SCIENTIFIC LITERACY FOR SUSTAINABILITY


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Division of Arts
School of Education
Murdoch University
Perth, Western Australia.
STATEMENT OF AUTHORSHIP

This is to certify that

(i) the thesis comprises only my original work towards the PhD;

(ii) due acknowledgement has been made in the text to all other material used; and

(iii) the thesis is approximately 80 000 words in length.

Karen Murcia
ABSTRACT

We only need to consider public media reports to appreciate that there is growing concern amongst citizens for sustainability. This concern arises from increasing appreciation that the current direction and rate of exploitation of resources is not sustainable and humanity’s actions today are arguably compromising future generations’ ability to meet their living needs. By drawing on the research of scientists, ranging from their evidence of the problems of sustainability to those promising solutions, the same press reports show strong links between sustainability and science. The appearance of such reports in the public media implies that citizens understand the interaction of science and sustainability and that they can engage critically with scientific research, including its applications and implications for sustainability. In this dissertation this understanding and capacity to engage critically is termed scientific literacy. The general question governing the research reported in this dissertation arose from this context and is: What does it mean for citizens to be scientifically literate within the context of sustainability? More specifically, because it is expected that university graduates are well educated in a socially relevant manner, with commensurate responsibilities and influence, the focus question studied in this dissertation is: What does it mean for university graduates to be scientifically literate?

It became apparent from the review of the literature, that the concept of scientific literacy was multidimensional. The three key dimensions that emerged were (i) the fundamental and enduring ideas and concepts of science, (ii) the nature of science and (iii) the interaction of science with society. These dimensions provided the framework for the research reported in this dissertation. Within this framework and based on the literature, two relationships amongst these dimensions were proposed. The first
relationship was that the dimensions were in a conceptual hierarchical order, with successive dimensions including the previous dimensions and expanding upon them. The second relationship was that students’ scientific literacy developed sequentially along the same hierarchy. It was proposed that development occurred sequentially, with development of concepts of science first, nature of science second and interaction with society last. It was proposed that a scientifically literate person would have reached the level of understanding that includes the interaction of science with society. Specific indicators of the successive dimensions were functional, conceptual/procedural and multidimensional, which at this highest level, includes the relationship between the first two dimensions and society.

This framework and the associated indicators were used as a structure and lens for interrogating the development of scientific literacy of 244 first year university students enrolled in Australia’s Murdoch University’s foundation unit, Life and the Universe. This is one of five units from which first year students are required to select one. The units are interdisciplinary in nature with Life and the Universe being a unit that covers generic issues in science. In part because of its content and in part because it allows students from all backgrounds to enrol, it was considered suitable for studying, illustratively, the development of scientific literacy of potential university graduates.

The development of scientific literacy was studied in three ways. First, participants responded to open questions about a newspaper report of science, before and after their studying in Life and the Universe, second, they responded to a Likert style questionnaire regarding the nature of science, again before and after studying the unit, and third, a subset of participants were involved in a focus group run over two years.
The participants’ responses to the open questions on the questionnaire were analysed for their critical engagement with the news brief, in terms of their ability to give reasons why the text should be accepted or rejected. The nature of requests for extra information about the news brief’s content was also analysed. Analysis of the initial responses to the open questions showed that more than fifty percent of the participants in this study did not demonstrate the ability to critically engage with science reported in the news.

The Likert style questionnaire assessed participants’ conception of the nature of science, with one end of the continuum reflecting a traditional view that science was a body of unchanging facts, derived from objective and value free observations, and the other reflecting a more contemporary view, that scientific knowledge was dynamic, open to change, had subjective components, and had scientists socially located so that their work was not free of values. Analysis of the initial responses to the Nature of Science questionnaire showed that more than fifty percent of the participants were located on the continuum towards the contemporary, socially located end. However, it also showed that the majority were still not sufficiently located towards the contemporary end of the continuum to view science as dynamic, with a changing body of knowledge. There was no statistically significant difference in these analyses in relation to participants’ gender, time out of school, course of enrolment or science background.

Unexpectedly, the comparison in the analysis of the news brief pre and post Life and the Universe showed that the number of participants engaging critically did not increase. More expectedly, the comparison of the pre and post Life and the Universe responses to the Likert scale showed that there was overall a statistically significant increase in the group’s contemporary, socially located, perspective of the nature of science during their participation in the foundation unit. Specifically, the participants demonstrated raised
awareness of the tentative and subjective nature of science and that scientists study a world in which they are a part and, as such, their work is not objective or value free. Nevertheless, there was substantial possibility of higher locations on the scale which the majority of participants did not reach. This statistically significant increase, but possibility for further improvement, is compatible with the lack of increase in critical engagement with the news brief and suggests that the statistical increase was not educationally significant.

The focus group data contributed greater depth of understanding to the researcher about the range in participants’ conceptions of the nature of science. The conceptions evident were consistent with the conclusions from the open questions and Likert style questionnaire and also highlighted limited understandings of scientific processes or scientific methods. It was evident that misconceptions and naïve understandings of the contemporary nature of science were present at the beginning and retained throughout the foundation unit learning experience. These limitations helped explain participants’ inability to engage meaningfully and to question critically the science news briefs contained in the questionnaires. Data from the focus group also suggested that a limited understanding of science terms prevented critical engagement with the content of the news briefs.

Following closely the focus group participants’ development of scientific literacy over a two year period, allowed the researcher to gain a greater depth of understanding of the participants’ development of scientific literacy than that which could be gained alone from the large scale administrations of the questionnaire. This experience highlighted that the development of scientific literacy was far more complex than the originally proposed sequential development across the three dimensions. The analysis of
converging sources of data challenged this proposition and resulted in a reconstruction of understanding about the development of scientific literacy. It was evident that the ability and disposition to critically question and act scientifically required parallel development of science content, socially located conceptions of the nature of science and understanding of its interaction with society. It was the blended and parallel development of these knowledge dimensions, at any level, that demonstrated scientific literacy.

In order to characterise the more complex structure amongst the dimensions in which parallel development occurred, a rope metaphor was used. This metaphor effectively represented the observed development of scientific literacy, as it made concrete the interwoven threads of multidimensional knowledge. It represented more realistically the complex, intertwining and multidimensional aspects of participants’ development of scientific literacy. Re-thinking the development of scientific literacy and representing the construct with the rope metaphor offered possibilities for effective pedagogy in higher education. The interaction of multidimensional threads of knowledge seems an integral part of the development of scientific literacy and suggests the need for teaching and learning experiences that are holistic in nature and driven by socially relevant contexts.
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CHAPTER ONE  SCIENTIFIC LITERACY: MEETING THE DEMANDS OF LIFE IN THE 21ST CENTURY

1.1 Introduction

“Cancer gene therapy hailed” (9/6/06)

“GM tomatoes new hope in disease fight” (5/7/06)

“Space probe spots lakes on Titan” (29/7/06)

“Antarctic ice reveals chilling release of greenhouse gases” (7/9/06)

“Scientists claim ozone is fighting back” (1/9/06)

This small sample of headlines from The West Australian daily newspaper in Perth, Western Australia provides us with a picture of the demands that are being placed on individuals and communities to understand, engage with and take up, science research, applications of science in the form of rapidly developing technologies and sustainable development practices. Science increasingly drives and shapes life in the 21st century. Humanity has an increasing science knowledge base and access to a diverse range of technologies that have, for industrialised nations, improved life expectancy, the quality of life and reduced the need for physical labour. Industries and homes have been powered by fossil fuels, health care has improved and many infectious diseases have been effectively controlled. Applications of science have revolutionised transport and allowed world wide communication. Advancements such as these have contributed to an upwardly spiralling world population and have come at a high cost to natural environments. The current and projected rate of consumption of natural resources by industrialised nations is considered unsustainable by many international organisations such as the United Nations (1992) and the World’s Scientific Academies (2000) and cannot be extended to developing countries in order to achieve an equitable standard of
living for all of humanity. In addition naïve use of technology has contributed to global pressures such as land degradation, loss of biodiversity, increased greenhouse effect resulting in global warming, now routinely acknowledged, and the depletion of the ozone layer in the stratosphere. These changes to our world have resulted in a major interplay between science and social and political action. As a result, set in a democracy, the position of this thesis is that there is a demand for every citizen to have as great an understanding of science as possible. This would enable them to make science informed decisions and take effective actions, especially regarding sustainability issues.

In our rapidly changing world, it could be argued that scientific literacy may now stand alongside language literacy and numeracy as an essential tool for effective living in contemporary society. This implies an increasing need to ensure scientific literacy is an educational outcome for all citizens. Clarifying and making useable the concept of scientific literacy is integral to achieving it as an outcome of science education. The term scientific literacy is often used to suggest a general, broad and useful understanding of science as a part of general education. Broadly speaking, scientific literacy stands for what the general community ought to know about science in order to have the competence and disposition to use science to meet the personal and social demands of life at home, at work and in the community. This definition is informed by the work of Willis (1998) in numeracy and is consistent with the assumptions of American Association for the Advancement of Science (AAAS) (1990), Goodrum, Rennie and Hackling (2001) and the international assessment of scientific literacy (PISA) undertaken by the Organisation for Economic Co-operation and Development (OECD) (2002).
The importance of scientific literacy for all citizens has been recognised internationally by organizations like the American Association for the Advancement of Science, National Research Council (U.S.), The Royal Society (U.K.), Science Council of Canada and Australia’s Department for Education, Science and Training. It is widely accepted that members of the community should have sufficient understanding and confidence to make informed decisions about important questions dealing with scientific matters. This ability is integral to social justice as it could empower people to critically reflect, evaluate and make informed policy and behavioural decisions on science-related issues. They may well be able to identify influencing factors and when science is being used to mystify or falsely used as ‘proof’. Implied here is an appreciation of the nature, aims and general limitations of science. This appreciation should be coupled with some understanding of the more important scientific ideas. These ideas and concepts are those that are relevant to everyday situations and will continue to have relevance throughout the next decade.

Growing demands are being placed on individuals and communities to understand, engage with, and take up sustainable development practices. This thesis takes the perspective that sustainability is the integration of economic, social and environmental objectives of society in order to maximise human well-being in the present without compromising the ability of future generations to meet their own particular needs. This perspective brings together key ideas of The World Commission on Environment and Development’s (Brundtland Commission) report, *Our Common Future* (1987), the United Nations 1992 Conference on Environment and Development and OECD’s 2001 policy brief, *Sustainable development: critical issues*. These reports argued that sustainability is an area of crucial international importance as the world strives to overcome diverse and complex environmental problems.
It can be argued that educating for scientific literacy is an integral part of achieving a sustainable future. Citizens should, as an outcome of their education, be able to choose to participate in public debate, decision-making processes and also to adapt lifestyle and work practices to meet the demands of a rapidly developing and changing world shaped by science. Without a reasonable level of scientific literacy, citizens of the future could be unable to appreciate science’s interaction with society or their role and the role of others in decisions, values and actions shaping humanity’s future. UNESCO (1994) as cited in BouJaoude (2002, p. 139) expressed the view that “scientific and technological literacy is a universal requirement if people are not to be alienated in some degree from the society in which they live, if they are not to be overwhelmed and demoralized by change.” A scientifically literate person would be less likely to have unrealistic and unrealisable expectations of science and they could display greater confidence and competence in dealing with science in daily life and as such be better able to engage with and respond to issues of sustainable development. The contemporary context of sustainability demands that we re-think science’s role within society and hence question what it now means to be scientifically literate. Ensuring a sustainable future demands that all citizens have at least a minimal level of scientific literacy. Achieving scientific literacy for all highlights the need for educational practices to be reviewed.

The theoretical framework of this thesis draws on five decades of literature on scientific literacy. The review of this literature, discussed in detail in chapter three, revealed scientific literacy was frequently stated as a goal of science education yet controversy and uncertainty was evident as the question was repeatedly asked: What should the scientifically literate person know, value and do as a citizen? (Laugksch, 2000). Factors that have contributed to this ambiguity are changing social climates, a diverse range of interest groups, the purpose for promoting scientific literacy and who is perceived as the
general population (Shamos, 1995; Laugksch, 2000). Yet common ideas and issues can, however, be traced through the development of scientific literacy as a social and educational concept. Scientific literacy can be viewed as multidimensional and a composite in some way of science concepts and ideas, the nature of science and the interaction of science and society (Arons, 1983; Bauer, 1994; Bybee, 1999; Fensham, 2002; Goodrum, Hackling & Rennie, 2001; Hurd, 1997; Miller, 1983; Norris & Phillips, 1999; Pella, 1976; Solomon, 2001).

The multidimensionality of scientific literacy is reflected in contemporary science curriculum. In Australia for example, greater national consistency in curriculum outcomes was prioritised by the Ministerial Council on Education, Employment, Training and Youth Affairs (MCEETYA) in 2003. This led to the Australian Curriculum Corporation’s (2006) draft Statements of Learning and Professional Elaborations for Science, which states, “Science is a dynamic, forward-looking, collaborative human endeavour that provides a distinctive way of thinking about and explaining the events and phenomena in the world. Science education endeavours to foster students’ curiosity, imagination and wonder. The rapid advances in science, including emerging and future science areas and technology and their impact on society and the environment, require science education to develop students who are scientifically literate (p. 2)” It is evident in this statement that scientific literacy requires an appreciation of the interconnections between science content, the nature of science and its implications for society.

Consistency with this rationale is already evident in the science curriculum documents of Australian states. For example the Australian Capital Territory Department of Education and Training’s Science Curriculum Framework states, “Science is not seen as merely objective and value free but is recognised as being a part of the human
experience. As such it is an integral part of daily life rather than belonging only in a laboratory. It is relevant to everyone. A knowledge of science is necessary for all students so they can understand the world in which they live, value the systems and processes that support life on our planet, and take an active role in their society (1993, p. 4).” In addition, Western Australia’s Curriculum Framework (Curriculum Council of Western Australia, 1998, p. 218) states, “science is part of human experience and has relevance for everyone. All people can experience the joy and excitement of knowing about and understanding the world in which we live... As a result of these endeavours; people can use their scientific understandings with confidence in their daily life”.

Science is represented in these curriculum documents as an integral part of life and living and hence of relevance and importance to all members of the community. It is evident that the useability of science or scientific literacy is the desired outcome of school science experiences. The focus is no longer on the teaching and learning of isolated science concepts and procedures but on a holistic approach that integrates the core content knowledge with scientific values, attitudes and skills into socially relevant contexts.

This research thesis is focused on higher education because scientific literacy is a desirable attribute of all citizens but, importantly, an attribute industry and the general community would expect from higher education’s graduates. These graduates will become experts in the community and hold positions of influence in social debate. For example, science graduates are potentially the advisors to the general community on science-related issues and so it is essential they appreciate the nature of their discipline, particularly its aims, limitations and interaction with society. Scientific literacy is a desirable attribute of all citizens and, in particular, it is an attribute now being expected
from Australia’s higher education graduates (for example see, UniSA, 2001; RMIT, 1999; UNSW, 2003; and Curtin, 2001).

Graduate attributes are a possible way of capturing scientific literacy in higher education. These attributes are professional qualities, skills and understandings agreed to as desirable for students to develop during their time at University. These attributes or qualities are a potential outcome that can take into account not only the content knowledge of a field but personal skills such as communication, critical thinking, collaboration, ethical action, social responsibility and international perspective. Overarching graduate attributes could support the defining, development and assessment of students’ scientific literacy learning outcomes in higher education.

The specific context for this research was a Murdoch University foundation unit titled *Life and the Universe* (LATU). There are a range of foundation units offered at this University, one of which is LATU, and enrolment in one is compulsory in all first year programs. Foundation units generally, are multidisciplinary in nature and are designed to introduce students to University study skills. These units aim to make a strong contribution to the development of students’ graduate attributes. Furthermore, LATU in particular is intended as a non-specialist science unit, introducing all students to the issues faced by science in an increasingly technological society. The teaching and learning offered in LATU made it an appropriate and interesting context for exploring scientific literacy and interrogating first year university students’ development of the construct.
1.2  **Research aims and objectives**

The central question underlying this research is: What does it mean to be scientifically literate in the 21st Century? This research aims to answer this question and in turn develop and evaluate a working framework and related indicators of scientific literacy at the first year university level. The initial framework would then be evaluated as it was used as a lens for investigating the development of scientific literacy amongst first year university students. This research aimed to achieve the following objectives:

- Develop a defensible, contemporary framework of scientific literacy.
- Develop indicators of levels of scientific literacy.
- Use the framework and indicators to investigate scientific literacy amongst a sample of first year university students.
- Evaluate the structure of the framework and its usefulness for investigating scientific literacy.
- Propose potentially effective teaching and learning strategies for the development of scientific literacy.

There have been many attempts, proposals and discussions regarding the defining of scientific literacy and approaches for developing the construct amongst all citizens but few have been grounded within the current transition to sustainability. This thesis is intended to fill that gap.

1.3  **Thesis structure**

Following this introduction, Chapter 2 provides an overview of ways in which science has shaped and continues to influence modern societies. Science’s role in the transition to sustainability is discussed with the view that it requires a multidisciplinary and
integrated perspective. This perspective of science for sustainability underlies the various educational initiatives proposed both nationally and internationally and discussed in this chapter. There are many educational contexts in which science for sustainability has relevance. However, the focus of this research was narrowed to higher education and so the University’s graduate attributes are considered as a means for capturing the construct in the final section of Chapter 2.

As indicated earlier, this dissertation draws together ideas from a range of sources regarding the conceptualising of scientific literacy. In order to arrive at a defensible and contemporary framework for analysing scientific literacy in the context of sustainability it has been necessary to examine the developing meanings of scientific literacy as a goal of science education in the last 50 years through to the current times in which a heightened interest is evident with the current questions of sustainability. A review of this literature is undertaken in Chapter 3.

Common ideas and dimensions emerged out of this review of the history of scientific literacy as a social and educational construct. The focus of Chapter 4 is on the dimensions of scientific literacy, including science terms and concepts, the nature of science and the interaction of science with society. Philosophies of science leading to the ‘new’ philosophy that informs the conceptions of the nature of science presented here are also discussed. The blending of these understandings is then represented in the framework for scientific literacy described in this chapter.

Understanding and evaluating news reports of science is often included in the literature as an attribute of a scientifically literate person with some suggesting it should be fundamental to any attempt to develop scientific literacy. Newspaper reports of science
are potentially an effective vehicle for both developing and assessing scientific literacy as they link scientific concepts with the real world. It could also be argued that newspaper reports are a concrete representation of important or topical societal issues that demonstrate the intersection of science with society. This thesis does not intend to identify all the science concepts integral to the achievement of scientific literacy but rather concentrates on the central place of the nature of science and its interaction with society as demonstrated concretely through science in the daily newspapers. In this way scientific literacy is being explored as a multidimensional construct with attention given to the interconnections between science content, its processes, values, assumptions and societal implications. This research’s rationale for using science news briefs in the investigation of scientific literacy is further developed in Chapter 4. The central ideas from this discussion are then evident in the indicators of levels of scientific literacy proposed at the end of Chapter 4.

In Chapter 5, the methodologies used in this research for interrogating the development of scientific literacy amongst the selected participants are elaborated. The discussion includes a description of the context, specifically the foundation unit Life and the Universe (LATU) and the research timeline and program which includes both the quantitative and qualitative components. The development, administration and analysis procedures are described for the pre and post-LATU Likert style questionnaires that also included open questions about a science news brief. This description then includes the qualitative program for analysing the comments and work samples contributed by the focus group of participants.

The findings from the analysis of the questionnaires administered pre- and post-LATU are included in Chapter 6. This chapter begins with a detailed summary of the
background information provided by the participants on the questionnaire. The findings from the analysis of participants’ responses to the news brief contained on the questionnaires follows and then lead into the findings from the RASCH analysis of the Nature of Science Likert scale, which in part demonstrates the validity of the scale for measuring the construct. The participants’ responses to each item on the Likert scale are also analysed and pre- and -post LATU comparisons are presented.

The next two chapters present the findings from the qualitative component of the research. The discussion in these chapters demonstrates the range amongst the focus group participants’ development of scientific literacy and the types of conceptions they held about the nature of science and its interaction with society. In Chapter 7 and 8, participants’ responses from the various data sources are viewed through the framework and indicators of scientific literacy proposed in Chapter 4. Their conceptions of the nature of science are explored in Chapter 7 and their views on the interaction of science with society and the influence of science content and terminology on engagement with science news briefs are addressed in Chapter 8.

In Chapter 9, the findings from the quantitative analysis of the pre- and post-LATU questionnaires are reflected on in relation to the more subtle differences in the participants’ reasoning and perspectives illuminated by the qualitative focus group study. Possible reasons for participants’ conceptions and misconceptions about the nature of science and its interaction with society are discussed. The converging findings then lead to the proposing of the ‘rope metaphor’ for illustrating the manner in which participants’ scientific literacy was observed to have developed.
In chapter 10 the metaphor of a rope built up of strands of understandings from the three dimensions of scientific literacy is used to reflect on teaching and learning in the foundation unit *Life and the Universe*. Implications of the ‘rope metaphor’ for the development of scientific literacy in this foundation unit are discussed. Implications of the metaphor are also discussed in the areas of University’s graduate attributes and, more specifically, in teacher education programs. Finally, consideration is given to future effective teaching and learning practises for the facilitation of students’ development of scientific literacy.
CHAPTER TWO

CAPTURING THE INTERSECTION OF

SCIENTIFIC LITERACY WITH SUSTAINABILITY

IN HIGHER EDUCATION

Science has led to revolutionary changes to the world and the manner in which people live. Change has positive and negative implications for sustainability but clearly some change has resulted in significant benefits to humanity. The average life expectancy has increased with improved healthcare, better sanitation, clean water supplies and increased agricultural output. Applications of science in the form of technological developments and the use of the world’s energy resources have reduced the demand for physical labour. It has generated a diverse range of products and processes which increase the quality of life. Ironically, these benefits to humanity have contributed to the environmental problems now challenging global communities and their ability to maximise human well-being in the present without compromising the ability of future generations to meet their own particular needs. This irony is developed later in this chapter.

2.1 Science and technology in the 21st Century

The great science achievements of the last century are evident in all aspects of life today in developed countries. Consider the impact of putting humans on the moon, televisions in every home and personal computers in many workplaces. Only time can tell precisely how science and technology will continue to evolve. Scientific discoveries and developments open up a vast range of possibilities in areas such as space exploration, health and gene technologies, design and construction, communication, alternative
energy sources and transport, to name just a few. We can look at the science of today and predict or even anticipate the way science will shape and direct humanity’s future.

A significant starting milestone for the new millennium would have to be the docking of the Russian rocket from the former Soviet Republic of Kazakhstan with the International Space Station. It took humanity a step closer to colonising the solar system and opened the possibility of attaining natural resources from space. Yet back on Earth alternative energy sources are being developed and trialled with the aim of replacing the depleted reserves of fossil fuels. Scientific knowledge has contributed to the development of solar cells, ocean wave-generated energy and wind turbines. Developed countries’ awareness of increasing energy demands has also impacted on the way they design and construct homes. Energy efficient design features make the most effective use of solar energy for heating and alternative building materials such as fibre boards made from re-cycled materials are replacing the traditional use of slow growing hard woods (Brown, McGhee, Malnic, Mitchell, Thomas & Willis, 2002).

Alternative energy sources are also impacting on the design of transport systems. The automobile may soon be revolutionised as electric, solar and hydrogen burning motors are explored. Rail transport is also evolving with two potential futures. Established railroads can continue to be developed for longer and faster friction reduced trains or entirely new lines can be built for new technologies. ‘Hovertrains’ cushioned by a flow of air under the train push it up as it moves along. Alternatively, there are ‘Maglev’ trains which use magnetic levitation created by the repulsion and attraction forces of magnetism; lifting and moving the train forward could be the way of the future. It could also be reasonably expected to see changes to marine transportation as ships are designed to move faster with changes to hull designs and methods of propulsion. Two
possible propulsion forces are gas turbines and water jets. Solar power, with the help of the wind, could also be a viable energy alternative. Air transport designers are also investigating ways to carry more people, more quickly and cheaply than ever before (Anderson, Burnham & Willis, 2002).

Gene technologies are also advancing rapidly. In the health field scientists have mapped the human genome and cloned mammals. Domestic pigs could be genetically engineered and cloned with organs specifically tailored for human implants. Human tissue can be engineered. For example, growing cartilage from a patient’s own cells could make hip and knee replacements obsolete. Gene therapy enables ‘corrective’ genes to be delivered to damaged cells and offers hope as a treatment for cancer, Alzheimer’s disease and some immune system deficiencies (Beckelman & Thomas, 2002). In agriculture we now have the ability to genetically modify crops and increase the productivity of farmlands (Brown et al., 2002).

Scientific knowledge and skills have already led to the design of new technologies which make surgery without scalpels a possibility. Energy sources such as lasers, electron beams or high intensity ultra sound can pass safely through the body, affecting only targeted tissue (Beckelman & Thomas, 2002). Nanotechnology has contributed tiny machines engineered to microscopic precision. Potentially, ‘nanobots’ could be the germ-sized machines of the future capable of performing miraculous medical tasks (Bilek, Brooks, de Sterke, McGhee, McKenzie, Phillips, Thwaites & Willis, 2002).

Furthermore, advances in electronics have given us personal computers that have 7.5 million transistors on a chip and it is anticipated that computer power will be magnified exponentially within the next decade. Superconductors which carry electrical current
with little or no resistance will contribute to the development of still smaller and faster computers. Optical fibres that transfer data through a fine glass strand as a pattern of very short light pulses have already completely replaced copper cables in the transfer of information.

In addition, wireless networks between all electrical items in the home and then via the Internet to the world beyond have been made possible with a computer chip called a ‘Bluetooth’. The Bluetooth chip contains a low power, short range radio receiver that can communicate with another Bluetooth chip within a current range of about 10 meters. Incorporating a Bluetooth chip into the mobile phone can now provide access to the World Wide Web. Mobile phones are evolving into universal communicators with the potential to converge all forms of information provision such as radio, television, telephone and the Internet (Brown & Conlon, 2002).

This discussion of science and technology in the 21st Century represents only a small aspect of what is known and available now, or in the foreseeable future. The continued development of science and technology is perhaps only limited by the collective imagination of humanity but without doubt science will continue to shape and direct the world in which we live.

2.2 Global pressures in the 21st Century

Occurring simultaneously with these developments, science has also contributed to the environmental pressures now facing the planet. Increased life expectancy has contributed to the current world population of approximately 6.4 billion people today. It is anticipated that the world population will rise to nearly 10 billion over the next 50 years (Worldwatch Institute, 2006). The rapid growth in population, individual
consumption levels and rapidly changing technologies has placed a strain on the environment and world economic and social structures. Global trends in climate change, environmental degradation and the depletion of natural resources are placing pressure on humanity and the desire for a sustainable future. In addition, inequitable distribution of global wealth and power means hunger, malnutrition, poverty and diseases such as malaria and AIDS continue to be the reality for many developing countries (Raven, 2002).

