean we have to struggle against being labelled.

Silver is one of the few biologists of international standing to speak up about the huge implications of what is going on in labs across America and Europe. He speaks rapidly and clearly, extrapolating from organisms like mice and fruit flies to human behaviour. On the wall of his office, he has a picture of himself with the first cloned sheep, Dolly.

"We are at the beginning of the revolution, rather than in the middle. Most people — most scientists — have no understanding of how powerful this technology is. Scientists are taught to do the experiments, get the data, and interpret that data, and not go beyond what that data says. People assume that the future technology is basically going to be the same as today's. They don't understand that the technology is exploding around us. Everything is going to be different."

He likens the current surge in genetic science to the growth of physics at the beginning of this century when the theory of relativity and quantum mechanics had altered understanding.

"Genetics will be more important than physics was. Physics was important to politics in a big way but genetics is going to affect everybody's lives. The important thing is that this is being driven by technology, rather than scientific understanding."

Silver is certain that there will be human clones soon, but more importantly genetic selection will become an accepted part of life. Those parents who spend money to give environmental and social advantages to their children today will make similar purchases to select certain genes for their children in the near future.

"I have asthma," said Silver. "Now, one of my three children has inherited asthma. No one has a problem with the idea of giving people a vaccine after birth to prevent asthma, but they do when you start talking about giving people a genetic vaccine before birth. I don't see the difference. The problem comes when the technology which may prevent asthma or diabetes is used by parents to give their children genetic enhancements which go beyond what an average child has."

"But this is America. Parents will claim the right to spend their money on giving children advantages. The problem is that the techniques used in biomedicine may very well be used to increase inequities in society."

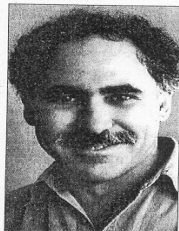
If there was any doubt in Silver's mind about this, it was dispelled by an advertisement placed last month in the student newspapers of Harvard, Princeton and Stanford.

An infertile couple wanted to buy unfertilised eggs from a student who had the characteristics of the woman. That is, one who was white, 1.7m and had a SAT (scholastic aptitude test) score of 99%. They were willing to pay \$50,000 for the right to use the eggs.

Silver, like everyone I talked to, agrees that the next big goal is human consciousness. His work with the mind of the mouse will contribute greatly to the way we begin to investigate the 10-billion neurons in our brain, but he is sceptical about the outcome.

"People think of a neuron as a dynamic switch, but it is much more complicated than that. This is dynamic information at the quantum level. Things are going on at the quantum level in our brains which have something to do with who we are. And we can't get at that."

Silver believes that the great mystery of human life is safe for a little while longer. But, as far as he is concerned, it is already too late to control genetic engineering. "At the beginning, there doesn't seem anything wrong in making small changes here and there. But then you slowly move to a point where it is disastrous. If the first step were a little more problematic, then people might not take that first step. But they will. They will. And then it may be too late."



Lee Silver: 'Genetics is going to be more important than physics was. It's going to affect everyone's life.'

DEVELOPMENT OF STRAND 3 INTO 5 DIMENSIONS

APPENDIX B.1

VERBATIM STATEMENTS: Catg 3 Impact of scientific activity

- 3 Impact of scientific activity
- 3.1: Input to/ from society
- 3.2: Control/ Testing
- 3.3: Risk management
- 3.4: Responsibility
- 3.5: Drawing the line

3.1	Input to/ from society
3.1.1	Society does not make an input
3.1.2	Society does not want to know/ does not care
3.1.3	Society should approve
	etc.

3.2	Control/ testing	
3.2.1	Control is necessary / out of control	
3.2.2	Fundamental values, root of problem	moved to 3.5.4
3.2.3	Scientists: responsible / internal control	
	etc.	

3.3	Risk management
3.3.1	Future effects can/ should be determined
3.3.2	No control/ out of hand/ new developments too fast
3.3.3	If you can't measure you can accept responsibility
3.3.4	Risks are necessary for progress, helpful and harmful go together
3.3.5	research to reduce danger

3.4	Responsibility
3.4.1	Scientists are blamed/ must accept blame
3.4.2	Certain applications are irresponsible
3.4.3	It's not the scientists who are to be blamed
	etc.