Striving to feed an ever increasing population has resulted in more natural environments being cleared for farmland. Brown (2001), as cited by Raven (2002), states that about one fifth of the world’s land is now cultivated and used for grazing 3.3 billion cattle, sheep, and goats. Most of this land area is already grazed at or beyond its capacity and has limited potential for the increased production needed to sustain the anticipated population growth. Yet, already the current level of destruction to natural habitats through land clearing has resulted in a significant loss of biodiversity. Worldwide, species to area relationship analysis led to the prediction that there could be a loss of two-thirds of all species on Earth by the end of this century. A loss of this magnitude has not been evident since the end of the Cretaceous period, a time of extreme and permanent change, from which Earth took millions of years to recover (Raven, 2002).

The importance of the world’s ecosystems and the species in them is perhaps self evident as they provide many of the resources needed to sustain human life, including food, timber, fuels, natural materials for pharmaceuticals and industrial elements. They also contribute to the cycle that purifies water, the various nutrient cycles maintaining soil fertility and the cleansing of the atmosphere (World’s Scientific Academies, 2000).
In addition, ecosystems directly affect the amounts and distribution of local precipitation and topsoil retention.

Brown (2001), as cited by Raven (2002), estimates that in just the last 25 years, about a fifth of the world's topsoil has been lost, a fifth of its agricultural land, and a third of its forests. It has been estimated that world-wide land degradation has affected 1900 million hectares of land. In Africa alone as much as 65% of the agricultural land is now unproductive due to soil erosion. Desertification in some cases may be caused solely by natural processes, but often both human and natural causes combine to accelerate desertification. Regardless of the balance of the cause, land degradation and desertification results in hunger and despair (United Nations, 2006). Australia is yet another example where land degradation is evident. The impact of clearing natural vegetation for agriculture has also resulted in increased soil salinity. Soil salinity is caused by the penetration of more water past the root zone into the underground water, which then leads to the migration of water and salt to the surface. Currently, it is predicted that in Australia there will be three times more compared to now, salt affected land by the middle of this century. Pearman (2002) equated the rate of growth in salt effected land to that of “about a football field every three minutes” (p. 3).

The destruction of natural ecosystems also has an adverse effect on water supplies as they have an influence on the amount and distribution of precipitates. Freshwater is quickly becoming a major constraint on development. The World Bank (1995), as cited by United Nations (2006), states that 40% of the world's population already faces chronic water shortages. Water supplies could run out in the next century if per capita consumption and excessive use in agriculture are not controlled. It is suggested that
between 1 and 2.4 billion people will live in water-scarce countries by 2050 (United Nations, 2006).

Furthermore, human activity magnified at times by the arguably naive and compromising use of scientific knowledge and technology, has changed the composition of the atmosphere by adding greenhouse gases such as carbon dioxide. This has been the result primarily of burning fossil fuels combined with accelerated land clearance. Since 1750, the atmospheric concentration of carbon dioxide has increased by 31% from 280 ppm to about 367 ppm today. The increased greenhouse effect is causing the world to heat up. It was predicted by the Intergovernmental Panel on Climate Change that the average global surface temperature will increase by 1.4 to 5.8°C from 1990 to 2100 (United Nations, 2006). The Australian Academy of Science through its online publication NOVA, Science in the News (2005) suggested that the effects of this rise in temperature could include:

1. More frequent extreme high maximum temperatures and less frequent extreme low minimum temperatures;
2. A decrease in snow cover;
3. An increase in the variability of climate, with changes in both the frequency and severity of extreme weather events;
4. Alterations to the distribution of certain infectious diseases; and
5. Rising sea levels. (p. 1).

Another significant change to the atmosphere contributed to by industrialised societies is the depletion of the stratospheric ozone layer by an estimated 8 per cent (Raven, 2002). The release of chlorofluorocarbons (CFCs) and similar chemicals by humans are the cause of ozone depletion in the stratosphere. Destruction of the ozone will result in
millions of people being exposed to dangerous doses of ultraviolet-B radiation. The reduction and elimination of production of many ozone-depleting substances in industrialized countries has had some effect as a decrease in levels of ozone depleting substances in the lower atmosphere has already been observed. Yet, the ozone layer continues to thin twice as fast as predicted. Measurements taken in 2000 show that the ozone “hole” over the Antarctic had expanded by about 3.5% to 28.3 million square kilometres (United Nations, 2006). Similar depletion of ozone is now being recorded over the Arctic with fears rising for a second ‘hole.’

The preceding discussion of environmental pressures facing humanity in the 21st century is intended as illustrative only. It is, however, suggestive of the complex and diverse nature of the issues and the impact such environmental problems can have on the world’s people. These environmental issues coupled with inequitable distribution of wealth and powers have resulted in a world where the World Bank, as cited by Raven (2002), estimates that:

- About a quarter of humanity lives in absolute poverty, on less than $1 per day.
- Depending on the criteria used, between an eighth and a half of the world's people are malnourished, with about 700 million of us literally starving. Some 14 million babies and young children under the age of four starve to death each year, at the rate of 35,000 per day. (p. 6)

Creating an equitable world, in which we can all be ‘rich’ with the industrialised world’s level of consumption, is unlikely to be achieved using the science understandings and technologies we possess now. In reality, the demand for resources would outweigh the carrying capacity of Earth. Raven (2002) states:
If everyone lived at the standard of industrialized countries, it would take two additional planets comparable to Earth to support them, three more if the population should double; and that if worldwide standards of living should double over the next 40 years, twelve additional ‘Earths’. (p. 7)

This would suggest that achieving industrialised standards for all people is unattainable. It should also highlight the complexity of issues in attaining a sustainable future for all members of our global community which appears to have moved outside the limits for a sustainable future due to the size of the human population, demands for consumption, and use of inappropriate technology. The challenge then is to find new ways of meeting the needs of humanity and to re-thinking our approach to development. This would include at least in part, controlling world population growth, finding an equitable and sustainable global level of consumption, and developing improved scientific understandings, technologies and practices to make sustainable development possible.

2.3 Facing the pressure: science for sustainability

Science offers attitudes and habits of mind which provide a strong basis for understanding our interconnected world and achieving a transition to a sustainable global environmental. Scientific research would improve our understanding of complex ecological processes, biodiversity and renewable energy sources such as wind turbines, solar cells and hydrogen generators.

Four Australian academies joined together in 2002 to respond to the challenges of sustainability: Australian Academy of Science, Academy of the Social Sciences in Australia, Australian Academy of Humanities, and Australian Academy of Technological Sciences and Engineering. The Joint Academies Committee on
Sustainability provided a mechanism for a cooperative approach to the achievement of sustainability (Pearman, Scaife & Walker, 2002).

As a first step to this collaboration, The Australian Academy of Science produced a document titled *A Blueprint* that identified key issues relating to the contribution of science to sustainability in Australia. It recognised the importance of an interdisciplinary approach and fostered collaborative activities by the four academies for achieving sustainability. Sustainability science was proposed as a vehicle for integrated analysis which would be a step towards new knowledge. This was presented as a holistic approach to assessing problems and developments that would build onto scientific observations by considering the social, economic and environmental dimensions (Pearman et al., 2002). It also demands that scientists contributing to sustainability have more than isolated technical knowledge as their expertise must be understood and applied at the interface with society. Scientists must be scientifically literate, understanding not only specialised concepts and ideas but also the values and assumptions in their field and the manner in which their work impacts and interacts with society. These demands may challenge some positivist type assumptions about science and its role in society but the need for broadening our views is urgent. Pearman et al. (2002) stated:

There is an urgent need, one that is made even greater by the issue of sustainability, for a broader understanding and definition of the role of science in modern society. (p. 4)

Coming out of the Australian Government’s initial primary focus on science, engineering and technology as facilitators and drivers of change was an increased awareness and recognition of the important part played by the social sciences and
The need for a multidisciplinary approach to research for sustainability was again highlighted in the area of health. For example:

Pathways to health and wellbeing are complex, multidimensional, and cross disciplinary. Investigation of the evidence base requires strategic partnerships across disciplines to elucidate these pathways and to adequately inform government policy, planning and service provision (Stanley, 2003, p. 13)

It is evident that both the social science and science academies see the need for a greater emphasis on interdisciplinary integration. This would demand a team approach to the way science is done and the building of partnerships between all members of the
community. It is also increasingly evident in this current context that all citizens have a reasonable level of scientific literacy in order for real change to occur. Furthermore, the Australian government appointed Chief Scientist stated, as cited by Pearman et al. (2002), *Australia needs a scientifically literate and critical society to support the transition to sustainability* (p. 6). This would contribute to democratic and informed community involvement in the selection of options for the future.

The achievement of a sustainable future will require an increasing number of citizens to be better informed about sustainability issues and to take actions such as consuming less energy, recycle materials and supporting others and their initiatives aimed at achieving sustainability. Issues such as global warming, loss of biodiversity and the implications of genetic research impact on all citizens, so better understanding of the concepts and the nature of research in the areas would enable citizens to respond with appropriate actions. Scientific literacy at the citizen’s level is essential for the development of sustainability and the protection and conservation of irreplaceable global resources.

### 2.4 Contributing to the solution: educating for scientific literacy

Access to, and understanding of, key scientific information is essential for citizens to participate, respond and make informed decisions and actions in response to the challenges that development has placed on global and local communities. Knowing about and understanding issues such as increased greenhouse effect, global warming, loss of biodiversity, depleted natural resources and many other topics is essential. Educating for scientific literacy is potentially an integral part of addressing these problems as a scientifically literate person is better able to understand and respond to sustainable development. Hurd (1997) views the ability to use advances in science and technology for improving various aspects of one’s life as building human capital and in
In this context, scientific literacy represents cognitive capacities for utilizing science/technology information in human affairs and for social and economic progress (p. 411).

Citizens will increasingly be required to make judgements and informed decisions about issues underpinned by scientific knowledge, but overlaid with much wider interdisciplinary considerations. Scientifically illiterate citizens, those without a basic understanding of the ways in which science and technology are impacted by, and impact society will be effectively disempowered and at risk of being misled in exercising their rights within a democratic society increasingly shaped and directed by science (Hodson, 2003).

An awareness of the increasing scientific demands being placed on citizens was illustrated at the international conference of the world’s academies held in Tokyo in 2000 titled, *Transition to Sustainability in the 21st Century*. This international forum concluded with the issuing of a statement that outlined the importance of science and technology in achieving global sustainability. The attending world’s scientific academies identified effective and relevant science education as an essential element of all aspects of the transition to sustainability. It was also highlighted that literacy was a practical concept that increasingly included scientific and technological components. It was also proposed that the world wide research enterprise could be significantly strengthened by including long-term collaborative basic research linked to societal goals. Research of this type could be strengthened by integrating disciplinary knowledge into interdisciplinary, locally focussed, problem-driven research and application efforts. They also proposed that the values of the scientific and technological community would contribute to building sustainability with recognition being given to science’s limitations.
and potential for some applications to cause harm rather than benefit (World’s Scientific Academies, 2000).

Education was also stated as a key contributor to achieving sustainability in the *Blueprint* (2002) generated by the Australian Academy of Science. It was stated that educational reforms for the transition to sustainability could include:

- Renewed emphasis on science studies in schools, founded on problems not just disciplines.
- Include appropriate modules in school science curricula to educate students on the ‘state of the world’ and the role of science in the transition to sustainability.
- Attention to public education in science and technology aimed at a science and technology literate and critical society.
- Establish centres for integrative science training, to allow for complex systems, including social and ecological aspects.
- Ensure that accredited science courses in universities include basic training in sustainability and the emerging “sustainability science” (Pearman et al., 2002, p. 5).

It was also noted in this document that the integrated and multidisciplinary focus aimed through sustainability science could pose problems for academics and universities but effort in this area was required in order to achieve excellence through to the doctoral level.

The Australian Council of the Deans of Science (ACDS) whose purpose is to promote the development of science through study and research in science faculties in
universities throughout Australia defined their role through five core principles contained in their 2004 policy framework. These were:

- Be advocates for the development of the current and next generation of scientists;
- Support programs that develop lifelong scientific literacy;
- Influence the development of policy relevant to research, research training, science education and scientific literacy;
- Establish links to further collaboration with cognate international science bodies and;
- Influence the development of policy to enhance and protect careers in scientific research. (p. 1)

The development of scientifically literate citizens was an integral part of the Dean of Science activities. They further stated that progress and sustainability will be enhanced where the community is scientifically literate. This would assist in ensuring that community participation in debate was informed by an evidence-based approach to making decisions and citizens could become informed consumers of science, such as, for example, in managing their health. The Council suggested that the development of lifelong scientific literacy could be contributed to by encouraging the development of programs of scientific literacy aimed at the primary, secondary, university and community levels and influencing state education authorities to adopt scientific literacy goals (ACDS, 2004).

The U.S. National Council for Science and the Environment (NCSE) also places a high priority on education in the transition to sustainability. The report from the 2003
National Conference on Science, Policy and the Environment, held in Washington included under the teaching of sustainability concepts the recommendation that education departments should encourage experiential, science-based, analytical and synthetic learning (NCSE, 2003, p. 19). According to this report, sustainability should not be viewed as a separate field of study, but rather as an approach to understanding that is integrated across the curriculum from K-12 and all post compulsory higher education.

The NCSE report also suggested that colleges and universities had a responsibility to reach all students, not only those majoring in a natural science, in order to facilitate their ability to integrate sustainability into both their professional and personal lives. A recommendation was that, all disciplines and majors should integrate sustainability, environmental, social, and science literacy, social change skills and understanding of values into their curriculum (NCSE, 2003, p. 45). Scientific literacy was again identified as a key component of an effective education contributing to the achievement of sustainability.

### 2.5 Developing scientific literacy through higher education

It is consistent with the above analysis, situated within the contemporary context of sustainable development, for scientific literacy to be a learning outcome for all types of general education. More specifically, it is likely to be an attribute industry and the community would expect from higher education’s graduates. This view was supported by the work of Reid and Petocz (2006) who conducted a research project investigating the ways that academics understood sustainability within their own disciplines. Their preliminary talks with industry members and academics identified the real need for universities to:

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Scientific Literacy for Sustainability 39
Prepare students for professional work so that they were able to contribute to their industries in ways that go beyond simple disciplinary expertise.

Sustainability, creativity and flair, and communication were some of those aspects of professional formation that were considered to be essential. (p. 109)

Scientific literacy and the nature of its contribution to the transition to sustainability can be captured as an educational construct in university graduates’ attribute statements. Many universities view developing graduates with a well-defined set of attributes as fundamental in providing quality education. This view is consistent with Australia’s Department of Education Science and Training (DEST) requirement that Universities state their graduate attributes in their annual Quality Assurance and Improvement Plans (DEST, 2001).

DEST has required universities to state their graduate attributes since 1998. Over time four core attributes aimed for by most universities have been identified. The core attributes listed in Table 2.1 were reported in the 2001-2003 Higher Education Report (DEST, 2001, p. 42).
It is evident in these statements that Australian Universities are now increasingly aiming to produce graduates that not only demonstrate discipline knowledge but who also have the understanding and ability to interweave ethical and social responsibility into their practice.

These core attributes were also identifiable within Murdoch University’s graduate attributes, as stated by Ballantyne, Lowe and Marshall (2004). Murdoch University’s graduate attributes are listed in Table 2.2.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge attributes</td>
<td>• Effective literacy and numeracy skills</td>
</tr>
<tr>
<td></td>
<td>• Ability to communicate and listen</td>
</tr>
<tr>
<td></td>
<td>• Appropriate discipline specific knowledge</td>
</tr>
<tr>
<td>Thinking Attributes</td>
<td>• Effective conceptual and problem solving skills</td>
</tr>
<tr>
<td></td>
<td>• Ability to question, be creative and combine theory and practice</td>
</tr>
<tr>
<td>Practical Attributes</td>
<td>• Ability to use information technology</td>
</tr>
<tr>
<td></td>
<td>• Proficient with technical skills appropriate to their discipline</td>
</tr>
<tr>
<td></td>
<td>• Ability to initiate and respond to change</td>
</tr>
<tr>
<td>Personal Attributes &amp; Values</td>
<td>• Committed to learning</td>
</tr>
<tr>
<td></td>
<td>• Flexible and able to work in teams</td>
</tr>
<tr>
<td></td>
<td>• Leadership skills</td>
</tr>
<tr>
<td></td>
<td>• Understand the concepts of ethical action and social responsibility.</td>
</tr>
<tr>
<td>Attribute</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Communication</td>
<td>Ability to communicate effectively and appropriately in a range of contexts using communication literacy, numeracy and information.</td>
</tr>
<tr>
<td>Critical and creative thinking</td>
<td>Ability to collect, analyse and evaluate information and ideas and solve problems by thinking clearly, critically and creatively.</td>
</tr>
<tr>
<td>Social interaction</td>
<td>A capacity to relate to and collaborate with others to exchange views and ideas and to achieve desired outcomes through teamwork, negotiation and conflict resolution.</td>
</tr>
<tr>
<td>Independent and lifelong learning</td>
<td>A capacity to be a self directed learner and thinker and to study and work independently.</td>
</tr>
<tr>
<td>Ethics</td>
<td>An awareness of and sensitivity to ethics and ethical standards on interpersonal and social levels, and within a field of study and /or profession.</td>
</tr>
<tr>
<td>Social justice</td>
<td>An acknowledgment of and respect for equality of opportunity, individual and civic responsibility, other cultures and historical times and an appreciation of cultural diversity.</td>
</tr>
<tr>
<td>Global perspective</td>
<td>An awareness of and respect for the social, biological, cultural and economic interdependence of global life.</td>
</tr>
<tr>
<td>Interdisciplinary</td>
<td>A capacity to acquire knowledge and understanding of fields of study beyond a single discipline.</td>
</tr>
<tr>
<td>In depth knowledge of a field of study.</td>
<td>Comprehensive and in-depth knowledge of a field of study and defined professional skills where appropriate.</td>
</tr>
</tbody>
</table>

Table 2.2: Murdoch University’s graduate attributes
Traditionally at Murdoch University students’ generic skills have been developed within foundation units, which are compulsory for all first year university students. These units are designed to introduce students to university study skills and to provide them with an interdisciplinary perspective of the world in which they live and their own learning. A review of these units conducted in 2001 indicated that they made a strong contribution to the development of students’ graduate attributes but recommended against complete reliance on these units for this purpose. It was suggested that the generic skills and interdisciplinary perspective developed in the foundation units should be scaffolded and further developed throughout degree programs (Marshall, 2003).

It is increasingly being recognised that general over-arching graduate attributes become meaningful when applied within discipline specific contexts (Bowden et al., 2000). In science-based courses or contexts they would require clarification and clearer identification. Particular programs in various Australian universities are working towards adapting or elaborating on their universities’ generic attributes to fit with their particular field of study. Examples are coming out of areas such as Engineering at Royal Melbourne Institute of Technology, Health Science and Engineering at Curtin University in Western Australia and science based graduate attributes at the University of New South Wales. General graduate attributes in science are being developed at the University of New South Wales (University of New South Wales, 2003). These are described, as the scientific and professional attributes that UNSW science graduates would have the opportunity to develop during their undergraduate science degrees. Scientific literacy was included as the contextualisation of the generic attribute, *skills of lifelong learning including information literacy*. 
As a result of their graduate attribute mapping exercises, the University of Queensland and the University of Adelaide, recognised the range of contexts and needs from diverse fields of study (B-HERT, 2003). In order to ensure graduate attributes are embedded in the learning and assessment process of every field they have aimed to translate and interpret attributes in context. For example, ethical and social sensitivity is defined in Engineering at the University of Queensland as,

Understanding of the social, cultural, global and environmental responsibilities of the professional engineer and the need for sustainable development (Gardner & Martin, 2003 p. 3).

In addition, the University of Adelaide has encouraged all faculties to integrate program specific attributes that use context specific language, into their curriculum (Crisp, 2003). This approach allows for the development of science course specific attributes that could take into account not only the content knowledge of a field but its nature and interaction with society. Linked with these knowledge dimensions could be personal skills such as communication, thinking, collaboration, ethical action, social responsibility and an international perspective. Explicit statements of such attributes and hence then, the opportunities students could expect to have through their degree program, encourages not only educators but also students to reflect on the broader purpose of their university experience.

Creating the space within the university to discuss graduate attributes could facilitate reflection and critical thinking about the fundamental understandings, skills and abilities required for professional practice in a society striving for sustainability. Graduate attributes are potentially a point of intersection between the social, economic and political factors that shape professions (James, Lefoe & Muhammad, 2004). Focussing
at the course and unit level could potentially support unit co-ordinators in constructing unit objectives and learning experiences that provide students with the opportunity to develop qualities desired by employers and the general community.

Universities’ explicit statement and commitment to developing graduate attributes is a promising initiative, particularly as historical reforms to curricula have primarily involved the updating of content knowledge, within the various discipline areas. Such reforms have not taken into account the need for a move to sustainability that demands a minimal level of scientific literacy. Building sustainable communities requires the defining and implementing of educational practices that enhance scientific literacy and as such education reforms must also take into account the nature of science and the interaction of science with contemporary society. We have been alerted to the urgency of the required reforms to education by Arons (1983) who stated;

The escalating impact of science and technology on moral, ethical, political, and societal problems has only continued to enhance the urgency of the problem of education and to heighten the pertinence of the liberal education objective. (p. 91)

A focus on the development of scientific literacy in higher education has been slow in coming despite its importance as an educational outcome for all citizens in the 21\textsuperscript{st} century. An overview of the history of scientific literacy as an educational construct is provided in Chapter 3 in order to better understand the variables influencing the relative emphasis given to developing scientific literacy through education. More recent Australian initiatives are also considered for the definition of scientific literacy.
CHAPTER THREE THE HISTORY AND DEFINING OF SCIENTIFIC LITERACY

The term scientific literacy has been in use since the late 1950’s and is often used to describe a desired outcome of science education, relating to what the general public ought to know about science. It is often used to imply a general, broad and useful understanding of science as a part of general education and not just for the specific development of specific technical knowledge for practising scientists. Science or scientific literacy for citizenship is an alternative phrase used at times to describe the minimal acceptable level of knowledge or skills required to function effectively in a society that is both increasingly complex and science and technology dependent (Dimopoulos & Koulaidis, 2003). Scientific literacy for all is frequently stated as a goal of contemporary science education yet controversy and uncertainty are evident in the literature as the question is repeatedly asked what should the scientifically literate person know, value and do as a citizen.

3.1 Interest groups

Despite the continuing interest in scientific literacy over the past decades we still strive for a clear and concise conception of scientific literacy. Factors that could contribute to this situation are who the interest group is, the different purposes for promoting scientific literacy, who is perceived as the general population and the various ways of measuring the construct. Laugksch (2000) identified four interest groups in the development and promotion of scientific literacy amongst members of society. These are the science education community, social scientists including public opinion researchers, sociologists and science communicators involved with informal science education.
Firstly, the science education community is concerned with the purpose, content, and evaluation of outcomes leading to the reform of science education. Attention to the relationship between formal education and scientific literacy has mostly been focussed on primary education but with increasing interest in the secondary and tertiary sectors.

Secondly, social scientists are essentially interested in the extent to which the general public demonstrates support for science and technology and their willingness to engage with science for policy development. Scientific literacy is relevant to activities such as identifying sources of scientific and technological information and measuring the public’s science knowledge, perceptions of the limitations of science including attitudes to science and technology in general.

The third interest group, the sociologists of science, are concerned with the construction of authority involving the ownership and control of science. Scientific literacy is investigated as the underlying construct influencing how individuals interpret, evaluate and negotiate scientific knowledge in their everyday lives.

The fourth interest group has an informal role within science education. This group is generally involved in science communication. The members of this group provide opportunities for the general public to acquaint themselves with science. This includes writers about science and those who report science in the news and wider media. People working in science centres such as museums, zoos and exhibitions are also included in this group of science communicators.

In addition, Shamos (1995) suggests scientists themselves are another relevant interest group. Their interest may extend from the competitive nature of research grants and the
dependence of such grants on the support present amongst the general population and hence government and private funding bodies. He cautions, however, that some practising scientists may have an understanding of science that is limited to a narrow area of a highly specialized discipline and hence they fail to view their practice in its social or even broader scientific perspective.

Laugksch (2000) suggested that each of the identified interest groups focussed their conception of scientific literacy on their targeted audience. Different views result due to who the audience is perceived to be and hence what should be known about science. This contributes to the number of different interpretations and definitions of scientific literacy. Rascoe et al. (1999) presents a similar finding. This research studied the interpretations of scientific literacy from a cross section of the U.S. society. They interviewed individuals who held positions of influence and responsibility related to science and scientific literacy. This included scientists, science educators, teachers, administrators, community members influencing educational decisions and parents. They found that no two people defined scientific literacy in the same way but their ideas were not mutually exclusive. Rascoe (1999, p. 15) stated that the participants’ characterization of scientific literacy usually differed in emphasis rather than being incompatible in nature.

3.2 The Historical context of scientific literacy

In addition to the focus group, historically the social climate of an era has influenced the defining of scientific literacy and the attention given to the concept. World War Two focussed attention on science and science education. After having witnessed the outcome of science being used for the development of the atom bomb, many scientists and various other interest groups saw educating the public for scientific literacy as a way
to make citizens more aware of the possibility of science being used for positive as well as negative ends and in so doing giving citizens greater input and control over future scientific enterprises. Preparing the population to engage intelligently with science-based societal issues was one favoured goal of science education. However, the need to reindustrialise took the primary focus, forcing school curricula to adjust in order to meet the need for larger numbers of science and engineering graduates (Shamos, 1995).

The heightened interest and awareness of scientific literacy during the late 1950’s was probably due to the concern expressed by the U.S. science community about the support the general public displayed for the necessary science for responding to the Soviet’s launch of Sputnik. Another resulting concern for the U.S. at this time was whether their children were being educated in a manner which would enable them to participate in an increasingly scientific and technological society. Increasing the level of scientific literacy amongst the population was seen as a solution to both of these issues (Laugksch, 2000). The National Science Foundation established in the U.S. in 1954 as an independent federal agency whose principal function was to support basic and applied research in science and engineering placed a higher priority on education programs with Congress increasing their budget from 3.5 million to 19 million and later 61 million US dollars (Shamos, 1995). Their response was to support projects, which would contribute to providing citizens with a broader understanding of science and its societal implications.

Pella (1976) described the 1960’s as an era when citizens were convinced of the importance of science in order to remain respectable in the world and science for the sake of science was viewed as adequate. Pella goes on to describe the 1970’s as a time when more scientists where engaging with environmental problems and being
challenged by the possible social effects of applying research. He argued that to be a
functioning citizen in this era demanded the ability to read and interpret technical
literature for personal welfare and decision-making. It was his view that science
education of the time did not meet this need of citizens as it focussed on the
development of scientists and resulted in the youth turning off science. Generally, there
was a large degree of pessimism regarding the effectiveness of post war programs that
resulted in a loss of support for science education.

Miller’s (1992) comments on a Science Indicators study conducted in association with
the US National Science Board in 1979 would support Pella’s view of scientific literacy
in the 1970’s. This study concluded 20% of U.S. adults were interested in, and informed
about, science and technology policy, about 20% were interested, and approximately
60% were not interested in science and technology policy.

From the 1950’s through to the late 1970’s various authors promoted issues associated
with scientific literacy. However, what was meant by the concept was not always clear
and multiple and diverse meanings were generated. Due to the plethora of
interpretations of the term scientific literacy, it has come to be an over arching concept,
which suggests comprehensiveness in the purpose, process and outcomes of science
Teaching in schools and to some extent virtually everything to do with science education.

The multiple and varied definitions continued in the late 1970’s and early 1980’s and
with the persistent lack of consensus, the usefulness of the concept appeared to decrease.
However, during this period the U.S. faced two more internationally based challenges.
The first stemmed from the emerging economic power of Japan and other countries such
as Korea and Singapore. This was perceived to be a threat to U.S.’s economic and
industrial leadership. A decline in U.S. science and engineering research was noted in addition to a reported poor comparative standing internationally in science achievement (American Association for the Advancement of Science, 1990). Shamos (1984) contributed to discussion on the apparent lack of scientific literacy amongst the population. Shamos suggested that despite the exposure to science in formal education few students emerged with a lasting impression of the scientific world. However, science and technology were seen as the key foundation for progress and international competitiveness.

The end of the 1980’s saw scientific literacy back on the US political agenda. This would at least be in part due to then President Reagan giving a higher priority to education. In this context there was again a heightened awareness and interest in scientific literacy that has continued to present, primarily through the work of the American Association for the Advancement of Science.

3.3 Conceptions of scientific literacy

One of the earliest attempts at defining scientific literacy was made by Pella, O’Hearn & Gale (1966). In this study, scientific literacy was broadly defined as science for effective citizenship. Pella reviewed 100 papers published between 1946 and 1965 for references to scientific literacy. In summary of their findings they concluded a scientifically literate person had an understanding of the (a) basic concepts in science; (b) nature of science; (c) ethics that control scientists work; (d) interrelationships of science and society; (e) interrelationships of science and the humanities and (f) differences between science and technology. Pella’s conception of scientific literacy was elaborated by Showalter (1974), as cited by Laugksch (2000), resulting in a definition of scientific literacy consisting of the following seven dimensions:
1. The scientifically literate person understands the nature of scientific knowledge.

2. The scientifically literate person accurately applies appropriate science concepts, principals, laws and theories in interacting with his universe.

3. The scientifically literate person uses processes of science in solving problems, making decisions and furthering his own understanding of the universe.

4. The scientifically literate person interacts with the various aspects of his universe in a way that is consistent with the values that underlie science.

5. The scientifically literate person understands and appreciates the joint enterprises of science and technology and the interrelationship of these with each and with other aspects of society.

6. The scientifically literate person has developed a richer, more satisfying, more exciting view of the universe as a result of his science education and continues to extend this education throughout his life.

7. The scientifically literate person has developed numerous manipulative skills associated with science and technology (p. 76).

Shen (1975) developed three categories of scientific literacy; practical, civic and cultural. The categories are less specific than the work of Showalter but took into account directly the influence of the interest group and the relevant audiences. Practical scientific literacy deals with the knowledge required to meet basic human needs in relation to food, health and shelter. The interest group in this category would primarily be developing countries. However, this category could also be relevant in industrialised countries in regard to consumer protection efforts. The second category, civic scientific literacy, covers the knowledge and understandings needed by citizens to participate in science-related public policy and decision making in areas such as health, energy and the environment. Citizens would then be equipped to contribute to debate about science
and science-related issues. The audience of the third category, cultural scientific literacy, would effectively be the ‘academic’ or higher education community as it embraces the motivation and desire to know something about science as a major human achievement.

Branscomb’s (1981) conceptualisation of scientific literacy, as cited by Laugksch (2000) expanded on Shen’s categories by more clearly identifying the relevant interest groups. The eight categories developed were: (a) methodological science literacy (b) professional science literacy (c) universal science literacy (d) technological science literacy (e) amateur science literacy (f) journalistic science literacy (g) science policy literacy and (h) public science policy literacy. Each category provided a context for Branscomb’s definition of scientific literacy, which Laugksch (2000) cites as the ability to read, write and understand systematized human knowledge. This definition developed out of an interpretation of the Latin root of literacy.

Miller’s initial Science Indicators studies in 1979 and 1981 proposed a multidimensional model of scientific literacy. This construct consisted of three dimensions: (a) a vocabulary of scientific terms and concepts; (b) an understanding of the process of science and (c) an awareness and understanding of the impact of science and technology on individuals and society (Miller, 1992). He viewed a minimal scientific vocabulary as essential to being scientifically literate as the individual who does not understand basic terms will find it nearly impossible to follow public discussion of scientific results (Miller, 1983). This model was contemporary in the context of the scientific society of the time and important to the consolidation of the concept of scientific literacy.

Arons (1983) incorporated and developed Miller’s three dimensions by identifying 12 attributes of a scientifically literate person. These attributes stem from the thinking that
scientifically literate individuals are able to correctly apply scientific knowledge and reasoning skills for problem solving and decision-making in their personal, civic and professional lives. In brief these attributes are:

1. Recognize that scientific concepts are invented or created by acts of human intelligence and imagination.

2. Recognize that to be understood and correctly used such terms require careful operational definition and an understanding that a scientific concept involves an idea first and a name afterwards.

3. Comprehend the distinction between observation and inference in a relevant context.

4. Distinguish between the occasional role of accidental discovery in scientific investigation and the deliberate strategy of forming and testing hypotheses.

5. Understand the meaning of the word theory in relation to formation, testing and validating.

6. The ability to critically question the outcomes of scientific research.

7. Have a sense that scientific concepts and theories are mutable and provisional rather than final and unalterable.

8. Comprehend the limitations inherent in scientific inquiry.

9. Develop enough basic knowledge and understanding in some area(s) of interest to allow intelligent reading and subsequent learning without formal instruction.

10. Be aware of instances in which scientific knowledge has had direct impact on intellectual history and views of the nature of the universe including humanity’s place within it.

11. Be aware of the interaction between science and society on moral, ethical and sociological planes.
12. Be aware of similarities in modes of thinking between various disciplines; for example forming concepts, testing hypotheses, discriminating between observation and inference, constructing models and doing hypothetical-deductive reasoning (p. 92).

In the mid eighties, the American Association for the Advancement of Science (AAAS) initiated a reform aimed at science, mathematics and technology education. As indicated by the initiative’s name, this project suggested that meaningful reforms to education depended on a long term view that took into the account the demands of life then and well into the 21st Century. Project 2061 was an aspect of this initiative that aimed to define the essential key aspects of science in a form which satisfied the scientific community. This project emphasized the interconnections between various disciplines and covered science, mathematics, technology and social science. It indicated that the scientifically literate citizen should know basic science principles rather than detailed science concepts and factual information.

In 1990 the AAAS published its first Project 2061 report titled Science for All Americans, which offered the following broad definition of scientific literacy:

Science literacy includes …being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes. (p. 4)
This perspective on scientific literacy then informed the development of a national curriculum framework in the United States titled National Science Education Standards (U.S. National Science Council, 1996). This framework defined scientific literacy by what an individual could do. It stated scientific literacy:

- Means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that the person has the ability to describe, explain and predict natural phenomena.
- Entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions.
- Implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it.
- Also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (p. 22)

This framework, according to Goodrum, Hackling and Rennie (2001) was different from past United States curriculum initiatives as it proposed that content coverage was no longer the focus but that less content should be taught so that it could be taught better. Support materials have since been published to support the implementation of the National Science Education Standards Framework. These include Benchmarks for Scientific literacy, which map out the levels of understanding and abilities that students
are expected to achieve on their way to becoming scientifically literate (National Science Council, 1996) and the *Atlas of Science Literacy*, co-published by *Project 2061* and the National Science Teachers Association (2001). This was a collection of conceptual strand maps that show how students' understanding of the ideas and skills that lead to literacy in science, mathematics, and technology may interact and develop.

The work of Hazen and Trefil (1991) on scientific literacy was similar to the perspective of *Project 2061* as they also distinguish between the doing and using of science. They described the doing as the work of the scientist and the using as the level of engagement required of a scientifically literate member of society. Hence they defined scientific literacy as the knowledge in the form of facts, vocabulary, concepts, history and philosophy, needed to understand public issues and to take part in national debate. In addition they presented the view that scientifically literate individuals should be able to place daily science news into a meaningful context. They presented 18 general principles of science, which they viewed as necessary to follow public debate. Hazen and Trefil’s conception of scientific literacy is heavily focussed on science content yet they acknowledged in addition to the general facts and concepts the scientifically literate individual needs to know about how science works and draws conclusions, and to know scientists as real people.

Shamos’ (1995) conception of scientific literacy also represented the construct as relevant to all citizens. He suggested that there were three levels of development, *which build upon one another in degree of sophistication as well as in the chronological development of the science orientated mind* (p. 87). The most simplistic form were *cultural scientific literacy*, which related to the terms and phrases needed to follow public debate about science issues reported in the daily news. The next level was
*functional scientific literacy* in which they are not only required to have a command of scientific vocabulary but be able to read, write and converse for responding to and communicating with another member of society in a meaningful context. The third and highest level of scientific literacy identified by Shamos as *true scientific literacy* involved also knowing about the scientific enterprise. This encompassed for example, an awareness of major theories that form the foundations of science; how science creates order out of a random universe; aims, roles and elements of scientific experiments and investigations; the role of critical questioning; analytical and deductive reasoning; logical thought and science’s reliance upon objective evidence. Shamos equated these mental qualities to what John Dewey in 1934 called *scientific habits of mind*. Shamos identified many problems with the scientific literacy movement and questioned if any real discernible progress had actually resulted. He in fact suggested, it was time to get on with the *normal business of science education* (p. 216).

Despite the presence of a strong negative voice in the field of scientific literacy, in England a seminar series funded by the U.K Nuffield Foundation titled *Beyond 2000: Science Education for the Future* continued to explore the achievement of scientific literacy for all citizens (Millar & Osborne, 1998). This report stated:

> Science curriculum should provide sufficient scientific knowledge and understanding to enable students to read simple articles about science, and to follow TV programmes on new advances in science with interest. Such an education should enable them to express an opinion on important social and ethical issues with which they will increasingly be confronted. It will also form a viable basis, should the need arise, for retraining in work related to science or technology in their later careers. (p. 9)

Specifically, scientific literacy was described in this report as including:
• Understand broadly the major scientific ideas, whilst appreciating the value of science and its contribution to our culture;
• Engage critically with issues and arguments which involve scientific knowledge;
• Understand the methods by which science derives the evidence for the claims made by scientists;
• Appreciate the strengths and limits of scientific evidence and;
• Make a sensible assessment of risk and to recognise the ethical and moral implications of the choices that science offers for action (p. 4).

This overview of the development of scientific literacy as a defined concept suggested the focus has shifted from concerns about the community’s perception of scientists to a broader understanding of science and its implications in a democratic society. Hurd (1997) viewed science today as becoming more holistic across disciplines and focussing more on the functional aspects of science and technology as it relates to human welfare, economic development, social progress, and the quality of life.

Bybee (1999) offered a broader contemporary definition of scientific literacy that aimed to be inclusive, taking into account an individual’s age, developmental stage, life and educational experiences. He proposed a framework of scientific literacy that recognized a continuum of scientific literacy that develops over a lifetime. Suggested in his framework was achievement encompassing more than just scientific knowledge or vocabulary. He proposed that scientific literacy should be a general educational goal as it encompasses the knowledge, skills and values that ought to be common to all students by virtue of their membership in society.
Bybee’s framework assumed an individual’s level of scientific literacy can change depending on the context, issue or topic rather than simply being scientifically literate or illiterate. He proposed the following dimensions for scientific literacy.

1. *Scientific and technological illiteracy*

   When asked a question relating to science or technology an individual would not have the cognitive capacity to understand or locate the question in the domain of science or technology.

2. *Nominal scientific and technological literacy*

   Demonstrates a token explanation for phenomena. Minimal understanding of term or topic as science related.

3. *Functional and scientific and technological literacy*

   Individuals can use scientific and technological vocabulary but it is often confined to a particular need and lacks conceptual embellishment.

4. *Conceptual and procedural scientific and technological literacy*

   Demonstrates a developing understanding of the way conceptual parts of a discipline relate to the whole discipline.

5. *Multidimensional scientific and technological literacy*

   Demonstrates a perspective of science and technology that includes the history of scientific ideas, the nature of science, the role of science and technology in personal life and society. Incorporates philosophical, historical and social dimensions of the discipline.

Incorporating aspects of Bybee’s conception of scientific literacy is the Organisation for Economic Co-operation and Development’s (OECD) Program for International Student Achievement (PISA). This is an international initiative with 32 participating developed countries, including Australia. This program has monitored and assessed the
development of scientific literacy of 15 year olds in the participating countries. The science framework used by PISA was also constructed on the inclusive assumption that varying levels of scientific literacy are possible. The executive summary of this program titled, *The Definition and Selection of Key Competencies* (2005) defined scientific literacy as:

The capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity (p. 16).

This definition of scientific literacy is consistent with those quoted earlier and illustrates the growing international agreement on the parameters of the construct. Furthermore, in order to measure the construct they expand it in three aspects. OECD online stated these as scientific processes, scientific concepts and situations or contexts. The blended nature of these aspects for demonstrating scientific knowledge is emphasized. They stated:

Although these aspects of scientific literacy are discussed separately it must be recognized that, in the assessment of scientific literacy, there will always be a combination of all three. The focus of the assessment is upon the outcome of science education as a whole. (p.1)

Here both scientific knowledge and the processes by which the knowledge were developed are viewed as bound and together were essential for scientific literacy. This conception of scientific literacy was closer to Bybee’s third level *conceptual and procedural scientific literacy.*
More recently still, and of significant importance to Australian science education, was the study undertaken for the Department of Education Science and Training by Goodrum, Hackling and Rennie (2001). They widely researched the status and quality of science teaching and learning in Australian schools. In this process they noted the underlying scientific literacy goal in the national frameworks but their findings suggested the construct was not acted upon in actual science education programs;

Australian educational jurisdictions have developed modern and progressive curriculum frameworks for school science, however, there is a considerable gap between the ideal or intended curriculum and the actual or implemented curriculum. (p. xiv)

The definition of scientific literacy that overlaid this research was informed by the international initiatives already outlined in the preceding discussion. They defined scientific literacy as:

The capacity for persons to be interested in and understand the world around them, to engage in the discourse of and about science, to be able to identify questions and draw evidence-based conclusions, and to make informed decisions about the environment and their own health and well being. (p. 15)

This definition clearly suggested that being scientifically literate requires more than simply knowing science content. It is a far more complex construct requiring an understanding of the processes of science and the capacity to use science for informed decision making.

Goodrum et al. (2001) made a series of recommendations aimed at closing the gap between the desired achievement of scientific literacy as an educational outcome for all citizens and the reality of science education practises in Australian schools. These recommendations have led to a number of initiatives including a project managed by the
Australian Science Teachers Association (ASTA). Rennie (2005) described the aim of this project as to *develop and trial a science awareness-raising model that could be used to increase the community’s awareness of science and what science is about.* This model was focussed at the community level and field tested with selected trial schools and their communities in all Australian states. It provided a structure for small community based projects that promoted scientific literacy in a manner that was appropriate to and connected with, the real life contexts of the participating communities.

An online evaluation report of the ASTA science awareness raising model described scientific literacy and science awareness as desirable outcomes. The evaluation of the project’s impact in these areas was focussed on the extent to which members of the community:

- Understood what science is about,
- Believed that science is useful to find answers for problems in the community,
- Understood why science is taught in our schools and its value to students,
- Were aware of the community project, and
- Understood the science-related issues and science knowledge associated with the project. (Rennie, 2003, p. 10)

A follow up project, School Community Industry partnerships in science (SCIps), based on the trialled model began in 2004, fostered community and industry partnerships in science. These projects were not intended as vehicles for teaching science ‘facts’ but more importantly to:
Assist people to understand how science is an integral part of what goes on in communities and how science can be used to make sensible decisions about peoples’ health and well being and the sustainability of their environment. (Rennie, 2005, p. 11)

Paralleling these proactive community based projects for developing scientific literacy amongst all citizens was the development of a science education assessment resource (SEAR) available free online to primary and secondary teachers. These resources were produced collaboratively by the Australian Council for Educational Research (ACER) and the Australian Curriculum Council; supported by extensive consultation with science education stakeholders. These assessment resources have been produced across six levels in accordance with scientific literacy progress maps produced as a part of the initiative. The progress maps are connected to the OECD, PISA (2002) conception of scientific literacy and the definition and elaboration of the construct by Goodrum et. al. (2001). Specifically, the SEAR website describes scientific literacy as:

A construct that encompasses the use of broad conceptual understandings of science for making sense of the world, understanding natural phenomena, and interpreting media reports about scientific issues. It also encompasses competencies related to asking investigable questions, conducting investigations, collecting and interpreting data, and making decisions. (p. 1)

Elements of the PISA (2002) definition of scientific literacy in the area of investigating ‘processes and concepts’ were drawn together into three domains forming the basis of SEAR’s scientific literacy progress maps. In brief, these domains are:

1. Domain A (Process Domain: experimental design and data gathering):
Formulating or identifying investigable questions and hypotheses, planning investigations and collecting evidence.

Interpreting evidence and drawing conclusions from their own and others’ data, critiquing the trustworthiness of evidence and claims made by others, and communicating findings.

3. Domain C (Conceptual Domain: applies conceptual understanding):
Using understandings for describing and explaining natural phenomena, and for interpreting reports about phenomena. (DEST, 2004, p. 2)

Some limitations are evident in these domains for capturing the multidimensional nature of scientific literacy. They do not include references to the value and assumptions inherent in the process of science or the development of scientific knowledge. They also have limited application for assessing understandings about the interaction of science with society. The authors’ awareness of these issues was evident in their discussion of the development of the scientific literacy progress maps on the SEAR web site:

Scientific literacy has been described here in three domains to facilitate the interpretation of student responses to assessment tasks. However, authentic tasks should require students to apply concepts and processes together, to address problems set in real-world contexts. (DEST, 2004)

Some alternative perspectives to defining of scientific literacy were evident in the literature. For example, Law, Fensham and Wei (2000) suggested some criticism of the approach taken by projects such as PISA due to their definition of education for scientific literacy being developed by scientists and science educators. As a result they believed these definitions of scientific literacy are based on what the scientific and
educational communities believe should be understood by all citizens rather than equipping citizens to meet the actual demands of modern society. These authors believed there was a need to identify the science knowledge and abilities adults require as they function in a variety of modern societal contexts. They aimed to do this by asking experts in society to identify and define the content needed by all citizens for scientific literacy. This was done within the societal contexts of everyday coping, participating in social decisions, technological development and scientific development. The experts surveyed in this study included an emergency care medical doctor, preventative care and community health education doctor, an official in a consumer council, a nutritionist and a youth worker. Hence their conception of scientific literacy was essentially functional and has the contextual dimensions of scientific and technological knowledge, scientific awareness, scientific values and scientific policy and legislation. They took the view that scientifically literate citizens should be able to communicate with trained experts within their society when they have the time, desire and motivation to do so (Law et al., 2000).

Roth and Lee (2004) went further to suggest there was a need to re-think the concept of scientific literacy. They proposed that scientific literacy was not a construct demonstrated by individuals as it was a collective property of communities. This proposition was based on the observation that society is built on a division of labour and that not everyone needs to know the same set of concepts:

First, scientific literacy more broadly and scientific knowledge more narrowly are aspects that characterize social activities rather than individuals. Because the division of labour is a fundamental process that links individual life and societal processes, individuals do not need to be knowledgeable in every domain. Rather,
they need to be able to participate in collective activity and to locate knowledge when and where they need it. (p. 284)

Roth and Lee’s perspective of scientific literacy evolved through a three year multi-site research project that in part investigated students’ science learning as they participated in a community effort to contribute knowledge about local waterways.

Furthermore, Lang, Drake and Olsen (2006) noted that many current initiatives like Roth and Lee’s claim that students must learn how to participate in public debates over real issues. They suggest that these initiatives entail new visions of what constitutes scientific literacy. Lang et al. (2006) suggested that scientific literacy is a literacy that crosses disciplinary boundaries and puts human values at the centre of educational practises (p. 178). These authors suggested that approaches to science incorporating rich social contexts and situations place demands on teachers to see science in a new light and to integrate the curriculum. Some authors have taken an integrated view of curriculum and focussed their discussion on language literacy skills within science education (Norris & Phillips, 2002; Yore, Bisanz & Hand, 2003; Fang, 2004; Yore & Treagust, 2006).

This current research recognises the integral place of language literacy skills within scientific literacy, particularly in engaging with science news reports but takes the broader view of scientific literacy represented throughout the preceding discussion of the history and defining of the construct. In chapter 4, the identification of dominant common ideas and issues in the literature on scientific literacy for all citizens is discussed and also the development of this research’s definition, framework and associated indicators for scientific literacy.
CHAPTER FOUR A FRAMEWORK AND INDICATORS OF THE DEVELOPMENT OF SCIENTIFIC LITERACY

Broadly speaking this research has taken the view that scientific literacy stands for what the general public ought to know about science in order to have the competence and disposition to use science to meet the personal and social demands of life at home, at work and in the community. All people should have sufficient understanding and confidence to make informed decisions about important questions dealing with scientific matter. Implied here is an appreciation of the nature, aims and general limitations of science. This appreciation should be coupled with some understanding of the more important scientific ideas. These ideas and concepts are those that are relevant to everyday situations and will continue to have relevance throughout the next decade.

This definition was informed by a review of the literature on the development of scientific literacy as a social and educational concept. Common ideas and issues were traced through the literature. It was evident that scientific literacy could be viewed as a composite, in some way, of science concepts and ideas, the nature of science and the interaction of science and society (Arons, 1983: Bauer, 1994: Bybee, 1999: Fensham, 2002: Hurd, 1997: Laugksch, 2000: Lederman, 1992: Miller 1983: Norris & Phillips 1999: Pella 1976: Shamos 1995: Solomon 2001). This research, as a result of the literature review, is based on a multidimensional model of scientific literacy that assumes the construct consisted of three dimensions: (a) scientific terms and concepts (b) nature of science, and (c) science and society. Although distinct dimensions, in practice it is their overlapping that results in scientific literacy. In this chapter, each dimension is explained and then considered in a blended manner for the development of the framework and indicators for scientific literacy.
4.1 Scientific terms and concepts

Scientific literacy requires some understanding of the more important scientific ideas. These ideas and concepts are those that are relevant to everyday situations and will continue to have relevance throughout the next decade. Such ideas should assist adults to function in a variety of modern societal contexts of everyday coping and personal decision-making (Law et al., 2000). This extends to following and, if choosing to, participating in social decisions involving science and scientific developments.

The framework to be proposed does not intend to define the specific concepts and ideas needed by all citizens for scientific literacy but rather considers the developmental nature of the understandings and individual’s engagement with the science concepts and ideas in news briefs.

4.2 Nature of science

In the context of science education, the nature of science has generally been referred to as the values and assumptions inherent in the development of scientific knowledge (Lederman & Zeidler, 1987). There are currently two main philosophical doctrines influencing science education. These are; firstly, the established and dominant ‘logical empiricism’ and secondly, the challenging perspective or ‘new’ philosophy. This new philosophy of science informs our understanding of the concept and contributes themes, which help to illuminate a contemporary and valid view of the nature of science. To understand the emergence of this new philosophy it is helpful to consider the history of these philosophies in science. An overview relevant to science education and this discussion begins with classical empiricism. This is followed by positivism, logical positivism and in turn, logical empiricism (Abimbola, 1983).
Classical Empiricism

One of the earliest attempts to define science can be attributed to Francis Bacon in the late 1500’s. His ideas significantly represent the major themes of classical empiricism. His work emphasised the idea of empirical observation and the use of experimentation to test ideas. An investigator could observe, collect and record data objectively: that is, with no preconceived ideas or underlying hypotheses. Using a process of induction, generalisations and relationships in the natural world could be made from these data. This process of induction involved finding two sets of agreeing phenomena, as well as looking for negative instances (Charlesworth, 1982). This was the method that Bacon believed separated science from other methods of inquiry. There are, however, inherent problems and difficulties in such a view of science. Bacon proposed that observations could be made objectively. He did not recognise that observations were made in light of preconceived ideas or theory or that observation of the world was largely theory dependent. The inferring of the general laws through the process of induction was limited to the particular example. Such limitations were not recognised by Bacon.

Another difficulty with Baconian induction was its lack of application to the formation of abstract theories. An example of one such theory is the atomic structure of matter. Bacon also neglected the social and cultural context of scientific knowledge. He did not recognise science as a social construct of the time, as he presented one scientific method which he believed remained constant and unchanging regardless of the context.

David Hume was another philosopher usually associated with classical empiricism. Hume viewed scientific knowledge as being based in facts of sensory experience, which he called ‘impressions and ideas’. These facts could be explained by general laws and theoretical systems. As science progressed the natural world would be explained by
fewer more general laws (Cleminson, 1990). Acceptance was again shown here of the
objectivity of impressions and ideas perceived in a social and cultural vacuum.

**Positivism and Logical Positivism**

Mathematical logic combined with the principles of empiricism form the foundations of
logical positivism. The norms of positivism are detachment, honesty and impartiality
(Cleminson, 1990). Only the scientific knowledge based directly on experience is
considered valid. Operationally defining the concepts for investigation allowed
experimentation and observations to determine correct and acceptable theories. A
difficulty with this philosophy becomes apparent when a limited set of observations are
used to verify conclusively scientific laws (Abimbola, 1983). This doctrine does not
acknowledge the human aspect of the scientific process. The creativity of the individual
is ignored, as is the social and contextual framework of the inquiry.

**Logical Empiricism**

Abimbola (1983) describes logical empiricism as a contemporary version of logical
positivism. This doctrine incorporates many different philosophical points of view, all
sharing common ideas. Like earlier philosophies of science, it was strongly based in
empirical methods of investigation, which view mathematics as the valid means of
analyses. There was a common interest in theory, explanation and the hypothetico-
deductivism method. Hypothetico-deductivism as a form of reasoning proposes that
science starts not from fact but from hypotheses. A hypothesis could not be shown to be
true by observation or experiment, but it could be shown to be false by contrary results
(Koulaidis & Ogborn, 1995). Thus science progressed gradually by eliminating
mistaken ideas. The belief in objective observation for the confirmation of scientific
knowledge continued.
A Transitional Philosophy

The work of Sir Karl Popper focussed attention on aspects of scientific practice that could not be accommodated by earlier empiricist/positivist assumptions. Abstract theories in science, particularly in physics, were clearly not induced from simple sensory observations. As an example, scientists were active and creative in the construction of the model representing the wave structure of light. Popperism opened science to the realm of creativity and imagination. Popper also proposed that scientific laws or theory could not be conclusively proven by a limited set of observations, but it may be conclusively disproved or falsified by a particular observation (Charlesworth, 1982). Thus scientific theories should be built around the doctrine of falsifiability. By falsifying scientific conjectures advancement towards truth can be made. Scientists are, however, never in a position to say finally and conclusively that knowledge is ‘fact’ or ‘truth.’ Scientific knowledge is always presented as tentative.

The ‘New’ Philosophy of Science

Various philosophers describe the new philosophy of science as a cumulative doctrine of different philosophical viewpoints. Common threads emerging from the work of philosophers such as Feyerabend, Kuhn and Polanyi contributed to the contemporary or ‘new’ philosophy of science.