3.5	Drawing the line
3.5.1	Certain applications are irresponsible/ misuse/ cloning etc
3.5.2	Helpful and harmful go together
3.5.3	Moral implications first
	etc.

APPENDIX B.2**Dimension 3: 5 aspects, coded units, references****3.3 Risk management****3.3.1 Future effects can/ should be determined (Responsibility)**

3.31	i.6.7	Scientists should / can be 100% sure	
3.35	v.6.6 v.6.7	Prediction is possible That's what we learn	
3.39	i.3.8	Broadcast only when 100% sure	
3.32	iii.6.12	You can see what the future effects will be	
3.36	vi.6.1 vi.6.2	Prediction of effects in advance But new developments come too fast	
3.34	v.6.5	Prediction of effects is necessary	
3.38	x.6.10	Scientists should look ahead before disasters occur	

QUESTIONS: **It is necessary that scientists predict the effects of their discoveries before they are implemented**

3.3.2 No control/ out of hand/ new developments too fast (Opposite of 3.3.1)

3.33	iii.6.10	No control...out of hand	
3.27	xiv.6.1	The viruses are becoming clever than humans	
3.36	vi.6.2	But new developments come too fast	

3.3.3 If you can't measure you can accept responsibility

3.37	vi.6.3a/b	If you can't measure you can't accept responsibility	
3.36	vi.6.1 vi.6.2	Prediction of effects in advance but new developments come too fast	

3.3.4 Risks are necessary for progress, helpful and harmful go together

(Consult aspect 3.5.2 below as well as paragraph 3.3.4.4 in Chapter 3)

3.5.2 Helpful and harmful go together Move to 3.3.4

Partial opposite of 3.3.1

3.310 = 3.51	iv.3.1	Risks are necessary automation can cause joblessness better be productive	
3.515	x.3.12+15 x.3.13 x.3.15	Negative effects just step...every step one more.. final solution Negative effects can be changed prevent....decreased CHECK	
3.53 = 6.43	v.3.12	Helpful and harmful go together	

3.3.5 Research to reduce danger (Because)

3.311	i.7.5b	Research must suggest improvements, reduce danger	

APPENDIX B.3**Dimension 3: Final refinement****Subcategory 3.3: Risk management**

	Statement	Ref	Notes
3.3.1	Future effects can/ should be determined	3.31, 3.35 3.39, 3.32 3.36, 3.34 3.38	Responsibility
3.3.2	No control/ out of hand/ new developments too fast	3.33 3.27	Opposite of 3.3.1
3.3.3	If you can't measure you can accept responsibility	3.37 3.36	"because" of opposite of 3.3.1
3.3.4	Risks are necessary for progress, helpful and harmful go together	3.310, 3.515 3.51, 3.53	Partial opposite of 3.3.1
3.3.5	research to reduce danger	3.311	"because"

APPENDIX C

25 statement pairs in open response questionnaire

1.1	Science education at university should include applied topics such as waste management and the effects of radiation	Science education at university should concentrate on the teaching of scientific theory only
1.2	The purpose of science education is to produce scientists who can also solve science-related social issues	The purpose of science education is to produce scientists who know their subject only
1.3	University education should also create an awareness of values, attitudes and controversies related to science and society and the environment	University science education should not include subject material on values, attitudes and controversies related to science and society and the environment
2.1	It should be left to scientists to decide on the implementation of their scientific discoveries	It should not be left to scientists to decide on the implementation of their scientific discoveries.
2.2	The values and concerns of society should be addressed when decisions must be made on the implementation of science and technology	Decisions on the implementation of science and technology must be based on scientific expertise
3.1	Scientists are responsible for whatever use is made of their discoveries by industry and technology	Scientists are not responsible for whatever use is made of their discoveries by industry and technology
3.2	We can rely on scientists that they will not let their research get out of control	We cannot rely on scientists that they will not let their research get out of control
3.3	Scientists are responsible for damage, such as pollution, to the environment	Scientists are not responsible for damage to the environment such as pollution
3.4	Scientists should predict the long term effects of scientific and technological developments	Scientists should not be expected to predict the long term effects of scientific and technological developments
3.5	Scientists must consider the moral implications of their research	Scientists cannot decide on the moral implications of their research
4.1	Scientists should be the ones who educate the public in basic science	Scientists should not be the ones who educate the public in basic science
4.2	All people should be educated in basic science	Only certain people should be educated in basic science
5.1	The scientists should be the ones who communicate scientific information to the public	It is not the scientists who should communicate scientific information to the public
5.2	The general public has a right to know about all scientific developments	There could be certain scientific developments that should be kept secret from the general public