Firstly, Polanyi (1958) himself a distinguished chemist, argued that personal participation was an integral and indispensable part of every scientific endeavour, and as such it was not a valid practice to split fact from values or science from humanity. He aimed through his philosophy of science writing to integrate science back into culture and to recognise the contribution of individuals’ values, beliefs and prior experiences to
their observations and interpretations of evidence. He questioned the role and reality of
objectivity in science. This was evident in his quote:

For once men have been made to realise the crippling mutilations imposed by an
objectivist framework- once the veil of ambiguities covering up these mutilations
has been definitively dissolved- many fresh minds will turn to the task of
reinterpreting the world as it is, and as it then once more will be seen to be. (p.
381)

Feyerabend (1973) also contributed themes about the subjective manner in which
interpretations were made and took a pluralistic approach to theories, suggesting they
should compete freely with one another. Furthermore, he argued that there was not just
one unproblematic method of science. This view was evident in his writing titled Theses
on Anarchism contained in the edited book, For and Against Method. For example:

Neither Lakatos nor anyone else has shown that science is better than witchcraft
and that science proceeds in a rational way. Taste, not argument, guides our
choice of science; taste, not argument, makes us carry out certain moves within
science (p. 117).

In addition, Thomas Kuhn’s (1962) work contributed themes about the culture and
context of science. He viewed science as functioning within the dominant paradigm of
the time. This paradigm or model defined what was considered ‘science’ at any given
time. It influenced the type and style of research and what was considered scientific
knowledge. Scientists ordinarily work within the framework provided by the dominant
paradigm in times referred to as ‘normal science’. A paradigm change occurs when the
scientific community is compelled to recognise phenomena which do not fit with the
established framework. Scientists were required to take a different view of the world and their task. This is what Kuhn referred to as periods of ‘scientific revolution’.

Themes, contributed by philosophers of science such as Popper, Polanyi, Feyerabend and Kuhn to the ‘new’ philosophy of science, placed the continuing nature of scientific research at the core of the scientific enterprise. They suggested that scientific results and knowledge were to be considered critically and not accepted as the unquestionable foundation of science. Contemporary philosophers rejected empirical methods as the sole tool of scientific analyses and recognised the role of creativity. Science was viewed as essentially a human activity and hence observations and the scientific process were not objective or neutral but theory based and value laden. Science was presented as a dynamic process based on continuous research coupled with both imaginative and critical thought and as such it does not provide simple solutions.

The ‘new’ philosophy of science emphasised that science is essentially a human activity and rejects the proposition that neutral and objective observations are possible. It recognises instead that observations and indeed the scientific process are theory based and value laden. Science does not provide simple solutions. It is a dynamic process based on continuous research coupled with both imagination and critical thought. The following basic tenets of the nature of science were proposed by Murcia and Schibeci (1999) in their study of primary student teachers’ conceptions of the nature of science and capture the major ideas emerging in the ‘new’ science philosophy. The development of these tenets was informed by the work of Abimbola, (1983); Cleminson, (1990); Lederman, (1992); Ryan & Aikenhead, (1992); and the AAAS’ Project 1061 Benchmarks (1993) as cited by Alters (1997):
1. Scientific knowledge has a temporary status and should not be accepted as unquestionable truth;

2. Scientists study a world in which they are a part and as such their work is not objective or value free;

3. New scientific knowledge is produced as a result of creativity and imagination coupled with scientific method;

4. Science progresses through continuing research and critical questioning;

5. Science is dynamic and ongoing, not a static accumulation of information;

6. Observations of the world are made through coloured lenses built up by prior knowledge, beliefs and theories; and

7. Scientists and the scientific community generally display the professional standards of openness of mind and honesty. They are moral and ethical in their approach to their profession (p. 1124).

It is proposed in this current research that conceptions of the nature of science can be located on a continuum between a traditional empirically located position and a contemporary socially located position. The empirical location would be a more traditional or positivist view of the nature of science. Assumptions empirically located would include that science was objective, value free, unproblematic and essentially a naturally constructed body of knowledge resulting from the discovery of principles existing in the natural world. The socially located position would be characterised by conceptions contributed by the ‘new’ philosophy of science. This more contemporary position would include assumptions such as science is value laden, socially constructed, dynamic, and a changing body of knowledge. Scientifically literate citizens would need to hold socially located conceptions of the nature of science for functioning in an informed way within contemporary societies.
The continuum of views about the nature of science is represented in Figure 4.1.

**Figure 4.1: Nature of science continuum**

### 4.3 Science and society

This dimension of scientific literacy refers to the application of science in daily life, the way it is implemented and its effect on social and natural environments (Kolsto, 2001). Science is a resource for learning about the world and requires citizens to have the knowledge, skills and disposition to make decisions and solve problems at the interface of science and society (Bingle & Gaskell, 1994). Embedded in this process was critical reflection and meaningful engagement with science as it applies to social issues and public debate. Examples of current topical sustainable development issues are nuclear energy, pesticides and fertiliser use, managing water resources, logging forests, soil salinity, cloning, genetically modified foods and embryonic stem cell research. Being scientifically literate included having an awareness of science in creating and solving social problems and the development of a sense of responsibility to influence and resolve dilemmas and problems at the interface of science and society. Central to this was a critical examination of the relevant science involved (Ratcliffe, 2001; Bingle & Gaskell, 1994; Chen & Novik, 1984). At the individual level this involved using critical reflection on science as a resource for making informed personal decisions on issues of
health and lifestyle, examples of which include childhood immunisation, antibiotics, hormone replacement therapy, exercise and healthy eating.

Science is not meaningful unless understood in relation to the whole (Chen & Novik, 1984). Engaging with science at the interface of society requires an integrated or multidisciplinary awareness of science as one part of the whole complexity of human social contexts that includes political, economic, moral, ethical and religious aspects. The intersection of the three knowledge dimensions is illustrated in Figure 4.2. For individuals to be scientifically literate they must have knowledge of the interaction of science with society, the nature of science and key scientific ideas and concepts. The way they act and think in order to make sense of the world in which they live would require a blending of these knowledge dimensions.

Figure 4.2: Interacting dimensions of scientific literacy
This figure illustrates the overlap of knowledge about the interaction of science with society, the nature of science and enduring and important scientific terms and concepts, which results in scientific literacy. A blended understanding of the three knowledge dimensions would empower scientifically literate citizens to think and act in an informed way within science contexts. They would have the confidence to use science as a tool for inquiry, learning and problem solving. Being scientifically literate would enable them to critically reflect on the use or role of science in a range of contexts. An understanding of the discipline’s aims and limitations would enable citizens to determine what was and was not science and when used in a misleading or inappropriate manner. These aspects of scientific literacy are captured in this research’s framework for scientific literacy, which is elaborated as Figure 4.3.

<table>
<thead>
<tr>
<th>Scientific literacy can be thought of as a blend of these three knowledge dimensions:</th>
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</thead>
<tbody>
<tr>
<td>• Nature of science;</td>
</tr>
<tr>
<td>• Interaction of science and society and;</td>
</tr>
<tr>
<td>• Enduring and important scientific terms and concepts.</td>
</tr>
</tbody>
</table>

Scientific literacy is clearly about KNOWING but it is also about a way of THINKING and ACTING.

Being scientifically literate requires the confidence, interest and or disposition to use or put into action a blend of these knowledge dimensions for engaging with science in context. As such, it requires the ability to:

| • Use science as a tool for inquiry or discovery; |
| • Use science for learning, informing or contributing to problem solving; and, |
| • Critically reflect on the use or role of science in context. |

Figure 4.3: A contemporary framework for scientific literacy
This framework does not suggest the specific science concepts needed by all citizens for scientific literacy or the range of situations in which science could be used at the interface with society. The framework is a description of scientific literacy that brings together a range of perspectives and could assist in building consensus amongst the stakeholders in science education. Its aim is to clarify the dimensions of scientific literacy and the behaviours required to act scientifically in a contemporary context and hence increase the usability of scientific literacy as an educational concept.

4.4 Indicators of scientific literacy

Indicators consistent with this framework of scientific literacy were developed to illustrate levels of developing scientific literacy. Bybee’s (1999) perspective of the development of scientific literacy was used to inform the development of indicators. Bybee’s levels were based on a threshold model that assumes degrees of scientific literacy are continuously distributed within the population. He proposed that general thresholds could be identified to indicate an individual’s overall scientific literacy and more specifically their level of development in a particular field or discipline. His levels of scientific literacy represented a continuum along which an individual can develop for a lifetime. However, it was assumed an individual’s level of scientific literacy may change depending on the context, issue or topic rather than simply being scientifically literate or illiterate. As such, scientific literacy or illiteracy could not be demonstrated or evaluated in a single context.

Some individuals will in their lifetime develop further than others on this continuum. Development can also occur across the continuum. This means some individuals will develop greater breadth at a particular level of scientific literacy but not increase to higher order thinking. The scientific literacy demonstrated by an individual at any given
time could be contributed to by various factors such as age, developmental stage, formal and informal education and general life experiences.

The three dimensions of scientific literacy, science knowledge, nature of science and science and society are identifiable within Bybee’s levels and contribute to defining the thresholds. The lower level thresholds are based on isolated science knowledge. Development up the thresholds requires a conceptual and procedural understanding of science. This involves some understanding of scientific method. The highest level of scientific literacy requires an understanding of the interaction between science and society. Scientific literacy at this level also includes the history, aims and general limitations of science. Bybee (1997) proposed the following four dimensions of scientific literacy at each level.

1) Nominal Scientific Literacy.

An individual would understand a term, question or topic as scientific but demonstrate misunderstandings in the area. At this level the individual may offer naïve explanations of phenomena.

- Identifies terms, questions as scientific.
- Demonstrates misconceptions.
- Has naïve explanations.
- Shows minimal understanding.

2) Functional Scientific Literacy.

At the level of functional literacy the individual can use scientific vocabulary but generally out of context and without the conceptual richness of the discipline.
- Uses scientific vocabulary
- Defines terms correctly
- Memorizes special responses
- Understands only a specific need or activity

3) Conceptual and Procedural Scientific Literacy

At this level the individual would demonstrate a developing understanding of the way conceptual parts of the discipline relate to the whole. They would have a working understanding of the processes of scientific inquiry in the context of laboratory investigations or scientific experiments.

- Understands conceptual schemes of science.
- Understands procedural knowledge and skills of science.
- Understands relationships among parts and whole of science.
- Understands organizing principles, disciplines and processes of science.

4) Multidimensional Scientific and Literacy

Scientific literacy at this level incorporates philosophical, historical, and social dimensions of the discipline. An individual at this level would demonstrate some understanding and appreciation for science as a whole and view the discipline as both a product and part of culture.

- Understands the place of science among other disciplines
- Knows the history of science.
- Knows the nature of science.
- Understands the interactions between science and society (p. 144).
The hierarchical development of understandings in the three knowledge dimensions contributing to the development of scientific literacy is illustrated in Figure 4.4.

Figure 4.4: A perspective on the development of scientific literacy

For this research the development of indicators was limited to the highest three levels of scientific literacy proposed by Bybee, as it was most likely due to the age and level of previous education that the first year university students in LATU would be generally at either the functional, conceptual and procedural or multidimensional level. In addition, the focus of this investigation is scientific literacy and does not attempt to include applications of science in the form of technology. As such the indicators of scientific literacy at the three levels do not include references to technology.
The basic tenets of the nature of science identified by Murcia and Schibeci (1997) informed the development of indicators. Scientific method is noted in these basic tenets of the nature of science but left undeveloped. The OECD (2000) assessment program PISA provided a clear development of the ideas and abilities associated with the scientific method. Here the concept was further developed to include scientific processes, ways of thinking and problem solving. The OECD describes in PISA the processes of science as:

1. Recognising scientifically investigable questions;
2. Identifying evidence needed in a scientific investigation;
3. Drawing or evaluating conclusions;
4. Communicating valid conclusions; and
5. Demonstrating understanding of scientific concepts.

These processes were integrated into the indicators adding to those in the dimension of the nature of science.

In addition, media reports of scientific research were considered to be an important source of lifelong science learning and as such evaluation of science news reports can influence the engagement, decisions and actions of all citizens in their life at home, work and in their broader civic context. Hence engaging with and critically evaluating the information and conclusions presented in such reports is an important aspect of scientific literacy. This view is evident in a range of studies that consider scientific literacy in the context of science news briefs (Korpan et al., 1997; Norris & Phillips, 1994, 1999; Wellington, 1991).
Scientific literacy should include the ability to look constructively yet critically at the science reported in newspapers. This should not only include ‘quality’ articles but also those from sources that would be read by most citizens. Constructive engagement with such articles requires individuals to understand the terms used, take a critical stance and make links from the report to the broader science discipline and social context. Korpan et al. (1997) suggest that skilled evaluation requires among other things knowledge about the research process and how this affects the quality of the investigation. Critical engagement with the report is required in the areas of scientific method, linking evidence to theory and the social context of the research. This would involve asking and answering questions on issues such as controls, sample size, kinds of data collected, possible causes and theories, sources of research funding, qualification and experience of researchers, motivation for the research and who will benefit from the findings. The ability to analyse and interpret science news briefs in this manner is another aspect of scientific literacy and as such indicators of this ability were developed and included at each level of the framework.

An assumption evident in the list of indicators included in Table 4.1 was that scientific literacy at the lower Functional level is focussed on scientific ideas and concepts and development up the scale of scientific literacy required a building of knowledge about the nature of science and ultimately at the highest level the interaction of science with society.

<table>
<thead>
<tr>
<th>Level</th>
<th>Indicators of scientific literacy</th>
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</thead>
<tbody>
<tr>
<td>Functional</td>
<td>• Can use scientific vocabulary in a particular activity or for a specific need, i.e., defining a term on a test.</td>
</tr>
<tr>
<td></td>
<td>• Can read a newspaper article and define a scientific term used.</td>
</tr>
</tbody>
</table>
| Conceptual and Procedural | Uses scientific vocabulary but without a broader conceptual understanding in relation to the discipline.  
| | Able to memorize and restate lists of vocabulary.  
| | Can successfully memorize and restate textbook vocabulary and ideas but without demonstrating a broader or in-depth conceptual understanding.  
| Conceptual and Procedural | Demonstrates an understanding of the way conceptual parts of the discipline relate to the whole discipline.  
| | Demonstrates an understanding of scientific concepts.  
| | Reads science news briefs and relates the content to the broader discipline and or the processes of science.  
| | Can use vocabulary in context or in laboratory work; e.g., can make observations, inferences, and hypothesize, etc.  
| | Demonstrates a functional understanding of scientific method; e.g., able to design, conduct, and report on a controlled scientific experiment or investigation.  
| | Recognises scientifically investigatable questions.  
| | Can identify evidence needed in a scientific investigation.  
| | Drawing or evaluating conclusions from first-hand data or reported science investigations.  
| | Communicating valid conclusions from first or second-hand data.  
| Multidimensional | Have some knowledge of the history of scientific ideas.  
| | Display an understanding of the aims and limitations of scientific processes.  
| | Understand the nature of scientific theories and the role of continuous testing and retesting that occasionally results in the discarding of new and old theories.  
| | Understand that scientific knowledge has a temporary status and should not be accepted as unquestionable truth.  
| | View scientists as studying a world in which they are a part
and as such their work is not objective or value free.

- Understands new scientific knowledge is produced as a result of creativity and imagination coupled with scientific method.
- Views science as progressing through continuing research and critical questioning
- Views science as dynamic and ongoing, not a static accumulation of information
- Displays an awareness of the concept of observations of the world being made from a personal perspective built up by prior knowledge, beliefs and theories.
- Shows confidence in scientists’ and the scientific community’s professional standards of openness of mind and honesty and their moral and ethical approach to their profession.
- Shows an awareness of the role science takes in their personal life and society generally.
- Incorporates the philosophical, historical and social dimensions of the discipline into the analysis, interpretation and evaluation of scientific knowledge.
- Shows an understanding of the cultural context of science.
- Makes connections within the discipline and with larger social problems and endeavours.
- Critically evaluates science news reports based on an understanding of the general aims, limitations and social context of the scientific enterprise.
- Demonstrate the competence and confidence to make informed decisions relating to scientific ideas.

Table 4.1: Indicators of scientific literacy
Assumptions about the multidimensional structure of scientific literacy and the hierarchal order of development in each dimension framed the research methodology. It was anticipated, however, that the assumptions underlying the framework, indicators and nature of students’ development of scientific literacy would be critiqued and reviewed as used in the research process. The next chapter describes the qualitative and quantitative methodologies used in this research.
CHAPTER FIVE

AN APPROACH TO INTERROGATING FIRST YEAR UNIVERSITY STUDENTS’ DEVELOPMENT OF SCIENTIFIC LITERACY

The interrogation of scientific literacy amongst first year university students at Murdoch University was contributed to by both quantitative and qualitative methodologies. It was anticipated that these two methodologies would provide converging evidence of students’ developing scientific literacy.

5.1 The participants

The quantitative dimension of the research dealt with data obtained from questionnaires administered to students both pre and post their participation in a first year foundation unit at Murdoch University; *Life and the Universe (LATU)*. Of the 230 participants completing the pre- LATU questionnaire only 166 could be identified within the post -LATU group who completed the second questionnaire. The second stage of the research was a qualitative two year longitudinal focus group study of a sample of participants. There were initially 18 students invited to participate in the qualitative study but 4 participants withdrew at different times. Table 5.1 provides an overview of the research activities and the number of participants involved.

<table>
<thead>
<tr>
<th>Year</th>
<th>Research activity</th>
<th>Number of participants</th>
</tr>
</thead>
</table>
| 1 (2001) | Pre-LATU questionnaire  
Post-LATU questionnaire                                                            | 230  
166 |
| 2 (2002) | Focus group: Pre-LATU questionnaire & focus group workshop discussion, written activities and LATU work samples. | 14 |
| 3 (2003) | Focus group, follow up: Post-LATU Questionnaire & follow up interview and written activities. | 14 |

Table 5.1: Overview of research activity
In addition, information from the Year 1 questionnaires completed by unmatched students post–LATU and the Year 2 questionnaires completed by students not invited to participate in the focus group, were collated and used to analyse the workings of the Likert scale on the questionnaire itself. This analysis involved a total of 503 questionnaires.

5.2 The context

The students participating in this research were enrolled internally in the Murdoch University foundation unit Life and the Universe (LATU). LATU is intended as a non-specialist science unit, introducing all students to the issues faced by science in a continually evolving technological world community (Lyons & Macey, 2001). The unit seeks to develop basic skills of scientific inquiry such as (a) recognition and description of a phenomenon (b) association of the observed phenomena with other observed factors (c) study of the process or processes causing the phenomena (d) development of an understanding of the mechanism behind the phenomena and (e) construction of a simple model to enable prediction of the phenomena (Lyons & Macey, 2001, p. 2). LATU contributes to the development of these outcomes through a series of lectures, tutorial discussion groups and assignments.

The nature of science and the interaction of science with society, although not explicitly ‘taught,’ are reflected in the unit materials, lecture themes and the associated workshop activities. The aims of the unit made it appropriate and meaningful to engage both the unit tutors and the students with this research.
5.3 Designing the questionnaire

The questionnaire was designed to assess scientific literacy through participants’ engagement with a newspaper brief and items on a Likert scale. The questionnaire had three sections. The first section included three open questions that investigated students’ engagement with science in a news brief. The second included a ten-item Likert scale measuring their understanding of the nature of science and the third section contained questions that provided background information about the participants. Two versions of the questionnaire were developed with the important difference being the news brief included. Questionnaire one was used pre-LATU and questionnaire two was used post-LATU with the same students. Both versions of the questionnaire are included as Appendix One. The structure of questionnaire one and questionnaire two is summarised in Table 5.2

<table>
<thead>
<tr>
<th>Page</th>
<th>Questionnaire One</th>
<th>Questionnaire Two</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Before opening the booklet please answer the following questions Q1. Do you believe drinking a glass of wine daily with a meal can reduce the risk of developing colon cancer? Why do you say that? Q2. Where do you get your information on current science issues? (Don’t include formal learning eg. University courses)</td>
<td>Before opening the booklet please answer the following questions Q1. Do you believe drinking orange juice daily can reduce the risk of heart disease? Why do you say that? Q2. As part of the unit Life and the Universe you produced a research project. What did that experience teach you about the way scientists develop and conduct research?</td>
</tr>
</tbody>
</table>

Scientific Literacy for Sustainability
<table>
<thead>
<tr>
<th>2</th>
<th>NEWS BRIEF READ: <em>Healthy Tipple</em>  Q3. After reading this news brief which states the researchers’ conclusion as, <em>the fruit of the vine may also reduce the risk of developing colon cancer</em>, are you now more certain, less certain or equally certain of your background belief as described in question 1. Explain your answer.  Q4. Suppose this conclusion is very important to you and that you must determine whether it is a reliable one. What additional pieces of information, if any, would you like to have about the researchers’ report to decide whether the researchers’ conclusion is true? Please list each point separately.</th>
<th>NEWS BRIEF READ: <em>Oranges Keep The Heart Doctor Away</em>  Q3. After reading this news brief which states the researchers’ conclusion as, <em>drinking three glasses of orange juice daily may reduce the risk of heart disease</em>, are you now more certain, less certain or equally certain of your background belief as described in question 1? Explain your answer.  Q4. Suppose this conclusion is very important to you and that you must determine whether it is a reliable one. What additional pieces of information if any, would you like to have about the researchers’ report to decide whether the researchers’ conclusion is true? Please list each point separately.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Nature of Science: Likert scale Questions 5 to 14</td>
<td>Nature of Science: Likert scale Questions 5 to 14</td>
</tr>
<tr>
<td>4</td>
<td>Background information Questions 15 to 18</td>
<td>Background information Questions 15 to 18</td>
</tr>
</tbody>
</table>

Table 5.2: Structure of Questionnaire one and Questionnaire two.

The news brief used in Questionnaire two was changed from Questionnaire one to reduce the possibility of participants simply repeating a response based on their memory.
of Questionnaire one. This approach was consistent with the methodology of Schibeci and Murcia (2000) who also changed the newspaper article used as a prompt for students’ responses to questions in their pre- and post-questionnaires.

To ensure comparability of the news briefs, the Questionnaire two brief was written to match the one used in Questionnaire one. This news brief was based on research published online. Writing the second brief ensured the structure and nature of the content of both news briefs were comparable. The online research report was modified to ensure it contained the same type of information and had the same structure as the news brief used in Questionnaire one. This is the same procedure used by Korpan et al. (1997) in their study: Assessing literacy in science: evaluation of scientific news briefs. In Korpan et al.’s study, however, the reports were all fictitious. The four reports were written to ensure they had the same structure which included researchers reporting a finding, description of a general concern or issue and an independent group promoting the importance of the finding and their arrival at a conclusion.

Korpan et al.’s study identified three influential text characteristics influencing participants’ engagement with the news brief:

1. Plausibility of conclusion;
2. Degree phenomena described in the news brief related to the science curricula; and
3. Personal familiarity with the described phenomena.

In response to the issue of plausibility, the context of the second article was kept in the health field, exploring the relationship between an aspect of diet and health. In addition, all key pieces of information were identified in the first article and included in the second. Furthermore similar ‘illocutionary’ points were included in the second report.
These are described by Norris and Phillips (1999) as words that help students to interpret pragmatic meaning: for example ‘possibly’, ‘might’, ‘tend’, ‘in the following’, ‘the first point’, ‘concluded that’, ‘it is assumed that.’ The comparable nature of the briefs allowed a comparison to be made pre- to post–LATU of the criticalness of participants’ engagement with science news briefs.

Another difference between questionnaires was that on Questionnaire one participants were first asked to list their information sources for ongoing informal science learning. This question was included to test the assumption that science news briefs are an important source of information for lifelong learning.

Background Information Questions

Both questionnaires contained the same set of background questions which aimed to gather information on participants’ gender and background: school leaver or mature age, post compulsory science subjects studied and course in which enrolled.

Science News Briefs: Open questions

Three open questions were asked to assess the participants’ engagement with the science news briefs titled, Healthy Tipple in questionnaire one and Oranges keep the heart doctor away in questionnaire two. The participants were asked to provide their response to the first of these questions before turning the page to read the news brief. This question asked them to consider the statement given. In questionnaire one this was: Do you believe drinking a glass of wine daily with a meal can reduce the risk of developing colon cancer? Why do you say that? In questionnaire two this was replaced with: Do you believe drinking orange juice daily can reduce the risk of heart disease? Why do you say that? Participants were required to state if they agreed or not with the statement
given and why? This question aimed to collect information about their background thinking and ideas on the research conclusion before they read the news brief in the questionnaire.

The inclusion of this question was motivated by a Canadian study (Norris & Phillips, 1999) which investigated 91 year 12 science students’ interpretation of popular reports of science. This study was based on the assumption that interpreting a piece of scientific writing depended upon all that one believes, which in part is what one believes and understands about the content of science, about the nature and source of scientific knowledge and the relationship between scientists and nonscientists. Prior to each news brief on their instrument, students were asked a question designed to gain information about their background knowledge of, and beliefs about, the topic. In light of this, identifying a participant’s background ideas and beliefs was viewed in this current research as an integral part of understanding their engagement with a news brief.

Once the question asking for background thinking was completed, participants were invited to turn the page, read the news brief and answer question 3. This question asked: *Are you now more certain, less certain or equally certain of your background belief as described in question 1? Explain your answer.* This question aimed to explore how participants positioned themselves with respect to the text. It was included in the questionnaire as this research hypothesised that thoughtful critical engagement with science news briefs was an indicator of scientific literacy.

Norris and Phillips (1999) also focussed on students’ ability to critically engage with a science news report. This focus was evident in their statement about interpreting science texts: *Science text does not wear its meaning on the surface: like any other type of text it
must be interpreted by the reader through active, critical engagement (p. 318). Their asking of an open question to explore the nature of students’ engagement with science news reports prompted the inclusion of question 3 in the current research. Using the same question structure as that in Norris and Phillips (1999) enabled the use of their tested and reported categories for classifying the level of criticalness of the participants’ stance with respect to the news brief and then provided opportunities for comparing findings.

The final question requiring participants to engage with the news brief was question 4 which asked: Suppose this conclusion is very important to you and that you must determine whether it is a reliable one. What additional pieces of information if any, would you like to have about the researchers’ report to decide whether the researchers’ conclusion is true? This question was contributed to by Korpan et al.’s (1997) study, which used students’ evaluation of scientific news briefs for assessing literacy in science. They asserted that evaluating conclusions found in media reports of scientific research was an important form of scientific literacy. They examined the types of requests for information made by university students as they evaluated scientific news briefs. It was anticipated that the type of requests for extra information made by the participants in the current study could be compared to this earlier study.

Nature of Science Likert scale

In addition to the news brief open questions, a ten item Likert scale measuring understanding of the nature of science was included in the broader questionnaire. This scale had a cumulative response pattern and used four response categories. An advantage of using a Likert scale was that the items did not have to be judged and scaled prior to its use. The range of possible responses could also make the participant more
comfortable in indicating their position rather than simply agreeing or disagreeing. In addition the graded response pattern may provide more information about the participants’ conception of the variable, giving more precise and reliable information (Judd, Smith & Kidder, 1991).