Appendix C:

5.3	There should be better collaboration between scientists and the community	Scientists cannot be expected to collaborate with the community
6.1	Scientists should be free in their search for knowledge	Scientists should be limited in their search for knowledge
6.2	The purpose of scientific research should be for the sake of more knowledge	In their research scientists must be motivated by the needs of society
6.3	As a scientist one has a special responsibility towards society	As a scientist one does not have a special responsibility towards society
6.4	Scientists should always make honest decisions in their work	Scientists cannot be expected to make honest decisions in their work all the time
6.5	New science can come out of Africa	No new science can come out of Africa
6.6	Scientists are the only ones who can save the world	Scientists are not the only ones who can save the world
7.1	Scientists should inform the public when there is a possible danger from scientific practices	Scientists should not inform the public when there is a possible danger from scientific practices
7.2	A scientist is responsible in his/ her individual capacity to alert the public to any possible dangers resulting from scientific activity in his/ her company	A scientist is not responsible in his/ her individual capacity to alert the public to any possible dangers resulting from scientific activity in his/ her company
8.1	Women scientists have a special role to play in science	Women scientists do not have a special role to play in science
9.1	Interaction is necessary between science students and the community	Interaction between science students and the community is not necessary

APPENDIX D

Cover page for questionnaires

UNIVERSITY OF SOUTH AFRICA

Chemistry Department

Research Project on Scientists and Society

QUESTIONNAIRE

Please fill in the attached questionnaire to assist us in our research on the relationship between scientists and society. Your thoughts on this topic would be highly appreciated.

Your participation is voluntary!

If you are willing to participate, remember that:

1. all information is confidential and anonymous
2. it will not affect your academic record
3. you will not be penalized if you do not participate
4. the information will be used for research and education only
5. you may contact us if you have any questions

You can make a difference by participating!

FOR PARTICIPANTS THERE WILL BE A LUCKY DRAW FOR A CHEMISTRY TEXTBOOK !

Please return questionnaire by Friday 15 June
to Ms D Rohm, Room G23, Tel 429 8067

WITH THANKS

APPENDIX E

The final fixed response questionnaire.

UNIVERSITY OF SOUTH AFRICA

Chemistry Department

Research Project on Scientists and Society

QUESTIONNAIRE

Please fill in the attached questionnaire to assist us in our research on the relationship between scientists and society. Your thoughts on this topic would be highly appreciated.

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1. all information is confidential and anonymous
2. it will not affect your academic record
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4. the information will be used for research and education only
5. you may contact us if you have any questions

You can make a difference by participating!

FOR PARTICIPANTS THERE WILL BE A LUCKY DRAW FOR A CHEMISTRY TEXTBOOK !

Please return questionnaire at the end of the practical to your lecturer

WITH THANKS

In the questionnaire you are expected to circle one of the options under each of the 20 statements

e.g.

1. Science education at university should include topics such as waste management and the effects of radiation

- A.** I AGREE with this statement because:
This knowledge will help students to become more efficient and responsible in their future work in industry, research, teaching or management.
- B.** I AGREE with this statement because:
Applied knowledge is important in understanding the corresponding theory
- C.** I AGREE with this statement because
. Scientists need this knowledge in order to protect the community
- D.** I DISAGREE with this statement because
Science education at university should concentrate on the teaching of scientific theory only
- E.** I DISAGREE with this statement because
Such topics should be optional

X: None of the above statements reflects my view, which is

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If you do not agree with any of the options, please fill in option X

Please fill in your student number

THANKS ONCE AGAIN !!

1. Science education at university should include topics such as waste management and the effects of radiation

- A.** I AGREE with this statement because:
This knowledge will help students to become more efficient and responsible in their **future work** in industry, research, teaching or management.
- B.** I AGREE with this statement because:
Applied knowledge is important in **understanding** the corresponding **theory**
- C.** I AGREE with this statement because
Scientists need this knowledge in order to **protect** the **community**
- D.** I DISAGREE with this statement because
Science education at university should concentrate on the teaching of scientific **theory only**
- E.** I DISAGREE with this statement because
Such topics should be **optional**
- X:** None of the above statements reflects my view, which is

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2. The purpose of science education is to produce scientists who can solve science-related social issues

- A.** I AGREE with this statement because
Scientists must be trained to assist in **solving** scientific **problems in society**
- B.** I AGREE with this statement because
Scientists must know about **all aspects of science**
- C.** I AGREE with this statement because
Science education should include a **broad spectrum of** social, ethical, practical and communication **skills**
- D.** I DISAGREE with this statement because
Science education should focus on **subject knowledge only**
- E.** I DISAGREE with this statement because
Scientists should **specialize** in their subject
- F.** I DISAGREE with this statement because
Science education equips you with the knowledge to **address any problem** that might arise
- X:** None of the above statements reflects my view, which is

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3. University science education should create an awareness of values, attitudes and controversies related to science and society and the environment

- A. I AGREE with this statement because
 This awareness would **broaden the minds** of science students
- B. I AGREE with this statement because
 Students will be more **aware of the effect of science** on society
- C. I AGREE with this statement because
 Scientific **knowledge and** human **values** cannot be separated
- D. I AGREE with this statement because
 Society will have a more **positive attitude** towards science
- E. I DISAGREE with this statement because
 Students should be able to form their **own judgements**
- F. I DISAGREE with this statement because
 Science is all about knowledge and **cannot be mixed** with societal issues
- X: None of the above statements reflects my view, which is

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4. It should be left to scientists to decide on the implementation of their scientific discoveries.

- A. I AGREE with this statement because
 Scientists **understand their discoveries** best
- B. I AGREE with this statement because
 Implementation of scientific discoveries by non-scientists may have **harmful consequences**
- C. I DISAGREE with this statement because
Other bodies such as government, financial controllers, ethics committees and representatives of the public should be consulted
- D. I DISAGREE with this statement because
 If decisions are based on scientific facts only, the environment and social **impacts** might be **ignored**

- E.** I DISAGREE with this statement because
Non-scientists could come up with **innovative** applications of scientific discoveries
- F.** I DISAGREE with this statement because
Society will only **support scientists** if the values and concerns of society are addressed
- X:** None of the above statements reflects my view, which is

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5. Scientists are not responsible for whatever use is made of their discoveries by industry

- A.** I AGREE with this statement because
 Scientists **cannot control** how scientific information is used by industry, the military or anyone else
- B.** I AGREE with this statement because:
 The **people who implement** scientific discoveries should be responsible for the risks involved
- C.** I AGREE with this statement because
 Scientists are employed to **do research** and not to implement it
- D.** I AGREE with this statement because
Funding agencies determine the type of research that is done and how it is implemented
- E.** I DISAGREE with this statement because
 Scientists must **prevent** that harmful **information** is made public
- F.** I DISAGREE with this statement because
 Scientists must always **follow up** how their discoveries are used.
- X.** None of the above statements reflects my view, which is

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6. We can rely on scientists that they will not let their research get out of control

- A.** I AGREE with this statement because
 Scientists are in possession of all the relevant **knowledge to regulate** themselves
- B.** I AGREE with this statement because

Scientists **can be trusted** to work in the interest of the public

- C. I DISAGREE with this statement because
All scientists should adhere to formal ethical **codes of practice**
- D. I DISAGREE with this statement because
The **public should monitor** what scientists do
- E. I DISAGREE with this statement because
This would be personal and everyone has **individual values**
- F. I DISAGREE with this statement because
Money often determines what decisions are made
- G. I DISAGREE with this statement because
Scientists **have to take risks** in order to make progress
- X: None of the above statements reflects my view, which is