The ten items included in the scale were derived from those used by Murcia and Schibeci (1999) in the study, *Primary student teachers’ conceptions of the nature of science*. In that study 15 true/false items were selected from the Test of Basic Scientific Literacy constructed by Laugksch and Spargo (1996a, 1996b). This instrument was described as a test of basic scientific literacy based on recommendations from the U.S. report, *Project 2061- Science for all Americans* (AAAS, 1990). A detailed development of this instrument is given in Laugksch and Spargo (1996b). As a result of reflecting on the analysis of the data collected by Murcia and Schibeci (1999) the items were reduced and modified to more closely reflect the ‘new’ or current philosophy of science and therefore a contemporary conception of the *nature of science*.

This Likert scale was cumulative in nature and as such was based on the assumption that people with a particular position on the *nature of science* will tend to agree with items on one side of their own position and will tend to disagree with items that fall on the other side. Participants’ understanding of the nature of science could then be located on a continuum between a traditional empirically located position and the contemporary socially located position that informed this research. The items used response categories that ranged from ‘strongly disagree’ through to ‘strongly agree’. The responses could be added with score reversal for negatively worded items, across the items to give the location of the person in relation to the construct (Andrich, 1996).
In addition, it should be noted the actual items included in the questionnaire did not reflect a middle ground or uncertainty in relation to the nature of science. Similarly an ‘undecided’ option was not included in the response format used in the questionnaire so the participants could not avoid engaging with any item. To further support not including an undecided category Andrich (1996) suggests it is different having an ambivalent position from being ambivalent to a relatively extreme position.

5.4 Administering the questionnaire

*Pre-LATU:* Questionnaire one was administered to first year students enrolled in *Life and the Universe* (*LATU*) in semester one 2001, which was year 1 of the research. All students enrolled internally in LATU were encouraged in the lecture and by their tutors to complete the questionnaire. However, it was made clear it was not compulsory and had nothing to do with assessment in the unit. Questionnaire one was administered in the second tutorial session in week two of the semester. Participants were given approximately 20 minutes to complete all aspects of the questionnaire. There were at this time 339 internal students officially enrolled in LATU. Two hundred and thirty students (68%) responded to the questionnaire.

*Post-LATU:* Questionnaire two was administered to all internal students who were present at the week 12 *LATU* tutorials. The questionnaire was administered by the tutors and students were again reassured that the questionnaire was not a part of the unit assessment and it was not compulsory. Of the 231 questionnaires completed post-LATU, 166 could be matched by the student ID number to questionnaire one completed by the participants pre-LATU.
5.5 Analysing the questionnaire

Analyses of the questionnaire were in two main parts: science news brief open questions and the Nature of Science Likert scale. Firstly, the participants’ responses to the open questions were categorized and then analyzed statistically with SPSS software. However, question 2 in the open section of questionnaire one was more simplistic in nature and could be effectively analyzed by determining response frequencies. This question asked, *where do you get your information on current science issues?* All the different types of information sources were listed and a tally was used to find the frequency of each. Secondly, the analysis of the Likert scale was based on the Rasch model and utilized RUMM2020 (Andrich & Luo, 2005) software. A detailed description of the two main parts of the analysis follows.

Science news brief open questions

Participants’ responses to question 1 were not analyzed in isolation but later used to assist in categorizing their engagement with the news brief in question 3. Question 1 was used for collecting information on the participants’ reactions to the research conclusion before reading the news brief on this topic. Responses to question 1 were read and interpreted in conjunction with question 3.

Participants’ question 3 responses were compared to their background reaction captured in question 1, in order to determine if they had engaged critically with the news brief. The nature of their engagement with the brief was classified according to the six point scale developed by Norris and Phillips (1999). This scale represents the level of criticalness of the participants’ stance with respect to the report.

1. *Deference:* Deferring absolutely to the report and stating certainty of beliefs based solely on more or less direct citation of the text.
2. **Echoing**: Agreeing absolutely with the report on the basis that their own beliefs are confirmed by the report.

3. **Affirmation**: Stating certainty of beliefs on the basis of paraphrased information from the report.

4. **Dominating**: Imposing background belief onto the text resulting in an implausible interpretation. Ignoring the report all together.

5. **Evaluating**: Stating certainty of belief by giving reasons why the text should be believed.

6. **Challenging**: Rejecting the report on the basis of reasons why it should be disbelieved, or explaining how the report fails to address their own beliefs.

7. **Other**: Off task responses that were irrelevant to the researchers’ conclusion or the information in the news brief.

The first three positions, **deference**, **echoing** and **affirmation** represent uncritical, text-based engagement with the news brief. The difference between them is whether the report is quoted directly, paraphrased or simply cited. The fourth position, **dominating** is also uncritical engagement but this time based on background beliefs. Uncritical engagement through positions one to four does not indicate a multidimensional level of scientific literacy. Positions five, **evaluating** and six, **challenging**, demonstrate interactive, constructive and critical engagement with the text and as such indicate a multidimensional level of scientific literacy.

Each participant’s pre-LATU response to question 3 was read in conjunction with question 1 and reflected through the category descriptions provided by Norris and Phillips (1999). Categorising of the response to question 3 was done separately to collating the participants’ background information. This was to ensure the background
information provided by a participant did not influence in any way the researcher’s
classification of their response. This classification process was later repeated for the
post-LATU question 3. At this time the responses were repeatedly read and compared to
the category descriptions to ensure the researcher’s awareness of these being post-
LATU was not influencing the classification. Comparisons were also made between
responses assigned a category to cross check the reliability of the classification process.

The frequency of participants responses in each category were then determined both pre-
and post- LATU. The first four and the last two response categories were collapsed to
contrast more clearly the critical or uncritical nature of the groups’ responses. The
proposed hierarchy of the collapsed categories in relation to scientific literacy was then
used to score critical responses as 2, uncritical responses as 1 and those off task
responses, the ‘other’ category as 0. This procedure then allowed a statistical
comparison to be made between subgroups and from pre to post-LATU.

Next, in question 4 participants were asked to list the extra information they would like
to have about the researcher’s report in order to decide whether the conclusion was
reliable. The process of analytic induction was used to develop categories for classifying
the responses (Abell & Smith, 1994; Murcia & Schibeci 1999). This process required
that the responses to each question be read repeatedly in order to identify trends in the
type of information given. Categories were generated based on these trends. Returning
to the responses of the participants validated the categories. Examples representative of
each category were located and used to illustrate and strengthen their description. The
categories were then reflected through the projects indicators of scientific literacy to
determine the level each represented; functional (F), conceptual and procedural (CP) and
multidimensional (M). The responses in each category, for each question, were again considered to insure they were consistent with the assigned level.

The categories and associated levels for question 4 were:

1. Social context (M): Social factors that could influence judgments and confidence in the quality of the research. Including issues such as, who are the researchers, what is the reputation of the research team, are they moral and ethical professionals and in what type of publications can their work be found. The motivation of the researchers and the funding source are also relevant issues, e.g., More information about the researchers and who funded the research.

2. Ongoing or related research (M): Recognition of the ongoing and dynamic nature of scientific research. An appreciation of the tentative nature of findings, the need for re-testing and an awareness of other research conducted in the area, e.g., Conduct further studies to confirm results.

3. Research methods (CP): How was the research conducted? This includes design, control groups, controlling variables, possible variables impacting on findings, sampling methods and sample size, e.g., Comparisons of age, weight and gender.

4. Data and Statistics (CP): Consideration of the type of data collected or the statistical methods used for analysing it, e.g., How conclusive was the data, were there any anomalies?

5. Clarification of the article (F): Requests for clarification or development of terms or information included in the brief, e.g., Greater explanation of how wine helps.

6. Off-task (F): Topics that are irrelevant to engaging with the researchers’ conclusion or the information contained in the news brief, e.g., Are people being cured?
The participants’ responses to each question were classified according to the categories. It was anticipated that these categories would be used to derive generalizations from the data that would be validated by returning to the respondents’ comments to find confirming and discrepant cases. The categories Korpan et al. (1997) used for classifying participants’ requests for further information about the science reported in news briefs were similar to those that were generated out of this research’s data. It was anticipated this similarity would provide an interesting comparison between findings from their study of Canadian university students and the research reported in this thesis.

As with question 3, responses to pre-LATU question 4 were read in isolation to ensure the background information provided by participants did not affect the researcher’s assigning of a category. In addition, the post-LATU responses were again read repeatedly and reflected through the category description to ensure consistent classification practice pre- and post-LATU. Comparisons between responses assigned to each category were also made to ensure reliability in the process.

The frequency of participants’ responses in each category for question 4 were then determined both pre- and post-LATU. The response categories were then collapsed to show more clearly the level of scientific literacy indicated by each. The hierarchal nature of the collapsed categories in relation to scientific literacy was demonstrated by scoring multidimensional responses as 2, conceptual and procedural responses as 1 and functional responses as 0. This procedure again allowed a statistical comparison to be made between subgroups and from pre to post-LATU.
Nature of science Likert scale

The Rasch model for polytomous, ordered response categories was used for analysing the nature of science Likert scale (Andrich 1985, 1996). The model makes three assumptions. First, the construct being measured is unidimensional. Secondly, that the construct is hierarchal and thirdly each item functions independently to the other items (Kemp and Bradley, 2006). It is a probabilistic model in which a participant’s probability of answering a question correctly is determined by the difference between the participant’s latent trait and the difficulty or relative strength of the item. In the model, the latent trait is the participant’s true ability or attitude. It assumes a participant’s performance may change depending on the instrument used but their latent trait remains the same. Similarly, item difficulty based on Rasch modeling remains the same no matter what participants have answered. In general, Rasch analysis models participants’ ability or attitude and item difficulty as a log transformation of the chances of a person responding to a given item in a certain way. For example, as item difficulty exceeds a person’s ability or strength of opinion, the chance of reporting difficulty with a particular activity increases. As person ability or opinion increases relative to item difficulty, the chance of endorsing difficulty with an activity decreases (Doyle et al., 2005).

The model explains how a person’s performance with regard to a specific latent trait can predict that person’s response (e.g., agree or disagree) on a particular scale item involving that trait. The mathematical model describes the relationship between scale items and participants as

\[ \log[pni/(1 - pni)] = Bn - Di \] (1)

Where \( Bn \) is the ability of a person \( n \) and \( Di \) is the difficulty of item \( i \). As can been seen from this equation, the probability \( (p) \) of a person correctly answering an item is solely
related to the latent trait and the difficulty of the item being answered (Boon and Scantlebury 2006). The model produces a set of scores that define the position of each item and each person against the underlying variable or construct. The unit of measure is the logit, the logarithm of the odds of success. Specifically the parameters (logits) represent a person’s attitude and an item’s inherent intensity in relation to the construct (Andrich, 1996). The model contains one location parameter for each person and one for each item. These parameters are used to express the probability of each possible response when a person deals with an item.

Rasch analysis can be used to map (person-item map) the ability of each person and difficulty of each task onto a single scale (Andrich, 1989). It should not be automatically assumed that the spacing between rating scale categories is equal, and that the total raw score for a respondent is on a linear metric. Rasch modelling recognises that it is harder to achieve a particular score on some items than others, and that numerically equal differences in coding do not necessarily imply equal difference in difficulty between adjacent levels of response.

The software program, RUMM 2020 (Andrich, Sheridan and Luo 2002) was used to test how well the Nature of Science Likert scale data fit the expectations of the measurement model. The program ordered the participants’ conception of the nature of science (latent trait) and the difficulty or intensity of the Likert style items on the same scale. Importantly, the analysis also provided sophisticated psychometric information about the quality (validity and reliability) of the Likert scale. In terms of the validity of the scale the Rasch analysis showed that all items ‘fit’ the same underlying construct, in this case the nature of science. The program generated parameter estimates and then examined the difference between these expected values and the observed values using
tests of fit. The overall fit statistics included item-trait chi square and an estimate of reliability. It was important to establish that the Likert scale was a true measure of the nature of science construct and that it consistently measured the construct.

The fit of the nature of science items to the model showed that the items were contributing to the unidimensional nature of science construct. The order of difficulty of each scale item and the distribution of all participants in relation to the items was determined and mapped. The RUMM 2020 program was also used to determine the frequency of participants’ responses in each category for the 10 scale items. The order of the category thresholds for each item was also examined using the Category Characteristic Curves. These graphical displays show if the thresholds between the levels of response, in the case of this research ‘strongly disagree, disagree, agree and strongly agree’, were in a natural order. Finally, an ANOVA (one way analysis of variance) was also conducted for each of the subgroups within the total population to determine if there were any statistical variations between subgroups: for example, males compared to females. This showed that the items were not biased towards a group within the sample.

The Rasch model assumes the items will perform in the same manner when used on a similar sample. This means the participants selected for the focus group component of this research could be located within the 2001 participants based on their responses to the Nature of Science Likert scale. Further analysis was conducted to determine if there were any statistically significant difference between the 2001 participants as a whole pre- to post-LATU and also if there was any variation pre-post LATU amongst subgroups: for example gender, females pre-LATU and females post-LATU. Any
variations pre to post-LATU were then analysed in relation to each item on the nature of science scale: for example item 8 pre-LATU compared with item 8 post-LATU.

5.6 Selecting the focus group participants

In order to gain greater depth of understanding of the trends identified in the large scale administration of the questionnaire, a two year longitudinal study of 14 focus group participants was conducted. These focus group participants were originally enrolled in LATU semester one 2002. Questionnaire one was used to select potential focus group participants. However, the questionnaire was only administered to students in three selected tutorial groups as these groups were led by tutors who had committed to assisting in the research process by collecting samples of students’ work.

The questionnaires from these tutorial groups were analyzed and potential focus group participants were identified. The Rasch analysis of the Nature of Science Likert scale in the questionnaire allowed the location of these students to be determined within the 2001 research participants. This meant the focus group could be viewed as a subset of the 2001 participants and represent the range of scores (logits) on the questionnaire and also the diversity of this group of first year students in terms of gender, time out of school, course of enrolment and science background.

Initially 18 students were selected who represented the diversity of the LATU population. The following students withdrew at various times from the research:

- A mature age female began the research process but was unavailable for the first workshop and then chose not to continue.
• Two school leaver males arrived for the workshop but were called away before it began and later chose not to continue.

• A school leaver male made three appointments for the final follow up interview but never arrived. He never formally withdrew.

It was anticipated that focusing on the resulting group of 14 participants would enrich the view of the development of scientific literacy amongst first Year University students enrolled in LATU. This interrogation would also contribute to a detailed reflection and evaluation of the framework and indicators of scientific literacy framing this research. The following time line represents the activity over semester one 2002, which resulted in the collection of data from the focus students.

**Collecting focus group participants’ LATU work samples**

The following timeline displayed in Table 5.3 for collecting work samples was negotiated with the LATU tutors supporting this phase of the research process.

<table>
<thead>
<tr>
<th>Week</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Selection and briefing of three LATU tutors, including raising their awareness of scientific literacy as defined in this research and the data collection requirements for the focus group participants in their tutorials.</td>
</tr>
<tr>
<td>2</td>
<td>Questionnaire one was handed out in selected tutorials by the three tutors and completed in 20 min. Analysis of the Questionnaire was completed and 6 respondents from each tutorial group were selected as focus participants. Collect and photocopy focus participants’ tutor information sheet and their diagnostic exercise.</td>
</tr>
<tr>
<td>4</td>
<td>Collect and photocopy reading log one for focus participants.</td>
</tr>
<tr>
<td>6</td>
<td>Collect and photocopy focus participants’ mid semester exam.</td>
</tr>
</tbody>
</table>
Table 5.3: Timeline for collecting LATU work samples

Tutors assisted in the collecting of focus participants’ work samples from LATU. These were photocopied and returned to the students. These materials include Tutor Information Sheet, Diagnostic Exercise, all Reading Logs, Essay, Project plan and Mid Semester Exam. The demands of these tasks are listed in the LATU unit guide and tutor marking guides and are briefly described below.

Diagnostic Exercise

- Read and summarize three brief science articles

Reading Log

- Encourages the habit of critical reading
- Material can be taken from any readings science fiction, science fact, scientific journals and daily newspapers
- Designed to help keep track of what is read
- Adopt a critical attitude to what is read
- Approach reading in a logical manner
- Log should include notes, bibliographical details and comment on its content and how it fits into the unit as a whole
- Includes a short summary bringing out the major points that the author made
- Comments on the article include how it fits into the scheme of things and the way in which it was written
- If fictional, is it plausible (scientifically or ethically)
• How it fits into the general body of science fiction writing

Reading log entries will reflect your growing body of knowledge on the subject

Essay

• Recognise and take account of the assumptions and implications in the wording of the topic
• Deal with the topic and its key ideas and terms
• Read with an open mind and a questioning mind
• Read in order to understand the parts of the argument and their relationship to the whole
• Evaluate continuously what you are reading in terms of the argument and in terms of the relevance of the material to the topic
• Select only points relevant to the topic and to your arguments
• Present ideas logically and coherently
• Ensure argument is internally consistent and supports and extends the central idea
• Take into account alternative points of view or interpretations
• Use specialist terminology correctly and only when necessary

Project

• Doesn’t involve the actual collection of data
• Work up a full experimental plan for the project
• Construction of a budget
• Anticipated results
• Design a project that should take no more than one year to conduct
• Draw conclusions from the work
• Make suggestions for ongoing future research.
• Way in which data is collected
• Need for experimental controls
• How to analyse and synthesise the data once collected
• Small scientific investigation in which they are expected to use the scientific method in the project

Mid Semester Examination

Question One: Article summary

• Identify the main points in the development of the articles thesis.
• What is germ-line engineering?
• What are the specific benefits?
• What are the obstacles?
• What is the time frame?

Question Two: What is the role of science fiction (SF) in science?

• SF has technological basis and attempts to explain concepts within the framework of basic physical laws
• SF is a softer medium for putting across scientific ideas
• SF reflects the role of imagination in science
• Many SF ideas are well founded in science and as such may be predictive of the future
• Scientists who write SF use it as a means for testing hypotheses as imagination allows freedom to explore the possibilities not possible within the rigid boundaries of empirical work
In a rapidly changing world SF is an approach for predicting the future and the consequences of current actions.

Question Three: Describe the current most popular scientific model for the origin of life on Earth.

- Gases, water, heat subjected to large amounts of ionising radiation from lightening and the sun, produced an organic soup of amino acids.
- Concentration of organics due to evaporation in tidal pools led to the formation of amino acids.
- Aluminium and silicon acted as catalysts in the formation of more complex ring molecules.
- Absorbed into clay forming micelles (balls) where the outside protected the inside.
- Micelles formed a surrounding protein membrane and developed a series of properties resembling a cell and incorporated RNA/DNA.
- Through survival of the fittest developed and grew into what is seen today.

Question Four: What is the Green House Effect?

- Short wave solar radiation incoming from the sun is easily able to penetrate the Earth’s atmosphere.
- After absorption by the Earth and the atmosphere re-radiated as long wave thermal radiation.
- This energy is trapped by the components in the atmosphere.
- Hence the atmosphere acts like a blanket keeping in the heat, which warms the atmosphere and Earth.
5.7 Focus group workshop 2002

In addition to providing copies of their work samples, the focus group participants were asked to attend a two-hour scientific literacy workshop in May 2002. Three workshops were run with the participants from the same tutorial group attending the same session. The participants were kept in their regular tutorial groups, as they were already familiar with these people. This reduced the need to familiarize the participants with each other and should have contributed to more open discussion. Keeping the workshops to a maximum of six participants enabled all participants to contribute to the discussion and their thinking could be probed more effectively through questioning.

The workshop was divided into two one-hour blocks. Each block started with a pencil and paper activity that the participants completed alone. The activity was then followed by group discussion. These activities and guiding questions for discussion are included as Appendix 2. Activity one was a mind mapping exercise. Students were asked to write in their own words what they meant by the term science and then expand their thinking of science by developing a surrounding mind map. Following this they were required to draw a picture of a scientist and surround the picture with words they thought described the work of their scientist.

The participants were asked to share their responses on the first activities and then the following questions were asked to stimulate discussion. The participants were also encouraged to ask questions of each other and contribute to or build on comments made.

- Can scientific knowledge be accepted as truth?
- What factors influence the direction scientific research takes?
- Do scientists research objectively?
• Do scientists display professional standards of openness of mind and honesty with a moral and ethical approach to their work?

In activity two, the participants were provided with three news briefs reporting science research from three different science disciplines. They were asked to read each and answer questions on only one. Upon completion participants were asked to explain why they had chosen their particular article to work in detail. The following questions were then asked to generate discussion:

• What is the purpose of scientific research generally?
• What role do you think science takes in your life and society generally?
• What is a scientific theory?
• What place does creativity have in science?

The three workshops were videoed in order to capture each group’s discussion of the activities, their response to the guiding questions and their interaction with other participants’ points of view. The dialogue captured through the video was transcribed to assist in the analysis process.

5.8 Following the focus group participants in 2003

All focus group participants were contacted via email and telephoned to invite them to participate in the follow up interview phase of the research. This process began in June 2003, approximately one year after the 2002 workshop and their completion of the LATU unit. At this stage of the research there were 15 focus group participants. All participants agreed to continue their involvement in the research and be interviewed in relation to their continued development of scientific literacy. However, one school
leaver male repeatedly missed his arranged interview time but never formally withdrew from the research. Unfortunately, due to the incomplete nature of the data, this participant was dropped from the group for analysis.

The participants were required to complete questionnaire two and the same set of activities used in the 2002 workshop (see Appendix Two). The science news briefs used as a prompt for activity 3 and the subsequent discussion were changed. This was to reduce the influence of participants’ workshop experience on their thinking and discussion of science in the news (Appendix Two). Participants were interviewed separately. The interviews were audio-taped and later transcribed to support analysis. These transcripts were sent to the participants to confirm that they were an accurate record of the interview and captured their thinking. Two participants added further comments to the transcript, which were elaborating on the comments they had made during the interview.

5.9 Analysing the focus group data

A checklist was generated to record and summarise the occurrence of indicators of scientific literacy in the focus groups’ data. These indicators, as discussed in chapter four were in three levels, functional, conceptual and procedural and multidimensional scientific literacy. The indicator checklist was used to support analysis and the summarising of all focus group data sources. An example of a participants’ checklist is included as Appendix Three. When a participant’s response to a question, discussion comment or work sample provided evidence of an indicator it was marked on the participants’ indicator summary table (1). Responses that suggested misconceptions or alternative views about an indicator were also recorded on the table as an asterisk.
In addition, as each piece of a participant’s data was examined, comments were made and quotes were recorded as evidence for the inferences made. The indicators were used as organisational headings for this detailed analysis and sorting of the data. It was anticipated that overtime this process would facilitate the identification of emerging trends in the focus group participants’ views of the nature of science, its interaction with society and their understanding of science terms and ideas in the context of news briefs.

**Questionnaire One**

The participants’ response to the news brief open questions and Nature of Science Likert scale items were recorded in the indicators checklist. Responses that were both consistent and alternatively inconsistent were recorded.

**LATU work samples**

All LATU work samples were read and analysed based on the indicators of scientific literacy. Comments that could provide evidence of scientific literacy were highlighted and explanatory notes were made directly. These materials were re-read and the highlighted comments were used as evidence of an indicator. This was recorded on the indicator checklist for each participant. Misconceptions or alternative views were again recorded. Comments and quotes were collated.

**Workshop materials and discussion**

The three written activities completed by each focus participant were analysed for conceptions of science, scientists, scientists’ work and the interaction of science and society. These conceptions were identified in the activity sheets and highlighted with explanatory notes. The participants’ activities were analysed in conjunction with their
explanations and comments from the associated workshop discussion. The transcript of the participants’ workshop comments was used to clarify and develop depth to the responses on their activity sheets. Participant quotes were recorded to support the analysis. Evidence of indicators was also recorded on the checklist using the previously described protocol.

In addition, analysis of the activity “Draw a Scientist” used the DAST- draw a scientist test indicators developed by Chambers and cited by Schibeci (2002). These indicators were; lab coat, eyeglasses, facial hair, symbols of research, symbols knowledge, signs of technology, captions. Schibeci explains these indicators were later expanded to include male, signs and labelling, pens/pencils in pocket and unkempt appearance. The presence of DAST indicators in the participants’ drawings was used to support inferences about participants’ conceptions of the nature of scientists and their work. Shibeci and Lee (2003) explain that citizens need to understand the way in which scientists work in reality if they are to engage critically and make informed decisions about science related issues. For example,

We can not claim to be prepared for ‘science for citizenship’ if we hold images of science and scientists which are stereotypical or inaccurate when we are making personal or social decisions (p. 179).

The follow up interview
The participants’ responses to questionnaire two, the workshop activities and their discussion of each were analysed in the manner described above. The process was kept consistent so that any observed variations in participants’ demonstration of indicators could be attributed to their development of scientific literacy.
Data summary

A frequency summary was made of the focus groups’ conceptions and misconceptions as recorded on the checklist of indicators (Appendix Four). This summary provided information about trends in the group and contributes information for reviewing the indicators of scientific literacy.

Ultimately, all aspects of the data analysis were drawn together through the ongoing collation of participant quotes and inferential comments. The emerging common ideas, issues and range in views about science knowledge, the nature of science and its interaction with society evident amongst the group, were identified and used to inform the qualitative findings presented in chapters seven and eight.

5.10 Reviewing the framework and indicators of scientific literacy

The use of the framework and associated indicators as a tool for analysing the focus group data allowed for them to be critiqued and tested against the empirical data. Underlying assumptions of the scientific literacy framework and indicators of development were reflected on as they were used to identify participants’ conceptions and misconceptions contributing to their scientific literacy. The summary of all participants’ demonstration of indicators should show the presence or absence of the various dimensions of scientific literacy. If indicators are not present, the questions to be answered will be (a) are they important (b) are they absent because of the questions asked in the interview or in the materials given or (c) are they irrelevant to the structure of LATU? Evidence from both the quantitative and qualitative aspects of this research is used to review the framework and indicators of participants’ development of scientific literacy.
The findings from the quantitative analysis of questionnaire one and two are reported in chapter six. The qualitative analysis of trends in the focus group participants’ conceptions are then discussed in chapters seven and eight.
CHAPTER SIX  PARTICIPANTS’ LEVEL OF SCIENTIFIC LITERACY: QUESTIONNAIRE FINDINGS

6.1 Participants’ background

The background information provided by the participants in the questionnaires is summarized in Table 6.1. The total sample includes all participants from 2001 pre- and post-LATU, all the 2002 participants and the 2003 focus group. The 2001 pre-LATU participants and the matched post participants are identified separately within the sample as matched comparisons are later made.