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7. **Scientists should predict the long term effects of scientific and technological developments**

- A. I AGREE with this statement because
Possible **danger** or harm could then be **prevented**
- B. I AGREE with this statement because
Long term **effects** can be **approximated**
- C. I AGREE with this statement because
Scientists should not only **use** their **knowledge** to make discoveries but also **to predict** the long term effects of such discoveries
- D. I DISAGREE with this statement because
Scientific knowledge is **not advanced enough** to predict long term effects
- E. I DISAGREE with this statement because
Scientific **findings** can **change**
- F. I DISAGREE with this statement because
Nature is **unpredictable**
- X: None of the above statements reflects my view, which is

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8. Scientists are responsible for damage, such as pollution, to the environment

- A. I AGREE with this statement because
Scientists are the ones who **produce products** which are **harmful** to the environment
- B. I AGREE with this statement because
There will **always** be certain **harmful side effects** accompanying positive scientific advances
- C. I DISAGREE with this statement because
Scientists do the basic research while **industry applies it**
- D. I DISAGREE with this statement because
Everyone is responsible for pollution
- E. I DISAGREE with this statement because
Scientists actually **use their knowledge to control** pollution
- F. I DISAGREE with this statement because
It depends on the **individual** and you cannot generalize
- G. I DISAGREE with this statement because
Consequences of research applications often appear at the end of a **long process** and **all who are involved** in it are responsible
- X: None of the above statements reflects my view, which is

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9. Scientists must consider the moral implications of their research

- A. I AGREE with this statement because
Science and technology impact on people=s lives and therefore **morality and scientific knowledge cannot** be kept **separate**
- B. I AGREE with this statement because
Scientists have the **knowledge to determine** the **consequences** of their actions
- C. I DISAGREE with this statement because
Society determines how scientific discoveries will be used or abused
- D. I DISAGREE with this statement because
Scientific knowledge is neutral and therefore socially and morally **value-free**
- E. I DISAGREE with this statement because
Funding agencies and commercial interests determine what research is done and how it is implemented
- F. I DISAGREE with this statement because
There are always **individual opinions** on what is right or wrong

G. I DISAGREE with this statement because
There should be general **codes of practice** for all scientists

X: None of the above statements reflects my view, which is

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10. All people should be educated in basic science

A. I AGREE with this statement because
Almost everything **revolves around science**

B. I AGREE with this statement because
A scientifically educated public can make **better choices** regarding the use of science and technology

C. I AGREE with this statement because
It will enable people to **fulfil their roles** in society more effectively

D. I AGREE with this statement because
The public will understand that science and technology do **not** have **all the answers**

E. I DISAGREE with this statement because
People should be able to **choose** what they want to learn

F. I DISAGREE with this statement because
Not everyone has the **ability** to understand science

X None of the above statements reflects my view, which is

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11. There should be better collaboration between scientists and the community

A. I AGREE with this statement because
Scientists could **solve** many **problems** in consultation with the communities

B. I AGREE with this statement because
The community has a **right to know** what scientists are doing

C. I AGREE with this statement because

Scientists can **convey** a balanced and **objective perspective** on scientific development and its consequences

- D. I AGREE with this statement because
The technical and **scientific** decisions by scientists should be **balanced by social** and ethical issues
- E. I AGREE with this statement because
Society will be more **interested in** science and **supportive** of science
- F. I DISAGREE with this statement because
The public will **not understand** the scientific facts correctly
- G. I DISAGREE with this statement because
People who have better **communication skills** than scientists should liaise between scientists and the community
- H. I DISAGREE with this statement because
Scientists have the responsibility of liaising and communicating **with other scientists only**
- X: None of the above statements reflects my view, which is

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12. Scientists should be free in their search for knowledge

- A. I AGREE with this statement because
Freedom is **essential for** meaningful **research**
- B. I AGREE with this statement because
Mankind always needs to **gain a better understanding** of man, nature and the universe
- C. I AGREE with this statement because
This will enable scientists to **improve** the **conditions** of mankind
- D. I AGREE with this statement because
Intellectual freedom is a **prerequisite for** scientists to exercise their **social responsibility** and avert dangers
- E. I DISAGREE with this statement
There should be **limitations** to prevent scientists from infringing on the rights of others
- F. I DISAGREE with this statement because
Scientists should be **aware of** their **responsibility** to society
- X: None of the above statements reflects my view, which is

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13. In their research scientists must be motivated by the needs of society

- A. I AGREE with this statement because
Scientific research should **improve life**
- B. I AGREE with this statement because
Scientists are nurtured and **supported by society**
- C. I DISAGREE with this statement because
Society wants **quick fix answers** which are not always useful
- D. I DISAGREE with this statement because
Scientists must **decide for themselves** how to focus their powerful knowledge
- E. I DISAGREE with this statement because
The purpose of scientific research is to investigate the **mysteries of nature**
- F. I DISAGREE with this statement because
Research depends on who provides the **funding**
- X: None of the above statements reflects my view, which is

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14. As a scientist one has a special responsibility towards society

- A. I AGREE with this statement because
Scientists have specialized and **powerful knowledge**
- B. I AGREE with this statement because
Scientists must **educate society** on the risks and benefits of science and technology
- C. I AGREE with this statement because
Scientists have a special responsibility to use their knowledge to **improve the quality of life**
- D. I AGREE with this statement because
Scientists are able to **predict** the long term effects of scientific and technological innovations
- E. I DISAGREE with this statement because
Scientists **do not have the power** to make a difference
- F. I DISAGREE with this statement because

All people have a responsibility towards society

X: None of the above statements reflects my view, which is

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15. Scientists should always make honest decisions in their work

- A.** I AGREE with this statement because
Honesty and integrity are necessary for **all of us** at all times
- B.** I AGREE with this statement because
When scientists are dishonest, the lives of innocent **people can be affected**
- C.** I AGREE with this statement because
Otherwise people would **lose** their **confidence** in science
- D.** I DISAGREE with this statement because
Scientists are **just normal people** who have weaknesses and make mistakes in the same way as everyone else
- E.** I DISAGREE with this statement because
Honesty forms **part of scientific practice**
- F.** I DISAGREE with this statement because
Scientists are only more truthful in their work because **other scientists** might try to **verify** their findings

X: None of the above statements reflects my view, which is

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16. New science can come out of Africa

- A.** I AGREE with this statement because
There is a great **potential** for innovations/ new ideas
- B.** I AGREE with this statement because
Africa has come up with excellent **scientific work already**
- C.** I DISAGREE with this statement because
We first need scientific **role models** on the continent

- D.** I DISAGREE with this statement because
More people need to be **interested in science**
- E.** I DISAGREE with this statement because
The **resources** are limited
- F.** I DISAGREE with this statement because
People **leave Africa** because there a better possibilities elsewhere
- G.** I DISAGREE with this statement because
Scientific knowledge is **internationally** shared
- X:** None of the above statements reflects my view, which is

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17. Scientists should inform the public when there is a possible danger from scientific practices

- A.** I AGREE with this statement because
It is important for the **safety** of the public
- B.** I AGREE with this statement because
People have a **right to know** what affects them in order to take the necessary action
- C.** I AGREE with this statement because
It is the **right thing to do**
- D.** I DISAGREE with this statement because
The **public** could start to **panic**
- E.** I DISAGREE with this statement because
Scientists should first **inform** their **employer** before going public
- F.** I DISAGREE with this statement because
Scientists should first consult the **law**
- X:** None of the above statements reflects my view, which is

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18. A scientist is responsible in his/ her individual capacity to alert the public to any possible dangers resulting from scientific activity in his/ her company

- A. I AGREE with this statement because
It is a **moral duty**
- B. I AGREE with this statement because
The safety of the **public comes first**
- C. I AGREE with this statement because
Companies often **do not address** dangerous situations
- D. I AGREE with this statement because
Scientists must **protect themselves** from legal action against themselves
- E. I DISAGREE with this statement because
The scientist should adhere to **company policy**
- F. I DISAGREE with this statement because
Some facts must remain **confidential**
- G. I DISAGREE with this statement because
The scientist could be **victimized** by the employer
- X: None of the above statements reflects my view, which is