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-group</th>
<th>Total sample</th>
<th>Pre LATU 2001</th>
<th>Post LATU 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>% (n)</td>
<td>% (n)</td>
<td>% (n)</td>
</tr>
<tr>
<td>Gender</td>
<td>Female</td>
<td>56.3 (283)</td>
<td>53.9 (124)</td>
<td>54.2 (90)</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>43.7 (220)</td>
<td>46.1 (106)</td>
<td>45.8 (76)</td>
</tr>
<tr>
<td>Time out of school</td>
<td>Mature age</td>
<td>23.8 (120)</td>
<td>22.6 (52)</td>
<td>19.9 (33)</td>
</tr>
<tr>
<td></td>
<td>School leaver</td>
<td>58.8 (296)</td>
<td>55.2 (127)</td>
<td>58.4 (97)</td>
</tr>
<tr>
<td></td>
<td>Unspecified</td>
<td>17.4 (87)</td>
<td>22.2 (51)</td>
<td>21.7 (36)</td>
</tr>
<tr>
<td>Course</td>
<td>Science-based</td>
<td>57.2 (288)</td>
<td>58.3 (134)</td>
<td>57.2 (95)</td>
</tr>
<tr>
<td></td>
<td>Non-science</td>
<td>41 (206)</td>
<td>39.5 (91)</td>
<td>39.8 (66)</td>
</tr>
<tr>
<td></td>
<td>Unspecified</td>
<td>1.8 (9)</td>
<td>2.2 (5)</td>
<td>3 (5)</td>
</tr>
<tr>
<td>Science background</td>
<td>1- no science</td>
<td>9.7 (49)</td>
<td>10.9 (25)</td>
<td>11.4 (19)</td>
</tr>
<tr>
<td></td>
<td>2- only biological science</td>
<td>25.8 (130)</td>
<td>23.9 (55)</td>
<td>22.3 (37)</td>
</tr>
<tr>
<td></td>
<td>3- only physical science</td>
<td>21.7 (109)</td>
<td>19.5 (45)</td>
<td>22.9 (38)</td>
</tr>
<tr>
<td></td>
<td>4- both phys. &amp; biol. science</td>
<td>42.8 (215)</td>
<td>45.7 (105)</td>
<td>43.4 (72)</td>
</tr>
</tbody>
</table>

Table 6.1: Participants’ background
Table 6.1 shows that there is a relatively even gender split. Of those who identified themselves as ‘mature age’ or ‘school leaver,’ 58.8% were school leavers. This is not conclusive as 87 participants choose not to provide the information required to determine the number of years since they left school.

The group has a high proportion of participants with a science background as 90.3% of all participants had formally studied a post-compulsory science based subject. In addition, 57.2% of the total sample is enrolled in a university science based course. Participants’ enrolment in *Life and the Universe* probably selected out students with a science background and an ongoing interest in science.

6.2 The questionnaire

The questionnaires contained four open questions dealing with participants’ engagement with a science news brief and a Likert scale composed of ten items on the nature of science. The total sample of 503 questionnaires, completed by all participants, was used to evaluate the working of the Likert scale. In addition a comparative analysis was made for the 230 pre-LATU participants and the 166 matched post-LATU participants on the open questions and the Likert scale.

*Open Questions: Science in the News*

*Question 1: Do you believe drinking a glass of wine daily with a meal can reduce the risk of developing colon cancer? Why do you say that?*

This question aimed to collect information on the participants’ reactions to the research conclusion before reading the news brief on this topic. The participants’ response to question 1 was not analyzed in isolation but later used to assist in categorizing their engagement with the news brief in question 3.
Question 2: Where do you get your information on current science issues? (Don’t include formal learning e.g., university courses).

Most participants responded with two or more sources; 671 responses from the 230 participants. The responses are ranked in the following table from most frequently to least frequently stated.

<table>
<thead>
<tr>
<th>Information Source</th>
<th>Response frequency %</th>
<th>(n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Television Programs</td>
<td>20.3</td>
<td>136</td>
</tr>
<tr>
<td>Newspaper</td>
<td>19.2</td>
<td>129</td>
</tr>
<tr>
<td>Magazines</td>
<td>17.1</td>
<td>115</td>
</tr>
<tr>
<td>Television News</td>
<td>15.9</td>
<td>106</td>
</tr>
<tr>
<td>Internet</td>
<td>8.6</td>
<td>58</td>
</tr>
<tr>
<td>Word of Mouth</td>
<td>8.6</td>
<td>58</td>
</tr>
<tr>
<td>Radio</td>
<td>4.6</td>
<td>30</td>
</tr>
<tr>
<td>Books</td>
<td>3.7</td>
<td>25</td>
</tr>
<tr>
<td>Science Journals</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>671</strong></td>
</tr>
</tbody>
</table>

Table 6.2: Sources of science information.

It should be noted that included in the category of Television programs was Quantum¹, Discovery Channel, National Geographic Documentary, ABC Documentary², SBS³. The Magazine category also included New Scientist, National Geographic, Australian Geographic, Scientific America, Readers Digest, health magazine and Greenpeace magazine. In addition the Radio category included triple j⁴.

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¹ Quantum: A weekly half hour science program produced by the Australian Broadcasting Corporation’s TV Science Unit.
² ABC: Australian Broadcasting Corporation. Australia’s only national non-commercial broadcaster.
³ SBS: Special Broadcasting Service. Australia’s multicultural and multilingual public broadcaster.
⁴ triple j: Australia’s youth radio station, broadcasting across Australia and online.
‘Television programs’ including popular science documentaries were the most frequently stated source of information. The ‘newspaper’ was the second most frequent source. Furthermore, news reports either from television or newspapers constituted 35.1% of all the responses. This information supports the level of importance given in this research to engagement with science news briefs as an indicator of scientific literacy.

**Question 3:** After reading this news brief, which states the researchers’ conclusion as, ‘the fruit of the vine may also reduce the risk of developing colon cancer,’ are you now more certain, less certain or equally certain of your background belief? Explain your answer.

Participants read the news brief and then answered question 3. Participants’ responses were classified into seven categories based on the nature of their engagement with the news brief. Categories 1 to 4 represent uncritical engagement with the news brief while categories 5 and 6 represent critical engagement. Examples of responses in each category are included in Table 6.3.
<table>
<thead>
<tr>
<th>Nature of Engagement</th>
<th>Category</th>
<th>Response Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical (2)</td>
<td>1. Evaluating: Stating certainty of belief (or degree of certainty) by giving reasons why the text should be believed.</td>
<td>I guess I am less certain. The conclusion drawn in the text seems valid and the information presented comes from a seemingly reputable study but I’m not completely convinced.</td>
</tr>
<tr>
<td></td>
<td>2. Challenging: Rejecting the report (or in part) on the basis of reasons why it should be disbelieved, or explaining how the report fails to address their own beliefs.</td>
<td>I would look at their overall lifestyle. What they eat, adequate rest, smoking, consuming other alcohol and exercise. Is the glass of wine the only factor common in those with reduced polyps?</td>
</tr>
<tr>
<td>Uncritical (1)</td>
<td>3. Deference: Deferring absolutely to the report and stating certainty of beliefs based solely on more or less direct citation of the text.</td>
<td>After hearing a scientific explanation I believe it to be true.</td>
</tr>
<tr>
<td></td>
<td>4. Echoing: Agreeing absolutely with the report on the basis that their own beliefs are confirmed by the report.</td>
<td>More certain that wine (in moderation) is good for you. It could only be a matter of time before other health benefits are discovered.</td>
</tr>
<tr>
<td></td>
<td>5. Affirmation: Stating certainty of beliefs on the basis of paraphrased information from the report.</td>
<td>I am more sure due to the reported work from people in New York who found that the ‘fruit of the vine’ reduces the risk of developing colon cancer.</td>
</tr>
<tr>
<td></td>
<td>6. Dominating: Imposing background belief onto the text resulting in an implausible interpretation. Ignoring the report all together.</td>
<td>Equally certain. Scientists may be wrong. Humans are fallible creatures.</td>
</tr>
<tr>
<td>Off Task (0)</td>
<td>7. Other: Misinterpretation of the articles content or irrelevant to the researchers’ conclusion.</td>
<td>The article says wine may reduce the risk and then says people who drink wine have more polyps than non-drinkers.</td>
</tr>
</tbody>
</table>

Table 6.3: Category descriptions for engagement with the news brief
6.3 Responses to question 3, pre- and post-LATU

The full distribution of the responses in each category generated for pre- and post-LATU question 3 is shown in Appendix Five. This extensive data is held in the appendix as it is not central to the interpretation of the criticalness of participants’ engagement with the news brief. The trends in the data are however, presented visually in Figure 6.1

Figure 6.1 illustrates the change in category frequencies for pre- to post-LATU responses to question 3. The figure clearly shows that a much greater proportion of participants post LATU were deferring absolutely to the report and stating certainty of their original ideas based solely on more or less direct citation of the news briefs content.

Figure 6.1: Science in the news, pre and post comparison of criticalness of engagement.
Critical engagement with science reported in the news was identified in this research as an important indicator of scientific literacy. When analyzing the participants’ responses a range of response types were identified but at a macro level this range simply represented critical, uncritical or off task engagement. For the purpose of identifying participants’ developing scientific literacy the categories were collapsed. Collapsing categories 1-2 and 3-6 into two larger categories *critical* or *uncritical* and then off task responses into the *other* category resulted in the distribution of pre- and post-LATU Question 3 responses as shown in Table 6.4.

<table>
<thead>
<tr>
<th>Data</th>
<th>Other 0 % (n)</th>
<th>Uncritical 1 % (n)</th>
<th>Critical 2 % (n)</th>
<th>Total 2 % (n)</th>
<th>Mean SD</th>
<th>Dependent t-test</th>
<th>Independent t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-LATU Total</td>
<td>10 (23)</td>
<td>46 (105)</td>
<td>44 (101)</td>
<td>100 (229)</td>
<td>1.34</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Pre-LATU Unmatched</td>
<td>7.5 (5)</td>
<td>57 (37)</td>
<td>35.5 (23)</td>
<td>100 (65)</td>
<td>1.277</td>
<td>N/A</td>
<td>t=0.938 p&lt;0.349</td>
</tr>
<tr>
<td>Pre-LATU Matched</td>
<td>10.5 (17)</td>
<td>42.5 (70)</td>
<td>47 (77)</td>
<td>100 (164)</td>
<td>1.37</td>
<td>t = -.576 p&lt;0.565</td>
<td></td>
</tr>
<tr>
<td>Post-LATU</td>
<td>2 (3)</td>
<td>56 (92)</td>
<td>42 (69)</td>
<td>100 (164)</td>
<td>1.40</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 6.4: Participants’ pre- and post-LATU responses to Question 3

*Note:* There was 1 person who did not answer question 3 in the pre-LATU group and 2 people in the post-LATU group. The total number of participants for analysis in question 3 was 164.

It was assumed there was a hierarchal order in the categories *critical*, *uncritical* and *other* in relation to the development of scientific literacy. The assumption of the ordinal nature of the categories was based on the review of the literature and the resulting framework and indicators of scientific literacy described in Chapter 4. *Critical* engagement was of the highest order and scored 2, which was followed by *uncritical*
scoring 1. Responses that were off task and categorized as other were misinterpretations of the articles' content or irrelevant to the researchers’ conclusion. These responses scored 0 as they represented the lowest level of engagement and hence scientific literacy. Placing participants’ responses on this scale allowed a statistical comparison to be made between subgroups and from pre- to post-LATU. A mean score was calculated for the group as a whole pre to post-LATU and for each subgroup. T-tests were then conducted to determine any significant difference pre- to post-LATU.

The independent t-test between the pre-LATU participants who were not identified in the post-LATU group (unmatched) and the pre-LATU participants who were also in the post-LATU group (matched) indicated that there was no statistically significant difference in the nature of their response to question 3. This suggested that the dropping out of pre-LATU participants in the post-LATU sample was random and that there was no significant selecting factor acting. As a result of this finding further comparisons were conducted only on participants who were present in both the pre- and post-LATU data.

The frequency distribution of responses, displayed in Table 6.4 suggested that pre-LATU more participants (47%) engaged critically with the news brief than uncritically (42.5%). This trend reversed post-LATU with only 42% engaging critically and 56% engaging uncritically. Yet, it was evident that fewer participants post-LATU were making responses that were irrelevant to the reported researchers’ conclusion. Overall the mean score pre to post-LATU increased slightly from 1.37 to 1.40 and as this would suggest, the dependent t-test, also displayed in Table 6.4 showed that the criticalness of participants’ engagement with science news briefs did not change significantly over the period in which they participated in LATU.
The category frequencies, means and associated t-tests for each subgroups response to question 3 are displayed in Appendix Six. The t-test probabilities suggested that gender, time out of school, course and science background had no significant effect on the criticalness of participants’ engagement with the science news brief.

*Question 4: Suppose this conclusion is very important to you and that you have to determine whether it is reliable. What extra information if any, would you like to have about the researchers’ report to decide whether this conclusion is true?*

Participants’ requests for extra information in response to question 4 were classified into the six categories described in the methodology Chapter 5. Examples of responses in each category are included in Table 6.5.

<table>
<thead>
<tr>
<th>Level of Scientific Literacy</th>
<th>Category</th>
<th>Response Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multidimensional (2)</td>
<td>1. Social context: Social factors that could influence judgments and confidence in the quality of the research.</td>
<td>Did the research have any links with the wine industry?</td>
</tr>
<tr>
<td></td>
<td>2. Ongoing research: Recognition of the ongoing and dynamic nature of scientific research.</td>
<td>Are there any other studies to which we can compare this? Conduct further studies to confirm the results.</td>
</tr>
<tr>
<td>Conceptual/Procedural (1)</td>
<td>3. Research methods: How was the research designed and conducted?</td>
<td>Did the sample come from similar ranges of age, family status, occupation and what were the other life style factors studied?</td>
</tr>
<tr>
<td></td>
<td>4. Data and statistics: Consideration of the type of data</td>
<td>Factual statistical data.</td>
</tr>
</tbody>
</table>
5. Clarification of article: Requests for clarification or development of terms or information included in the brief.

More information on the experiments conducted and how they relate to the topic.

Greater explanation of how wine helps.

6. Off-task: Topics irrelevant to engaging with the researchers’ conclusion or the information contained in the news brief.

Is the test successful?

Are people being cured?

Table 6.5: Participants’ question 4 requests for extra information.

These categories also represent a hierarchical order in relation to scientific literacy.

Moving up through the categories from off task to social context represents increasing development of scientific literacy. Each category is representative of the three levels of scientific literacy proposed by Bybee (1997) and used for analysis in this research. The categories off task and clarification of article represent functional development.

Increasing procedural understandings are present in categories data and statistics and research methods. Responses in these categories were representative of a conceptual/procedural level of scientific literacy. The categories at the highest multidimensional level were ongoing research and social context. Responses in this category indicated some awareness of the dynamic nature of science, the tentative nature of research findings and the interaction of science with society.
6.4 Responses to question 4, pre- and post-LATU

Pre-LATU a total of 63 participants made requests for information that fitted 2 categories while 6 participants made requests fitting into 3 categories. In contrast 9 participants did not respond and as a result the total number of requests for information was 296. The full distribution of responses in each category is shown in Appendix Seven.

Post-LATU participants’ requests for extra information were classified into the 6 categories used for the pre-LATU data. There were 6 participants who did not respond to this question. In addition, 39 participants made requests fitting 2 categories and 1 participant made a request fitting into 3 categories. Hence for the total population number of responses is 201. The distribution of responses in each category is also displayed in Appendix Seven. Trends in the data are observable when comparing the pre- and post-LATU requests for extra information, as displayed in Figure 6.2

![Figure 6.2: Science in the news; requests for extra information](image-url)

Scientific Literacy for Sustainability
It can be seen from this display that the majority of participants both pre- and post-LATU made requests for extra information about the research methods used in the reported research. There was also a general increase in the group’s level of scientific literacy as post-LATU participants made more requests for extra information in categories at the conceptual/procedural and multidimensional levels. There were fewer participants post-LATU making requests at the functional level of scientific literacy.

Participants’ requests for extra information were taken as an indicator of their level of scientific literacy. Collapsing categories 1-2, 3-4 and 5-6 into the three larger categories Multidimensional, Conceptual/Procedural and Functional provides a view on the participants’ level of scientific literacy. The resulting frequency in each category is shown in Table 6.6.

<table>
<thead>
<tr>
<th>Data</th>
<th>Functional 0 % (n)</th>
<th>Conceptual/Procedural 1 % (n)</th>
<th>Multidimensional 2 % (n)</th>
<th>Total 100 % (n)</th>
<th>Mean</th>
<th>SD</th>
<th>Dependent t-test</th>
<th>Independent t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-LATU Total</td>
<td>17 (37)</td>
<td>56 (124)</td>
<td>27 (60)</td>
<td>100 (221)</td>
<td>1.10</td>
<td>.656</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Pre-LATU Unmatched</td>
<td>14.5 (9)</td>
<td>56 (34)</td>
<td>29.5 (18)</td>
<td>100 (61)</td>
<td>1.148</td>
<td>.654</td>
<td>N/A</td>
<td>t = -0.608 p&lt; 0.544</td>
</tr>
<tr>
<td>Pre-LATU Matched</td>
<td>17.5 (28)</td>
<td>56 (90)</td>
<td>26.5 (42)</td>
<td>100 (160)</td>
<td>1.088</td>
<td>.6577</td>
<td>t = -1.026 p&lt; .307</td>
<td>N/A</td>
</tr>
<tr>
<td>Post-LATU</td>
<td>15.5 (25)</td>
<td>52.5 (84)</td>
<td>32 (51)</td>
<td>100 (160)</td>
<td>1.16</td>
<td>.672</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 6.6: Participants’ pre- and post-LATU responses to Question 4

Note: These frequency summaries and analysis only include one request for extra information in response to question 4 from each participant. In addition, 9 participants did not respond to question 4 pre-LATU and 6 participants did not respond post-LATU. The total number of participants for analysis in question 4 was 160.
This analysis was based on the assumption that there is a hierarchal order in the 
*Functional*, *Conceptual/procedural* and *Multidimensional* levels of scientific literacy. 

In order to measure developing scientific literacy the categories used in question 4 were 
placed on a scale of 0 to 2 that represented this hierarchal order. The *Multidimensional* 
category was of the highest order and scored 2, which was followed by 
*Conceptual/procedural* scoring 1. The *Functional* category scored 0 as it represented the 
lowest level of scientific literacy that was expected from First Year University Students. 
Placing participants’ requests for extra information on this scale allowed a statistical 
comparison to be made between subgroups and from pre- to post-LATU. A mean score 
was calculated for the group as a whole pre- to post-LATU and for each subgroup t-tests 
were then conducted to determine any significant difference pre- to post-LATU.

The independent t-test between question 4 responses from the pre-LATU participants 
who were not identified in the post-LATU group (unmatched) and the pre-LATU 
participants who were also in the post-LATU group (matched) again indicted that there 
was no statistically significant difference between these groups. This also supported the 
earlier assumption that the dropping out of pre-LATU participants in the post-LATU 
sample was random and as such all further comparisons for question 4 were conducted 
only on participants who were present in both the pre and post-LATU data.

The participants’ requests for extra information about the research reported in the 
science news brief suggested that the majority of participants, pre-LATU (56%) were 
operating at a conceptual/procedural level of scientific literacy. This trend continued 
post-LATU with 52.5% of participants continuing to operate at the 
conceptual/procedural level. There was, however, a 5.5% increase post-LATU in the
number of participants operating at a multidimensional level of scientific literacy with a corresponding 2% decrease in the number of participants operating at a functional level. The mean increase pre to post-LATU was, however, minimal and as would be expected the dependent t-test showed that there was no significant difference in the participants level of scientific literacy pre to post-LATU as measured by question 4.

There was consistently a small increase in the mean score across all subgroups. However, the minimal increases observed were not statistically significant, as shown by the t-test probabilities displayed in the tables included in Appendix 8. This suggested that gender, course, time out of school and science background had no significant effect on the participants requests for extra information about the news brief pre- and post-LATU.

In addition, Appendix Nine displays the response categories for the 69 pre-LATU participants and the 40 post-LATU participants making multiple requests for extra information in question 4. Most of these participants’ responses support the assumption that development up the categories was hierarchal in nature. However, 8 pre-LATU and 6 post-LATU participants’ responses did not. These responses were at level 0 (functional) and 2 (multidimensional).

### 6.5 Likert scale: The nature of science

The Nature of Science Likert scale was analyzed using the Rasch model. This initially involved determining the working of the scale and its fit to the model. The participants’ responses were then analysed and a comparison was made between the matched participants Pre to Post LATU.
6.6 Working of the scale

This section of the analysis includes all participants from 2001, 2002 and 2003. All responses to the Likert scale were included in order to give the maximum data possible for analysing the working of the scale.

<table>
<thead>
<tr>
<th>Item</th>
<th>Item Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Creativity and imagination play an important part in science.</td>
<td>-1.319</td>
</tr>
<tr>
<td>10: The bodies (e.g. government departments) which supply the money for research influence the direction of science.</td>
<td>-0.959</td>
</tr>
<tr>
<td>9: The spreading of scientific information is important to the progress of science.</td>
<td>-0.525</td>
</tr>
<tr>
<td>6: Scientists may, because of their background, personal beliefs and values, emphasize different interpretations of evidence.</td>
<td>-0.492</td>
</tr>
<tr>
<td>3: Scientists study a world in which they are a part and as such their work is not objective or value free.</td>
<td>0.173</td>
</tr>
<tr>
<td>8: Scientists can seldom bring final answers to matters of public debate (e.g., nuclear power)</td>
<td>0.474</td>
</tr>
<tr>
<td>7: Science is an activity carried out by many different people and as such often reflects values and viewpoints related to society (e.g., views on women, political beliefs)</td>
<td>0.479</td>
</tr>
<tr>
<td>2: Scientific knowledge has been tested but should not be accepted as unquestionable truth.</td>
<td>0.666</td>
</tr>
<tr>
<td>5: There is not a set of fixed steps that scientists always use which leads to scientific knowledge.</td>
<td>0.704</td>
</tr>
<tr>
<td>4: Science is based on a dynamic, ever changing body of knowledge.</td>
<td>0.798</td>
</tr>
</tbody>
</table>

Table 6.7: Order of difficulty of each item

The logits listed in Table 6.7 give an indication of the location of each item on the empirically/socially located continuum used to represent the nature of science. Items that were reverse worded on the questionnaire were reworded to be consistent with the
Rasch analysis and this study’s perspective of the nature of science. For example, Item 4 was stated on the questionnaire as *science is based on an accumulated static body of knowledge*. This reverse worded item was changed, for the purpose of interpretation, to read *science is based on a dynamic, ever changing body of knowledge*, which makes the item consistent with this research’s contemporary socially located view of the nature of science.

Item one had the lowest logit value, which suggests participants found this socially located conception of the nature of science the easiest to accept. At the other end of the scale, item 4 had the highest logit value suggesting participants found it the most difficult to accept and that they would hold empirically located views in relation to this statement.

Figure 6.3 illustrates clearly the location of items on the scale and in addition it shows the distribution of all participants in relation to the items.

![Figure 6.3: Distribution of all participants in relation to the items.](image)
The items are located in the lower logit range from -1.5 to 1 and the participants measured range from -1 to 3 logits. The items are not well located in relation to all the participants. The participants in the upper range do not appear to be targeted by the questions and as such may not be well discriminated between. However, the following map of the item thresholds (Figure 6.4) illustrates that the third category (SA or SD) in the items is providing a challenge to the higher rating participants. The item thresholds are spread across the range of participants and contribute information about the participants in the upper scale range. Items 8, 5 and 2’s third category extends to the highest located person.

Figure 6.4: Item thresholds and distribution of participants
Table 6.8 contains the item-person interaction or test–of–fit summary, which provides an indication of the overall quality of the measurement instrument.

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>PERSONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Fit Residual</td>
</tr>
<tr>
<td>Mean</td>
<td>0.000</td>
</tr>
<tr>
<td>SD</td>
<td>0.763</td>
</tr>
<tr>
<td>Skewness</td>
<td></td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-0.421</td>
</tr>
<tr>
<td>Correlation</td>
<td>0.000</td>
</tr>
<tr>
<td>Complete data DF =</td>
<td>0.893</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>RELIABILITY INDICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Item Chi Squ</td>
<td>91.820</td>
</tr>
<tr>
<td>Total Deg of Freedom</td>
<td>80.000</td>
</tr>
<tr>
<td>Total Chi Squ Prob</td>
<td>0.172435</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LIKELIHOOD-RATIO TEST</th>
<th>POWER OF TEST-OF-FIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi Squ</td>
<td>Power is LOW</td>
</tr>
<tr>
<td>Degrees of Freedom</td>
<td>[Based on SepIndex of 0.412]</td>
</tr>
<tr>
<td>Probability</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.8: Item-person interaction

The mean person’s location is 0.623, which is to the right of the arbitrary 0 mean location of the items. This indicates that the items are not well targeted to discriminate amongst the people who are at the highest level on the socially located end of the nature of science continuum. The weak discrimination of the items amongst the higher rating participants is also indicated by the separation index of 0.412 and the low power of fit.
The participants in this study may well be a homogenous group relative to the general first year university student population as the participants’ enrolment in LATU would have resulted in a degree of self selection.

The total item Chi square of 91.820 is close to 80 degrees of freedom indicating the scale items are consistent with the Rasch model. The total Chi square probability is 0.172 which is well above the acceptable cut off of 0.05 and again demonstrates the fit of the data to the model. It needs to be recognised, however, that with a low separation index of 0.412, the power of this test of fit is not overly strong.

A closer analysis of the items, shown in Table 6.9, illustrates which items were worst fitting or not functioning as intended.

<table>
<thead>
<tr>
<th>Item Label</th>
<th>Location</th>
<th>SE</th>
<th>Residual</th>
<th>DegFree</th>
<th>DatPts</th>
<th>Chi Sq</th>
<th>Prob</th>
<th>degF</th>
</tr>
</thead>
<tbody>
<tr>
<td>creativity</td>
<td>-1.328</td>
<td>0.083</td>
<td>0.959</td>
<td>449.38</td>
<td>503</td>
<td>2.937</td>
<td>0.938</td>
<td>8</td>
</tr>
<tr>
<td>funding</td>
<td>-0.961</td>
<td>0.075</td>
<td>-0.273</td>
<td>447.59</td>
<td>501</td>
<td>8.799</td>
<td>0.359</td>
<td>8</td>
</tr>
<tr>
<td>communicating</td>
<td>-0.544</td>
<td>0.063</td>
<td>-1.500</td>
<td>449.38</td>
<td>503</td>
<td>11.482</td>
<td>0.175</td>
<td>8</td>
</tr>
<tr>
<td>interpretations</td>
<td>-0.499</td>
<td>0.071</td>
<td>-0.011</td>
<td>448.49</td>
<td>502</td>
<td>10.628</td>
<td>0.223</td>
<td>8</td>
</tr>
<tr>
<td>not objective</td>
<td>0.156</td>
<td>0.066</td>
<td>0.100</td>
<td>446.70</td>
<td>500</td>
<td>3.530</td>
<td>0.896</td>
<td>8</td>
</tr>
<tr>
<td>debate</td>
<td>0.474</td>
<td>0.064</td>
<td>1.751</td>
<td>444.91</td>
<td>498</td>
<td>24.526</td>
<td>0.001</td>
<td>8</td>
</tr>
<tr>
<td>society</td>
<td>0.484</td>
<td>0.060</td>
<td>0.128</td>
<td>446.70</td>
<td>500</td>
<td>6.867</td>
<td>0.551</td>
<td>8</td>
</tr>
<tr>
<td>questionable</td>
<td>0.691</td>
<td>0.070</td>
<td>-0.124</td>
<td>441.34</td>
<td>494</td>
<td>7.498</td>
<td>0.484</td>
<td>8</td>
</tr>
<tr>
<td>no fixed steps</td>
<td>0.717</td>
<td>0.062</td>
<td>0.344</td>
<td>444.91</td>
<td>498</td>
<td>9.973</td>
<td>0.266</td>
<td>8</td>
</tr>
<tr>
<td>dynamic</td>
<td>0.809</td>
<td>0.064</td>
<td>-0.617</td>
<td>447.59</td>
<td>501</td>
<td>5.989</td>
<td>0.648</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 6.9: Individual Item-Fit with items in their location order

The Chi Square value for each item in Table 6.9 is within an acceptable range, with only one item showing marked misfit. Item 8 fits the model least having the largest Chi Square value of 24.526. The Item Characteristic Curves (ICC) shows the fit of the participants in nine class intervals to the Rasch model. The observed mean for each class
interval is indicated and plotted against the model or expected values. Item 8, the worst
fitting item is plotted (Figure 6.5) over item 1 which in contrast does fit the model well.