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19. Women scientists have a special role to play in science

- A. I AGREE with this statement because
Women=s scientific knowledge can **benefit family** and household
- B. I AGREE with this statement because
Women can come up with **entirely different** scientific developments
- C. I AGREE with this statement because
Women can act as **role models** to other aspiring women scientists
- D. I AGREE with this statement because
Women are **people oriented**
- E. I DISAGREE with this statement because
Women are in the **minority in science**
- F. I DISAGREE with this statement because
There is **no difference between** male and female scientists
- G. I DISAGREE with this statement because
Science is not about being male or female

X: None of the above statements reflects my view, which is

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20. Interaction is necessary between science students and the community

- A.** I AGREE with this statement because
Science students could **inform the community** on dangers of chemicals and how to handle them safely
- B.** I AGREE with this statement because science students could **promote an interest** in science among the community
- C.** I AGREE with this statement because
Science students can become **aware of the needs of society**
- D.** I AGREE with this statement because
Science students need to **give back to the community** that nurtured them
- E.** I DISAGREE with this statement because
It would **not be easy** to achieve in practice
- F.** I DISAGREE with this statement because
Science students do **not** have **enough experience**

X: None of the above statements reflects my view, which is

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APPENDIX F

Explanatory document for panel members for compilation of attitude profile

VALIDATION OF QUESTIONNAIRE ON THE STUDENTS= VIEWS ON THE SOCIAL RESPONSIBILITY OF SCIENTISTS

The design of the multiple choice questionnaire is based on interviews which were conducted among Unisa science students. There are 20 statements, each with 5 - 7 options plus 1 extra option for a personalized opinion. The following 9 aspects of the social responsibility of scientists are addressed: education, decisionmaking, the impact of scientific developments, education of the general public, communication, whistleblowing, scientific research, women in science and science students. Statements pertaining to these aspects are distributed randomly throughout the questionnaire. The multiple choice questionnaire has been completed by 125 first to third year Chemistry students.

At this stage 5 - 7 options to each of the 20 statements need to be evaluated with respect to the positiveness of students= attitudes towards the social responsibility of scientists. A scale of 1 - 12 is employed, with the lower end denoting the attitude that scientists have no responsibility towards society, while a value of 12 represents a deep social commitment of scientists.

The following are examples of negative attitudes towards social responsibility:

- Science education at university should focus on pure scientific theory.
- Scientists and/ or technologists should decide on the implementation of scientific discoveries.
- The general public is not educated enough to understand scientific matters.
- The individual scientist cannot feel responsible when coming across harmful scientific and technological practices.
- Scientific research should focus on the discovery of theoretical knowledge.
- Women scientists are not any different to their male counterparts.
- Science students should focus on their studies only.

The following would range at the opposite end of the spectrum of attitudes towards the social responsibility:

- Science education should include education in ethical values and decisionmaking;
- Decisions on the implementation of scientific discoveries should be made by the general public who is directly affected.
- The public should be educated and informed on scientific matters by the scientists themselves.
- The positive and negative effects of scientific discoveries should be communicated openly to the public by the scientists.
- Scientists should blow the whistle on harmful scientific and technological practices.
- In their research scientists should first and foremost consider the needs of society.
- Women scientists can bring social awareness to science and technology
- Science students should be involved in the society that nurtured them.

The above examples are given as a guideline. The individual opinions of the validators are required. Average trends will ultimately be determined. In the event of large discrepancies, a panel will be requested to arrive at an agreement.

Your input is appreciated!

APPENDIX G

SCORING TABLE FOR ATTITUDE PROFILE

ASSESSMENT OF STUDENTS= ATTITUDES TOWARDS THE SOCIAL RESPONSIBILITY OF SCIENTISTS

Procedure: (see separate handout as example)

- \$ Statement No: denotes A to G of the AGREE/ DISAGREE statements in the questionnaire
- \$ Focus on: in this column you can insert your opinion view on how >socially responsible or not@ the statement is
- \$ Value: A highly socially responsible attitude will have a value of 12. whereas an attitude which puts science or the individual first will have an attitude below 6

QUESTION 1

Statement No	Focus on	Value 1-12	Remarks