![Figure 6.5: Item characteristic curves for items 1 and 8.](image)

Item 8 does not discriminate well as the observed proportion of participants are flatter
than the theoretical curve. This item does, however, generally fit the model as the
observed means still largely follow the curve. In contrast, item 1’s ICC demonstrates fit
to the model. The expected value for participants in each class interval matches the
theoretical curve.

Removing item eight from the analysis would marginally improve the internal
consistency of the instrument as shown in Table 6.10. This table shows the separation
index increased slightly to 0.453. However, despite the small improvement the item was
retained as it contributed information about the participants’ views of science’s role in
social debate.
Table 6.10: Item 8 out item-person interaction

The categories (strongly agree, agree, disagree and strongly disagree) were working as they were intended in most items. Each category had a range of logits in which it was the most probable to be accepted. In addition, as the participants’ conception of the nature of science or their person location (logit) increased so did the probability that they would accept category 3. Alternately, participants with a low person location (logit) were more likely to accept category 0. The working of item categories is illustrated by the following category probability curve for item 3. (Figure 6.6)
The categories in items 1, 6 and 9 were not working as they were intended. In each item’s category probability curve one is never the most likely response. This suggests that on items 1 and 6 the respondents did not discriminate between disagree and strongly disagree categories. Illustrating this is Figure 6.7, the category probability curve for item 9.
Collapsing categories 0 and 1 in items 1, 6 and 9 could improve the working of these items.

Figure 6.8: Item 1 Collapsed Category Probability Curve.

Figure 6.9: Item 6 Collapsed Category Probability Curve.

Figure 6.10: Item 9 Collapsed Category Probability Curve.
The instability of category 0 in items 1, 6 and 9 would have been contributed to by the small number of participants choosing this response, as shown in Table 6.11.

<table>
<thead>
<tr>
<th>Item</th>
<th>Label</th>
<th>0/SD % (n)</th>
<th>1/D % (n)</th>
<th>2/A % (n)</th>
<th>3/SA % (n)</th>
<th>Total % (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Creativity</td>
<td>0.2 (1)</td>
<td>1.8 (9)</td>
<td>41.1 (207)</td>
<td>56.9 (286)</td>
<td>100 (503)</td>
</tr>
<tr>
<td>10</td>
<td>Funding</td>
<td>0.4 (2)</td>
<td>7.6 (38)</td>
<td>57.3 (287)</td>
<td>34.7 (174)</td>
<td>100 (501)</td>
</tr>
<tr>
<td>9</td>
<td>communicating</td>
<td>2.2 (11)</td>
<td>4.2 (21)</td>
<td>35.8 (180)</td>
<td>57.8 (291)</td>
<td>100 (503)</td>
</tr>
<tr>
<td>6</td>
<td>interpretations</td>
<td>1.4 (7)</td>
<td>7.2 (36)</td>
<td>59.9 (301)</td>
<td>31.5 (158)</td>
<td>100 (502)</td>
</tr>
<tr>
<td>3</td>
<td>not objective</td>
<td>3.2 (16)</td>
<td>34.6 (173)</td>
<td>50.2 (251)</td>
<td>12 (60)</td>
<td>100 (500)</td>
</tr>
<tr>
<td>8</td>
<td>Debate</td>
<td>5.8 (29)</td>
<td>33.7 (168)</td>
<td>52 (259)</td>
<td>8.4 (42)</td>
<td>100 (498)</td>
</tr>
<tr>
<td>7</td>
<td>Society</td>
<td>7.8 (39)</td>
<td>34.3 (171)</td>
<td>46.7 (234)</td>
<td>11.2 (56)</td>
<td>100 (500)</td>
</tr>
<tr>
<td>2</td>
<td>questionable</td>
<td>5.6 (28)</td>
<td>52.9 (261)</td>
<td>36.7 (181)</td>
<td>4.8 (24)</td>
<td>100 (494)</td>
</tr>
<tr>
<td>5</td>
<td>no fixed steps</td>
<td>9.5 (47)</td>
<td>37.5 (187)</td>
<td>46.2 (230)</td>
<td>6.8 (34)</td>
<td>100 (498)</td>
</tr>
<tr>
<td>4</td>
<td>Dynamic</td>
<td>9.9 (50)</td>
<td>55.1 (277)</td>
<td>29 (146)</td>
<td>6 (30)</td>
<td>100 (503)</td>
</tr>
</tbody>
</table>

Table 6.11: Category response frequencies with items shown in their location order

Table 6.11 shows the items again in their location order but with response frequencies shown for each category. Strongly disagreeing with an item would place a participant at the empirically located end of the continuum while strongly agreeing with an item would suggest the participant is socially located. The frequencies displayed in Table 6.11 show that more than 50% of the participants were located at the socially constructed (SA) end of the continuum for 8 of the 10 items. Item numbers 2 and 4 were the exception as on these items the majority of the participants were empirically located (SD). That was they disagreed with:
Item 2: Scientific knowledge has been tested but should not be accepted as unquestionable truth; and

Item 4: Science is based on a dynamic, ever changing body of knowledge.

6.7 Variation amongst sub-groups

Generally, items were working consistently amongst sub-groups, as illustrated by Figure 6.11, which is an Item Characteristic Curve plotted over with the person factor- gender. This graph shows the item working across the 9 class intervals and for gender as the fit is generally consistent with the model.

![Item 1 ICC plot-over gender.](image)

Tables 6.12 to 6.15 display the ANOVA summary (one-way analysis of variance) for each sub-group (person factor) within the total sample. The probabilities show no significant variation in the functioning of most items across the class intervals. Item 8 is the exception, consistently demonstrating some degree of variation across class intervals.
Table 6.12: ANOVA summary for Gender

Gender did not affect participants’ response to most items but there appears to be some effect on Item 4 (P<0.011).

Table 6.13: ANOVA summary for Age

Time out of school (age) did not affect the participants’ response to any item. There was, however, some effect on the response to Item 1 when considered in relation to class interval (P<0.030).
<table>
<thead>
<tr>
<th>Item</th>
<th>Class Interval</th>
<th>Course</th>
<th>Class Interval &amp; Course</th>
<th>Total Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>P</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>1</td>
<td>0.278</td>
<td>0.973</td>
<td>7.175</td>
<td>0.008</td>
</tr>
<tr>
<td>2</td>
<td>1.079</td>
<td>0.376</td>
<td>1.714</td>
<td>0.191</td>
</tr>
<tr>
<td>3</td>
<td>0.587</td>
<td>0.789</td>
<td>1.126</td>
<td>0.289</td>
</tr>
<tr>
<td>4</td>
<td>0.779</td>
<td>0.622</td>
<td>8.494</td>
<td>0.004</td>
</tr>
<tr>
<td>5</td>
<td>1.204</td>
<td>0.295</td>
<td>0.331</td>
<td>0.566</td>
</tr>
<tr>
<td>6</td>
<td>1.381</td>
<td>0.202</td>
<td>0.271</td>
<td>0.603</td>
</tr>
<tr>
<td>7</td>
<td>0.953</td>
<td>0.473</td>
<td>1.735</td>
<td>0.188</td>
</tr>
<tr>
<td>8</td>
<td>3.155</td>
<td>0.002</td>
<td>2.056</td>
<td>0.152</td>
</tr>
<tr>
<td>9</td>
<td>1.679</td>
<td>0.101</td>
<td>7.829</td>
<td>0.005</td>
</tr>
<tr>
<td>10</td>
<td>1.229</td>
<td>0.280</td>
<td>0.089</td>
<td>0.766</td>
</tr>
</tbody>
</table>

Table 6.14: ANOVA summary for Course

The course in which participants’ were enrolled appeared to influence responses to Item 1 (P<0.008), Item 4 (P<0.004) and Item 9 (P<0.005). In addition there was some affect on Item 3 when considered against class intervals (P<0.019).

<table>
<thead>
<tr>
<th>Item</th>
<th>Class Interval</th>
<th>Science Background</th>
<th>Class Interval &amp; Sc. Bgrd.</th>
<th>Total Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>P</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>1</td>
<td>0.31</td>
<td>0.962</td>
<td>0.601</td>
<td>0.615</td>
</tr>
<tr>
<td>2</td>
<td>0.987</td>
<td>0.446</td>
<td>3.413</td>
<td>0.017</td>
</tr>
<tr>
<td>3</td>
<td>0.417</td>
<td>0.911</td>
<td>1.726</td>
<td>0.161</td>
</tr>
<tr>
<td>4</td>
<td>0.738</td>
<td>0.658</td>
<td>0.641</td>
<td>0.589</td>
</tr>
<tr>
<td>5</td>
<td>1.361</td>
<td>0.211</td>
<td>1.574</td>
<td>0.195</td>
</tr>
<tr>
<td>6</td>
<td>1.499</td>
<td>0.155</td>
<td>2.06</td>
<td>0.105</td>
</tr>
<tr>
<td>7</td>
<td>1.103</td>
<td>0.359</td>
<td>1.513</td>
<td>0.210</td>
</tr>
<tr>
<td>8</td>
<td>3.251</td>
<td>0.001</td>
<td>1.841</td>
<td>0.139</td>
</tr>
<tr>
<td>9</td>
<td>1.587</td>
<td>0.126</td>
<td>2.012</td>
<td>0.111</td>
</tr>
<tr>
<td>10</td>
<td>1.219</td>
<td>0.285</td>
<td>0.736</td>
<td>0.531</td>
</tr>
</tbody>
</table>

Table 6.15: ANOVA summary for Science Background

Science background did not affect participants’ response to most items, but there appears to be some effect upon Item 2 (P<0.017) and also Item 8 if it is considered against class interval (P<0.018).
6.8 Comparing the matched participants pre- to post-LATU

The participants’ mean logit increased over the period in which they were studying in LATU from 0.594 to 0.727 (Figure 6.12). A matched 2 tailed dependent t-test between 2001 participants’ Pre and Post mean logits resulted in a probability < 0.01. This suggests there was a significant improvement in the participants’ performance on the Likert items while studying in the unit *Life and the Universe*.

Table 6.16 shows the average logit increase for each subgroup. The independent t-tests conducted on the data indicate that the observed improvement while studying in LATU was not consistent across all subgroups. The improvement shown by mature age
participants was significantly greater than the school leavers. In addition, participants with any science background showed a significantly greater improvement than participants with no science background.

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-group</th>
<th>Average Logit Diff. (post-pre)</th>
<th>(Indep. t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Females</td>
<td>0.142</td>
<td>0.580</td>
</tr>
<tr>
<td></td>
<td>Males</td>
<td>0.091</td>
<td></td>
</tr>
<tr>
<td>Time out of school</td>
<td>Mature age</td>
<td>0.469</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>School leaver</td>
<td>0.081</td>
<td></td>
</tr>
<tr>
<td>Course enrolled in</td>
<td>Science based</td>
<td>0.066</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-science</td>
<td>0.183</td>
<td>0.248</td>
</tr>
<tr>
<td>Science background</td>
<td>1- no science</td>
<td>0.446</td>
<td>Compared to no sc.</td>
</tr>
<tr>
<td></td>
<td>2- biological</td>
<td>0.108</td>
<td>0.044</td>
</tr>
<tr>
<td></td>
<td>science</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3- physical science</td>
<td>0.066</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>4- both</td>
<td>0.076</td>
<td>0.020</td>
</tr>
</tbody>
</table>

Table 6.16: Pre- and post-LATU logit difference amongst subgroups.

Comparing the pre- and post-LATU logit value for each scale item also suggests the improvement was not consistent across all items. The independent t-test probabilities displayed in Table 6.17 suggest there was no significant improvement in 7 of the items. There was, however, a decrease in the level of difficulty of Items 3 and 2 with participants being more likely to respond in a socially located manner. There was however, an increase in Item 4 suggesting participants had moved away from a socially located perspective.
Table 6.17: Pre- and post-LATU variation on items

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre Logit</th>
<th>SE</th>
<th>Post Logit</th>
<th>SE</th>
<th>Post-Pre Logit</th>
<th>SE Diff.</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1.762</td>
<td>0.129</td>
<td>-1.493</td>
<td>0.15</td>
<td>0.269</td>
<td>0.197</td>
<td>1.359</td>
</tr>
<tr>
<td>10</td>
<td>-0.683</td>
<td>0.108</td>
<td>-0.826</td>
<td>0.134</td>
<td>-0.143</td>
<td>0.172</td>
<td>-0.830</td>
</tr>
<tr>
<td>9</td>
<td>-0.49</td>
<td>0.091</td>
<td>-0.34</td>
<td>0.102</td>
<td>0.15</td>
<td>0.136</td>
<td>1.097</td>
</tr>
<tr>
<td>6</td>
<td>-0.469</td>
<td>0.11</td>
<td>-0.494</td>
<td>0.122</td>
<td>-0.025</td>
<td>0.164</td>
<td>-0.152</td>
</tr>
<tr>
<td>3</td>
<td>0.433</td>
<td>0.102</td>
<td>0.064</td>
<td>0.113</td>
<td>-0.369</td>
<td>0.152</td>
<td>-2.424</td>
</tr>
<tr>
<td>8</td>
<td>0.448</td>
<td>0.09</td>
<td>0.469</td>
<td>0.119</td>
<td>0.021</td>
<td>0.149</td>
<td>0.140</td>
</tr>
<tr>
<td>7</td>
<td>0.349</td>
<td>0.092</td>
<td>0.458</td>
<td>0.105</td>
<td>0.109</td>
<td>0.139</td>
<td>0.780</td>
</tr>
<tr>
<td>2</td>
<td>0.95</td>
<td>0.104</td>
<td>0.508</td>
<td>0.116</td>
<td>-0.442</td>
<td>0.155</td>
<td>-2.837</td>
</tr>
<tr>
<td>5</td>
<td>0.675</td>
<td>0.092</td>
<td>0.7</td>
<td>0.103</td>
<td>0.025</td>
<td>0.138</td>
<td>0.181</td>
</tr>
<tr>
<td>4</td>
<td>0.549</td>
<td>0.103</td>
<td>0.954</td>
<td>0.111</td>
<td>0.405</td>
<td>0.151</td>
<td>2.674</td>
</tr>
</tbody>
</table>

Table 6.18: Items 2, 3 and 4’s response frequency for each category.

Table 6.18: Items 2, 3 and 4 response frequencies

<table>
<thead>
<tr>
<th>Item</th>
<th>Response Category</th>
<th>Pre LATU % n=230</th>
<th>Post LATU % n=166</th>
</tr>
</thead>
<tbody>
<tr>
<td>2: Scientific knowledge has been tested but should not be accepted as unquestionable truth.</td>
<td>0 / SD 7.5  5</td>
<td>1 / D 51.5  49</td>
<td>2 / A 37.5  38</td>
</tr>
<tr>
<td>3: Scientists study a world in which they are a part and as such their work is not objective or value free.</td>
<td>0 / SD 4  3</td>
<td>1 / D 42  23</td>
<td>2 / A 46.5  57</td>
</tr>
<tr>
<td>4: Science is based on a dynamic, ever changing body of knowledge.</td>
<td>0 / SD 5  12</td>
<td>1 / D 58  57.5</td>
<td>2 / A 31  24.5</td>
</tr>
</tbody>
</table>

The LATU experience seems to have increased participants’ awareness of the tentative and subjective nature of science. More participants were disagreeing with the idea that *scientific knowledge has been tested and can be accepted as truth*, and, in addition,
more were agreeing that *scientists study a world in which they are a part and as such their work is not objective or value free*. In contrast, the participants as a group moved further away from this research’s perspective that science is dynamic in nature with a greater acceptance of the questionnaire statement *science is based on an accumulated static body of knowledge*.

The next chapter is a discussion of the findings from an interrogation of the focus group participants’ conceptions of the nature of science. The range of focus group data sources viewed through this research’s framework of scientific literacy resulted in a deeper understanding of the trends identified in the large scale administering and analysis of the pre and post-LATU questionnaires.
CHAPTER SEVEN    FOCUS GROUP PARTICIPANTS’ CONCEPTIONS
OF THE NATURE OF SCIENCE

The profile of focus group participants is included as Appendix Ten. This includes background information, their pre- LATU questionnaire responses used for focus group selection and the corresponding follow up information from their post-LATU questionnaire. Each participant’s comments in their questionnaires, LATU work samples, worksheets, workshop discussion and their follow up interview were analysed using the framework for scientific literacy and the associated indicators developed in this research. The presence of indicators in each participant’s data was recorded on the Indicators of Scientific Literacy table as either a conception or a misconception. All participants’ conceptions and misconceptions were collated and summary tables were completed for the focus group as a whole. The summaries of the focus groups conceptions and misconceptions, as described in chapter 5, are included in Appendix 4.

These summaries of focus group participants’ conceptions showed that the greatest numbers of indicators were recorded at the multidimensional level of scientific literacy. This would have been contributed by the types of activities and questions used for data collection. All indicators were present in the data but knowledge of the history of scientific ideas was rare as this was not targeted in activities or in discussion and most participants did not make historical references to support their views. Students also had limited opportunity, or in fact need to, demonstrate their ability to memorize and restate lists of vocabulary.

In addition to the summarizing of indicators of scientific literacy, trends and emerging themes were identified through an analysis and collation of participants’ comments in
relation to the indicators. These themes then provided a way for looking from the data back at the framework for scientific literacy and contributed the headings shaping this chapter’s discussion of conceptions of the nature of science. The conceptions discussed represent the diversity of the group and the highest and lowest levels of scientific literacy. The headings represent the themes that emerged and dominate issues from the participants and as such contributed to reflection on the framework and the manner in which scientific literacy developed.

7.1 **Aims and limitations of science**

There was a dominant view amongst the participants that science could provide a technical solution to the world’s problems and had the potential to improve humanity’s quality of life through the development of new technologies.

*Improving our lifestyle*

The view that science’s purpose was to improve our lifestyle was illustrated by Ingrid who wrote on the post LATU questionnaire, *scientific research allows us to better understand the things that happen around us and in our world. This can enable us to make improvements to our situation and better our way of life.* Jessica’s response also reflected this view. She wrote on the workshop activity that science was *the discovery of new things and inventing technology to make life easier. Improvement of technologies.*

*Technological solutions*

Scientific understandings leading to technological solutions was also a dominant participant view of the purpose of science. For example, Lisa developed the thesis in her LATU essay that science and technology could enable humans to inhabit planets such as Mars. She argued that this could potentially offer solutions to the environmental
degradation caused by over population on Earth: *we are able to use the resources from outer space to help fix our problems*. In addition, *humans are not yet educated and technologically advanced enough to be able to perform these tasks, but we are learning more and more each day and this research could mean the survival of our species on a whole new world*. Lisa did not consider the social context or implications of such research. She did not consider the limitations of terra-forming science but rather viewed it as the technical solution to over population.

Further illustrating the view that science has all the answers was Wendy’s comment made in the LATU diagnostic writing exercise: *it took 20 years to realise this, which is a cause for concern that scientists are not doing their job properly and are wasting money that could be spent on something much more vital for the environment*. This suggests Wendy may have unrealistic expectations of science’s ability to provide knowledge and immediate answers or solutions.

*Ethical implications*

In contrast, there was some awareness of factors that could limit science’s ability to provide technical solutions to all the world’s problems and to improve the quality of life. There was some evidence that participants were considering the possible negative side effects or implications of science. For example, Tess stated in her reading log, *the story teaches us that the unknown and the experimental can be very dangerous, and it needs to be researched very carefully and fully understood before being applied to humans. It teaches us that nature shouldn’t be tampered with and science needs to know its boundaries and it can’t play god*. This is further illustrated by Ingrid who wrote in the workshop activity, *science may not all be good as with it comes [with] moral and ethical implications that need to be considered*. Tess suggested in the workshop
discussion that ethical implications could be regulated by legislation that could actually hinder the progress of science. She said, *a big part of it is ethical and legislative limitations. If the government says no you can’t conduct that type of science in this country then obviously that’s a limitation.*

### 7.2 Scientific knowledge can have a temporary status

Most participants generally accepted scientific knowledge as ‘truth.’ This was usually qualified by the need for ‘proof,’ evidence and repeated research. However, these ideas were generally undeveloped and stated more as a method of science. It should be noted this indicator of scientific literacy had the greatest number of misconceptions. A few participants did, however, perceive scientific knowledge as tentative in nature due to the potential for future research to ‘disprove’ or falsify earlier findings.

*Scientific knowledge is fact or truth*

Wendy’s comment in the workshop discussion illustrates her acceptance of scientific knowledge as fact. She said, *Scientists will try and prove them, to make them facts. I suppose they can hypothesise, but if they can’t prove it then it won’t become a fact at all or it just stays there until someone else can prove it.* This view also continued into her follow up interview; *through experiments a theory can be proven, or not. When it’s proven it becomes scientific knowledge, after numerous tests and experiments it’s definitely true.* When Lisa was asked in the interview if the product of scientific research could be accepted as fact she replied, *if it’s been researched thoroughly and proven, then yes.* She expanded what she meant by ‘thoroughly researched’ with, *if it’s been done in depth and has been tested several times.* Doug’s interview comment was consistent with Lisa’s view. He said, *scientific knowledge can be accepted as truth when*
there is enough statistical evidence or proof to show it does what it claims and it has been around for a couple of years to prove and establish itself.

In the workshop, Ingrid responded to the question, can scientific knowledge be accepted as fact or truth with, *if it’s been proven again and again and again then it can because it becomes law*. In the follow up interview Ingrid appeared to have become more aware of the tentative nature of research findings but still held to the view of scientific knowledge as fact. She said, *there’s always been certain cases where they can disprove certain theories, but in most cases it’s accepted as truth, especially when it’s backed up by studies.*

Hazel’s interview comment also illustrated the conception of scientific knowledge as truth. She was, however, clearly struggling to equate two diverse disciplinary perspectives of truth and proof:

Truth in science is something we can test that will give you something that explains how something works and you can test and prove that it is so. Truth in a sense is as much limited by the limitations of the experiment as by anything else. I suppose I come from two different perspectives. I come from science and also doing arts – an arts degree where nothing is true and it’s all manufactured so that I find it hard to juggle the two concepts in my head but science generally is something that if you can prove it and it can be reproducible and also be accepted as in a sense a given or as a theory or as a way of explaining the world then it holds true.
Inconsistent conceptions about the status of scientific knowledge

Todd appeared to have developed a degree of uncertainty in relation to the status of scientific knowledge. For example, on the interview worksheet Todd wrote, *if other people conduct the same or similar experiments and they get similar findings then knowledge could be accepted as fact.* However, in discussion when asked to explain this view he said, *It can’t be accepted as truth as people are always redoing the experiments and finding that they were wrong, so it’s not true It’s just current knowledge. Things are never actually proved; some things are just proved wrong. Science is always changing.*

Marie’s thinking also evolved during her participation in the research. She began in the workshop discussion by saying: *I think an idea can be proven, with enough research you can prove.* However, later in the follow up interview Marie said, *scientific knowledge can be proven but I don’t think it’s definite as there is always room for something to go wrong.*

Scientific knowledge is tentative

Newton’s discussion of the nature of scientific knowledge in the follow up interview showed an understanding of the tentative nature of scientific knowledge. For example, he said, *someone finds something new not long after a certain discovery and it gets modified and changed. Whatever is discovered always has a question mark over it because it’s always tested and changed in some way so there’s nothing set in concrete.*

Further illustrating the tentative nature of scientific knowledge, Fiona said in the workshop discussion, *can you ever prove it? There might be one exception that crops up in a few years that ruins everything that has ever been thought about.* In the follow up interview Fiona said,
I don’t think you can really confirm anything straight away, especially in science, as it’s an ongoing thing. Even if it’s been proven lots of times, there still may be an exception. What if something else is discovered down the track that falsifies everything which had been accepted as the truth?

Jane expressed in the follow up interview that she did not believe anything could ever be tested again in exactly the same way. Hence the findings of any research were limited. She explained, *I don’t believe anything can ever be tested again and get exactly the same results so it can be one truth but not the whole truth.*

### 7.3 The continuing nature of scientific research

There was limited awareness amongst participants of how critical questioning progresses science. Participants had a procedural focus emphasising aspects of scientific method such as repeated trials and more experiments for greater accuracy or evidence for accepting scientific knowledge.

*Repeated experimental trials*

Wendy’s response to the news brief on Questionnaire 1 suggested she had an awareness of the continuing nature of scientific research and repeated experimental trials. She said, *testing the experiment again on a number of different people so that the conclusions can be more accurate.* Newton also demonstrated an awareness of science progressing through repeated research. He described research on the interview worksheets as, *testing to shed light, re-examination, re-configuration.*
The work of other researchers

Other participants focussed on the replication of research by other scientists working in the same or similar fields. For example, Fiona wrote on her workshop activity, *you would want more information on other experiments that have been conducted on electromagnetic fields and other opinions from scientists and the public who are victims of follicle damage.* On the follow up interview worksheet Fiona also suggested evaluating the researchers’ conclusion by *finding out about previous research into brain injuries.*

Hazel’s comments further considered the repeated nature of scientific research by exploring the opinions of other researchers and perhaps generating critical questioning:

> I would want to go and talk to other people in the field, someone who is more expert in the field and see how they view such claims. Whether they thought they were completely impossible or if there was other work sort of backing it up. Get a sense of what they’ve done and what else there is out there to support what they are trying to get at.

Tentative theories

An understanding of the tentative nature of a theory and the potential for new research to result in the rejecting of a theory was evident amongst most participants. However, discussion on this topic was generally limited and there was evidence amongst some of a lack of confidence in their understanding of the term theory. For example, Marie said in the workshop discussion, *scientific theory is something that is yet to be proven. I don’t really know.* The tentative nature of a theory was also illustrated by Ingrid’s follow up interview comment: *a theory is an idea that comes up, gets studied and researched. It’s not exactly proven but just a theory and ideas, which everyone goes by.*
Other participants suggested the view that a theory had been proven by evidence but could be disproved by further experiments. This is illustrated by Tess’ workshop comment: a scientific theory is accepted because someone has proven it, this is why it happens. Its not wrong until someone disproves it; scientific theory is right until proven wrong. Hazel further developed the concept of a theory by suggesting a theory was a way of making sense of knowledge. In the workshop discussion she said, the study of knowledge gets interrupted by changes in modern ideas. Evolution was the main theory and people just disregarded religious based theories and had fundamental shifts.

7.4 The dynamic and changing nature of scientific knowledge

There were frequent misconceptions evident in participants’ responses in relation to the development and evolution of science and scientific knowledge. Participants frequently expressed the view that science was based on a steadily accumulated body of knowledge, which gradually grew as new knowledge was discovered. There was limited awareness of science being dynamic in nature and subjected to revolutions in understanding that result in shifts in the discipline’s dominant paradigms.

Accumulated knowledge

The conception of science as static and based on accumulated knowledge is well illustrated by Fiona’s response to the purpose of science on Questionnaire 2. She wrote, to find out more about the unknown topics and to add to what is already known, confirming it and leading to theories. In the interview she added, science has been like a growing body of information that you sort of build onto. Ingrid’s interview response to how has scientific knowledge developed also illustrates this conception. She said, all the
findings over the years and research that’s been done have contributed to our knowledge today.

**Changing body of knowledge**

There was some awareness amongst participants of scientific knowledge changing as a result of new research findings ‘disproving’ prior knowledge. For example, in her follow up interview Hazel said, *I don’t think it’s (science) a static body of knowledge because we learn new things and that changes our viewpoint on things, so it’s constantly developing.* Ingrid’s responded to the question in the workshop, is scientific knowledge static also illustrates this conception: *it’s always changing. Scientists had all these things they thought were true but they’ve been proven wrong since then. The things we are discovering today are becoming more accurate, probably more likely not to be disproved in the future.*

**7.5 The role of creativity and imagination in science**

The participants were all aware of creativity and imagination influencing the development of scientific knowledge. The awareness demonstrated by this group may not be typical of the general First Year university student population as their participation in LATU, which develops generic learning skills within the context of science fiction, would have heightened their awareness of creativity in science. There was however, a range of views in relation to the way creativity intersected with scientific methods.

*Thinking of new ways*

Primarily, creativity was presented as essential for thinking of new ways of solving problems, designing experiments or devising new things. For example, in the workshop
discussion Todd said, *science is about gathering knowledge through the use of a logical method*. He described a logical method as, *doing things step by step and making sure you don’t let anything get by*. He later added, *scientists see a problem or something and they need to be creative to think of a theory that can explain it*. In the follow up interview Todd said, *creativity allows scientists to think of new ways to solve problems and having different ways of looking at things*.

Wendy’s LATU exam also illustrated this perspective. She wrote, *creativity allows scientists to think of new advancements in science. Without imagination scientists couldn’t think of new ways to improve society and science could not advance*. On a workshop activity Wendy described science as *involving experimentation and research*. She also included the terms *imagination and creativity*. When discussing this activity she added, *it involves experimentation, discoveries and the imagination to think up new things*.

Fiona further developed this perspective by introducing the idea that there was a two way interaction between creativity and scientific knowledge, with one informing the other. On the workshop activity Fiona wrote, *imagination stimulates the process of finding facts and knowledge*. She later added during discussion that *scientific knowledge comes from imagination and vice versa*. *Having creativity helps to solve new problems. You can’t just follow what the previous people have done. You’ve got to think of a different way that you can attempt to fix things*. In the follow up interview Fiona said, *scientists have to be creative otherwise they would stick to what is already known and what’s already gone before*.
Science fiction, a creative vehicle for exploring possibilities

Science fiction was viewed as a creative vehicle for exploring the possibilities and thinking outside the constraints of the present. This view was illustrated by Newton on his LATU exam. He wrote, *science fiction inspires a creative approach to science and often discoveries are made by thinking outside the realms of possibility.* Jessica also expressed this view on her LATU exam. She wrote, *science fiction allows the reader to see the possibilities in science and to imagine what could possibly happen, it explores new areas in science.*

Doug built on the role of science fiction for exploring possibilities by suggesting that in some cases what was once science fiction had become a reality. He said, *it does take creativity and imagination to devise new things. Science fiction is obviously good for that because quite a few things which were originally science fiction are now true, they have happened.*

Scientific methods limit creative potential

Jane’s LATU exam short answer response to the role of science fiction in science suggested she viewed scientific method as devoid of creativity. She viewed fictional writing as a way of expanding this evidence-bound approach to research. She stated, *the ideas that many scientists have are limited to evidence and experimentation so science fiction’s role is to expand the imagination and the possibilities.* Jane’s interview workshop description of science had discovery as a central and connecting theme. She stated, *science is a way of thinking, a structure that leads to the discovery of how material things occur.* She again focussed on scientific method stating that science works with observation, conjecture, experiments, set steps to discovery. While discussing her response in the interview Jane related viewing creativity as important to
the progress of science. She explained that there has to be a little spark of creativity, like an inspiration to continue.

Tess clearly perceived scientific methods as inhibiting scientists’ creative potential. For example, in the reading log Tess wrote, Scientists may be too mechanical having lost their creativity; perhaps because he was too caught up in the technicalities and not the creativity of science.

7.6 The nature of scientific methods

Participants had participated in the development of a group project proposal in LATU that had involved principles of scientific method and controlled experimentation. This experience would have impacted on the participants’ ability to identify, discuss and propose aspects of controlled scientific experiments. The evidence of this amongst participants varied but the majority did raise some issues related to control procedures, groups or variables when engaging with reports of scientific research in news briefs. The discussion of scientific methods was, however, often limited to procedural terminology and ideas were left undeveloped.

Limited procedural understanding of controlled experiments.

Todd’s requests for extra information about the news brief on Questionnaire 1 suggested some understanding of scientific method as he considered sample size and variables that could have affected the findings. These included the amount of wine drunk and how many of them drank wine. His workshop activity requests for information to evaluate the research reported in his chosen news brief were more limited and did not reflect a procedural understanding of scientific method. He asked about the relationships between mice’s central cavities and humans. Limited engagement with scientific
procedures was also evident in his ideas for testing the researcher’s conclusion. He wrote, *do more experiments on mouse fertility with emf, comparing birth rates and survey some humans about the amount of appliances in their home and compare their birth rates and fertility problems.*

Similarly, Jane used procedural terminology when describing scientific research but without developing the concepts. In the workshop discussion she explained that scientific work was *a rigid form due to hypothesis, experimenting and conclusions that rely on statistics and number evidence.* In response to her chosen news brief in the workshop Jane made a limited procedural level request for information about the research design. She asked *what and how experiments have been conducted to come to this conclusion.* She did not consider ways of testing research conclusions through controlled experiments.

In addition, Wendy did not consider aspects of controlled experiments. Her proposal for testing the researchers’ conclusion in the follow up interview, did not suggest she had a functional understanding of scientific methods or controlled experimentation. Her ideas were limited to sample sizes. She stated *I would get 20 to 25 subjects suffering from different brain injuries or disease and test how they react over a period of 3-4 years to see if they actually improve.*

*Controlled scientific experiment*

On the follow up interview worksheet Lisa showed some procedural level understanding in her response to how she would test the researchers’ conclusion stated in the news brief. The following quote illustrates her appreciation of controlled experiments. She
wrote, *see what was kept the same and then different, compare means for the control and test group.*

On the workshop activity Jessica raised a range of issues related to scientific methods and controlled experiments. She identified variables that would need to be controlled in order to test a hypothesis, such as *age, gender and race.* She also stated that a study would require *a large number of patients.* She identified a question that could be investigated scientifically: *grow damaged brain cells in a culture and then expose them to the protein and see what happens.*

Ingrid’s requests for extra information about the research reported in the news brief used in the workshop suggest some understanding of the need to control variables. She wrote, *information on the mice such as age and health. Other factors that may affect results.* She also demonstrated some understanding of the need for a control group. She wrote, *test different levels of electromagnetic fields on each of the organisms and keep controls, animals not exposed to the electro fields. Compare controls and tests to see which have a higher proportion.* These developing understandings were not carried through to her post LATU activity. She stated she would test the researchers’ conclusion, *carry out studies on patients once a way to use the protein had been developed. Observe and study the protein in the brain of people suffering injuries.*

In the workshop activity Fiona described a means for testing the researchers’ conclusion that demonstrated her ability to propose a controlled scientific experiment. She wrote, *take a group of women, a random sample and expose them to electromagnetic fields. Have one group exposed to high levels, another to medium and a control with no exposure. Have the same conditions surrounding each group.*
In the follow up interview Hazel made the following comments when discussing the credibility of research reported in news brief. She said,

I thought it seemed fair because they mentioned in here that they had done controlled experiments and it was laboratory conditions and also I like the fact that they used a control group –to discount the psychological effects. If people just thought this will help my memory and I will have done better then that’s the whole placebo effect.

7.7 Scientists study a world in which they are a part

The participants generally demonstrated a growing appreciation for subjectivity in science. The methods of science and the rigour of scientific experiments were described as an attempt to be as objective as possible but essentially science was perceived as a human activity and as such influenced by factors such as prior learning, values and expectations.

The human element

In the follow up interview, Todd stated having recognised the human element in research and hence the limitations to scientific objectivity. He said, *science tries as hard as it can to be objective but nothing can be objective if a person is doing it. They will always put their views into it and find what they want to find.* In the interview Wendy also identified various human factors that she believed could influence research. For example, *the way a scientist was brought up, where they were educated. It depends on everything, their beliefs and what they were taught.* She added, *scientists probably aim to be objective but I’m sure that eventually it becomes subjective. That’s because each
person usually will have a personal interest or motivation that they may try to hide but it will eventually come out.

The idea that scientists try to suppress their subjective tendencies was also raised by Jane in her interview. Clearly she did not accept that scientific research could be conducted in a totally objective manner. She stated, *I don’t think anything can be truly objective, everybody has a view, always unconscious, it’s always an interpretation.*

*Prior learning and expectations affect objectivity*

Some participants believed scientists would ‘see’ what they expect to find as a result of prior learning which caused them to ignore or consider differences as error. For example, in the workshop discussion Fiona said, *scientists try to be objective but everyone has their own biases and conditioning in the way they’ve been brought up so there are some things that they can never be objective about.* She later added, *what’s been discovered in the past may mean scientists are not even looking at what’s actually there to begin with. Maybe they’re thinking this can’t be right, as this is all that can happen. They could be getting into one frame of mind and missing some new observation that could be helpful.* Fiona maintained a consistent perspective of objectivity in science throughout the research. In her follow up interview she said, *scientists couldn’t really be objective all of the time, especially with experiments. Set research has been done before and people tend to think this is what is supposed to happen, this is what’s going to happen and if it doesn’t happen like that you’ve stuffed it up.*

Another example came from Jessica in the workshop discussion. She said, *most scientists try to be objective but the fact that they are human and they have feelings*
means they can’t do it all the time. In the follow up interview Jessica suggested scientists were not always researching objectively. She said they’d want to get results, when starting there’s often a result they want, so they are going to try and get that result rather than something else.

Furthermore, Marie suggested in her interview that pressure from an employer could focus a scientist’s effort on finding a particular result and limit their ability to be objective. She said, scientists aren’t always objective as they work to find what the company wants them to try and find. Their values and beliefs would also affect their work, like what they want to see so they try to find it. They go to find it because it’s their belief so they want to follow that belief.

Methods of science contribute a degree of objectivity

Other participants viewed the methods of science as contributing a degree of objectivity. For example, on the workshop activity Hazel defined science as, objective, reasoned, interested observation and discovery of all things pertaining to the world around us. Later when discussing objectivity in science Hazel said, I think there is a certain sense of objectivity. I suppose they are meant to be objective with data and measurements. I think they try to be objective by going through a scientific method, but there is sort of this sense that there is something you expect and your expectations could ruin your objectivity. Hazel further explained her view of the nature of science experiments in the interview. She said,

If you’re trying to prove something you want it to be reproducible data and you want someone else on the other side of the board to be able to reproduce the results of your experiment. So I think science is quite stringent in experimental design as you want to try and cut out as much of the errors creeping in as you
Hazel’s view of objectivity in science developed over the research period. She became increasingly aware of subjectivity in science. For example, in the follow up interview she said there are limitations to how objectively we can prove something, so while we can say this is true we’ve always got to be aware that for science it is subjective and we could find out something new that could completely turn it on its head or it could change. She later added in the interview,

Science can’t say that it is objective because your beliefs, your values impinge on everything. But we try and that’s one of the reasons, I suppose, they’re so stringent in the experiments. You try to make it as foolproof as you can but you’re never going to quite get there because you’re always going to look at things from your own perspective which is as much culturally determined as from scientific knowledge. For example, in experiments when you are describing colour; colour is such a subjective thing. There is no objective way to measure colour or stuff like that so it is subjective to a certain extent.

In contrast, a few participants held strongly to the view that science was objective. For example, Doug said in his interview, in most cases science has been done objectively throughout the years, textbooks and experiments with each step – methods, aim, and procedures. Newton further illustrated this perspective in his interview. He stated, because they are so objective they don’t really have the capacity to take on other beliefs and values other than their own. They are very objective about the way they think and perform their experiments and how they communicate with other people.
7.8 Scientists’ observations of the world are made from a personal perspective

Closely linked to participants’ perspective of objectivity in science are their views on the factors that can influence scientists’ observations of the world in which they live and work. Prior learning and the impact it has on scientists’ expectations for an experiment has been considered by participants as influencing the degree of objectivity in science.

*Personal beliefs and values*

In addition, some participants raised personal beliefs, values and childhood experiences as factors that could influence scientists’ observations. For example, in the workshop interview Todd stated that scientists’ interpretation of evidence could be influenced by personal beliefs. He said, *they find what they expect to find in the experiment or what they want to find in the experiment. If they want to prove something wrong then they’ll prove it wrong.* In the follow up interview Todd listed the following factors as influencing a scientist’s observations, *how they have been brought up or what they have learnt before, their values.*

This is further illustrated by Ingrid and Hazel. In the follow up interview Ingrid said, *everyone has been raised differently and grow up with certain values that will always influence them in some way. There will always be thoughts in the back of their mind.* On the workshop activity Hazel expanded on her definition of science to include, *strong human element, views of science constrained by own inherent views, biases and beliefs.*

7.9 Professional attributes and standards of the scientific community

Most participants continued to hold stereotypical images of scientists despite the attempt made in LATU to deconstruct these views and normalise scientists. Scientists were often presented by the participants as having extremes in their personality. They were
presented as intelligent, work-driven individuals but participants did not accept unconditionally that scientists were open minded, ethical and moral in their work. It appeared this was dependent on the individual scientist and external influences such as the media, employment criteria, and competition for funding. Funding pressures and the need to deliver economically viable outcomes were suggested as reasons scientists may at times “break the rules.”

The participants’ drawings of a scientist contained multiple stereotypical indicators such as male, lab coat, glasses and wild hair. Scientists were consistently depicted as a male with only a few exceptions. Interestingly, participants who presented non-stereotypical images were relating to a personal role model of a scientist such as a family member, lecturer or medical consultant. One participant who was studying in a science course depicted herself as the scientist.

**Stereotypical images of scientists**

Participants’ stereotypical images of scientists were determined by DAST- draw a scientist test indicators developed by Chambers and cited by Schibeci (2002). Participants’ included in some way all of these indicators, i.e., Coat, eyeglasses, facial hair, symbols of research, knowledge or technology, male, pens/pencils in pocket and unkempt appearance. Examples of the participants’ stereotypical images of a scientist follow.

Todd’s workshop drawing was an example of a fairly stereotypical image of a scientist. It included indicators such as male, unkempt appearance, lab coat and pens in the pocket. He described the scientist as *good* and *self-important*. On the interview worksheet he described the scientist as a *research specialist, smart and honest.*
Wendy’s workshop drawing of a scientist also showed various stereotypical indicators. These included male, unkempt appearance, lab coat, facial hair, test tube, pens in pocket, glasses, and lab coat. In addition to these indicators the terms she surrounded her drawing with included *scary, crazy, genius, failures, success, good and bad.*

Lisa’s workshop drawing of a scientist included male, bald, facial hair and lab coat. She included the descriptors *experiments, research, chemical trials, explosions, ideas, friendly, unique and smart.* In discussion she made the comment that the scientist was *a wacky old guy with lots of ideas, which may be a little far fetched.* On the follow up interview worksheet she described a scientist as *creative, intelligent, imaginative, eccentric and open-minded.*

Jane’s workshop drawing of a scientist included five stereotypical indicators. These included male, unkempt appearance, facial hair, eyeglasses and symbols of knowledge. She later explained knowing that her representation of a scientist was stereotypical but that she believed that was still the norm. In response she said, *it’s just how I see it.* Surrounding her drawing was a description of scientists’ typical personality and behaviour. Her description included *smart, practical, busy learning all the time, intensely interested* and that work *takes over their life.* In discussion she also added that a scientist was *somebody who is really passionate about what they do.*

In the workshop activity Ingrid drew a stereotypical view of a scientist. This included five stereotypical indicators, which were lab coat, male, test tub, glasses, and wild hair. She described the scientist’s approach to his work with, *long hours in the lab, shows lots of hard work, discovering new formulas or new scientific laws, lots of explosions from chemical reactions.*
Scientists are ‘normal’ people

In the follow up interview Newton explained having deliberately avoided stereotyping his representation of a scientist. He drew a female with long hair, glasses and wearing a dress. In addition he surrounded his picture with the following descriptors: objective, accurate, creative, methodical, conscientious, ethical, futuristic, inquisitive and essential. These descriptors suggest he has confidence in scientists and their professional standards and ethical approach to their work.

In the workshop activity Marie represented a scientist in a non-stereotypical manner. Her scientist was a female wearing a dress. Her descriptors included, normal person, well read, knowledgeable, friendly, no coats, family member, father or mother. Marie’s drawing of a scientist was again non stereotypical on the interview worksheet. She drew a female wearing a dress and included these descriptors, genetics, researcher, abnormal chromosomes and their effects, family/children, young/old.

Hazel’s drawing of a scientist only contained two stereotypical indicators and these were male and wearing glasses. Her descriptors included complex, balance, preoccupied, technical, underpaid, under funded, and undervalued. Later on the interview worksheet Hazel drew a picture of a scientist with no stereotypical indicators. She drew a female with long hair tied up, wearing jeans, a t-shirt and running shoes. Her scientist had a back- pack bag containing a lab coat and she was holding a microphone. Hazel surrounded her drawing with the words, communication, practical, breaking down stereotypes, hands-on, curious, exciting, passionate, varied, busy, hard but rewarding, mind stretching.
Scientists open minded or not?

Participants related that scientists were fairly closed minded in their approach to their work and its interaction with society. Participants presented scientists as narrowly focused on their own research, disconnected from other scientists and society generally. Illustrating this was Newton who viewed scientists as narrow in their disciplinary focus. For example, *scientists are always basically concerned with their one avenue of research. They can’t afford to be open minded as they need to focus totally on this one line of research which hopefully leads to a result they can publish.* In the follow up interview Newton viewed scientists as socially disconnected. This was evident in his use of descriptors such as, *isolated, non-social,* and *results driven.* He described scientists as *stuck in their own disciplines, not having much relationship with each other.*

Marie also suggested that scientists were not always open minded. She said in the workshop discussion, *if they are working for example on a new drug they are usually only focussed on getting the drug out, getting all the tests done, getting it out as quickly and as productively as possible.* Jane’s interview comment expands on this focussed view of research. She said, *discoveries never really link and science is at times isolated and narrow minded.*

In contrast, there were participants who suggested scientists were open minded to new ideas, alternative research and the unknown. For example in the workshop interview Wendy said, *they have to be open minded otherwise they wouldn’t be using or testing new theories.* Tess’ workshop comment further illustrates the view that scientists are open minded to new ideas. She said, *scientists would have to be open to new ideas, otherwise there’d be nothing left to research.* Ingrid went on to explain in her follow up
interview that scientists are open-minded. She said, they don’t know what their studies are going to find so they have to be open-minded to any results.

Morals, ethics and breaking the ‘rules’

Participants consistently took the view that there would be diversity amongst scientists just as there would be amongst any group of people and as such the moral and ethical standards of scientists would vary between individuals. For example, Todd said in the follow up interview moral and ethical standards depend on individual scientists, I don’t think you should make a generalisation. Ingrid’s workshop comment also illustrated this position. She said, probably depends on the scientist, for example environmental scientists are researching stuff for the good of the environment and humanity so they would be moral and ethical.

Some participants suggested factors such as the media or employment selection criteria would make scientists accountable and encourage ethical and moral conduct For example, in the follow up interview Jessica suggested scientists had to act ethically because of the accountability imposed by the media. She said, they have to be ethical because a lot of what is happening is covered by the media and people are going to question if they should be doing this. They are going to get this backlash from those who are viewing the news. Furthermore, in the interview Ingrid said, if a scientist didn’t have standards then they wouldn’t have got the job in the first place. They have certain methods and an understanding that there would be certain standards to follow.

Doug agreed that most scientists would be ethical and moral but that funding pressures and the need to get results could push some to take unethical steps. He said in the workshop,
Most act ethically but there are always a couple of rotten apples to spoil the bunch. They try so hard to get government grants and then work their whole lives towards something, they get the idea they’re being ripped off, exploited. In the follow up interview he said, there could be scientists out there that might take certain unethical or immoral steps just to get the right result. They have standards to uphold but the question is whether all conform to those standards. Sometimes to get the job done they may have to skip over the line.

Newton also related in the workshop discussion, thinking that funding pressures could result in scientists *breaking rules and forging ahead without regulations*. He also suggested that scientists *are being manipulated by the value of the dollar and commercial prospects*. Fiona also suggested in her interview that pressure on scientists to achieve end results could result in unethical actions. She said, *if scientists were doing something worldwide that everyone was going to find out about they would have to be ethical but a lot of the time they only want to go for something and find out what happens and get the end result without considering the ethics or being open minded.*

*Scientists can, but should they?*

Some participants expressed concern for scientists’ inability to see the potential social implications of their work. It was suggested that scientists should give consideration to possible future scenarios for their research and consider not just what can be done but what should be done. For example, in the LATU essay Wendy posed the question, *is it ethically and socially right to cause a degeneration of our natural environment by using cloning to increase the human population when there is no need to create more life?* She added, *scientists are looking at what they can do rather than what they should do.*
Furthermore, in the follow up interview Jane raised the idea that scientists are not always forward thinking enough to foresee the possible uses for their discoveries. She gave as an example the development of the atomic bomb. She said, *it doesn’t come across as being very open-minded and looking beyond what is being studied or looking out to the real world and seeing what’s going to happen.* Jane did not believe it was the scientist who had been immoral or unethical but rather the people who decided to use the scientific knowledge to build the atomic bomb. She explained *it may not be the scientists that haven’t been moral; it’s just how it’s been dealt with outside of that and taken advantage of.* She did add, however, that she expected scientists to look to the future and consider the possible implications of their work. She stated, *you can’t predict the future but just have a consciousness of what you are doing.*

Hazel also suggested in the workshop discussion that scientists should consider the implications of their work. She said, *you (scientists) can be open minded but then you have to look at the consequences of your actions. Like if you say this is something I can do and then there are consequences in another direction you have to consider the social effects and the ethics involved.*

The following chapter explores how these conceptions of the nature of science impact on the role participants see science taking in their personal lives and society generally. Participants’ views on the interaction of science with society reflected in many ways their conceptions of the nature of science.
CHAPTER EIGHT  PARTICIPANTS’ CONCEPTIONS OF THE 
INTERACTION OF SCIENCE WITH SOCIETY

This chapter contains participants’ views on the interaction of science with society and also considers the participants’ engagement with science concepts emerging in social contexts such as the daily newspaper.

8.1 Science’s role in society

Participants essentially viewed science as providing the knowledge and technical solutions required to solve social and environmental problems ultimately contributed to by the world’s increasing population. This is illustrated by Ingrid’s writing in her LATU essay. She wrote, there is a trend that can be seen between the advancement of technology and the demise of our natural planet. As our population increases exponentially, inversely our ecosystems deteriorate. These problems will only continue to grow as our population grows. Science was presented by participants generally as integral to continued development, improvement of life and the solution to the demise of the planet. For example, Tess wrote on an interview activity, science is important to the further development and sustainability of the world and us.

There was, however, a range in participants’ views on the extent of sciences’ role in social debate and the solving of societal problems. Some suggested science could provide technical solutions, while others believed science could contribute information to debate but not final answers. There was evidence that some believed science contributed to the creation rather than the solution of social and environmental problems.
Science has solutions

Some participants presented science as the technical answer or solution to societal problems. Science would provide the knowledge and contribute to the development of technologies for the improvement of life and for resolving problems. For example, in the workshop, Wendy explained science’s role in society as to explain what’s happening, the basic facts to people. She stated thinking the purpose of scientific research generally was to advance society in life, health, knowledge and happiness. This perspective was further illustrated by Doug in the workshop. He said, scientists try to provide solutions to the common problems affecting society, like new cures for diseases and new technologies.

Examples of science solutions to problems and the improvement of life were given by various participants. For example, in the follow up interview Doug said, science can help increase the efficiency and effectiveness of water management and discover new ways, like water recycling, changing salt water to fresh. Everyday life could be improved through science. In a few years technology will become more readily available and cheaper so we’ll all be able to benefit from it. Marie also suggested in her interview that science was the art of discovering and researching in the domains of medicine, technology and the environment in order to advance in the world. Finding new treatments, saving the environments ozone, curing diseases, finding out e.g., does sunscreen work? Marie developed in more detail her ideas about cloning and its potential contribution to society. She wrote in her reading log, Cloning will be able to change many lives for the better. Prevent and cure diseases, organ transplants with no anti-rejection drugs or the loss of life to save another.
Another example discussed in more depth was water management in drought areas. Jessica said in her interview, *I don’t think there is a way to exactly create water without using science. Science can help find ways to conserve it like, shower heads to reduce water use, how much to put on the gardens and developing fertilizers that help to conserve water so we don’t need to water as much.* Furthermore, Fiona suggested in her interview that science could provide answers to important questions about water management. She said *more research on what we could do if we ran out of water and where we are going next. We could find out more about global warming and how it is going to have an impact, how the environment is changing and what effect it has on rainfall.* Hazel also suggested that science would provide the technology and structure for addressing water management problems. In the follow up interview she said, *science can contribute to our water management, for example using grey water in the gardens. The technology is there that can contribute to better water management. Technology does play a part in putting a structure in place, saying what we can do with it.*

Newton also viewed scientists as having the answers to social problems and issues. He stated in the workshop discussion that *science has answers to social debate, even if we contest it or are horrified by what is coming out.* He explained his confidence in scientists’ answers to debates by; *they can back up their ideas and their facts with scientific confirmation.* For Newton, any debate or uncertainty was based on society not necessarily liking the solution. For example, *a scientific discovery may be a social problem but it is just a scientific fact getting social implications.* He later said in the follow up interview, *you can look to the scientific facts and improve life through technology.*

*Science provides solutions but then it’s up to society as to how they are implemented*
Scientific ideas or resulting technologies potentially offer solutions to societal problems or endeavours. Yet some participants did not see the solution as one dimensional. The answer or resolution would depend on the interaction of the community members with the offered science. It was suggested that science provided information to the public but the answer was dependent on the impact of people’s beliefs and values on their uptake of the science. For example, Ingrid said, *science may be able to fix the problems but if people need to change or go along with the scientific fix then they may not be willing to do that.* In the follow up interview she said, *scientific research can warn the public, help them make decisions in their lives and make them more aware of what’s happening around them. Science can give you information but not the answers as answers come down to what the people believe and their values.*

Furthermore, scientists cannot solve environmental problems alone. It is important for the general community to first recognise the problem and be prepared to contribute their support to the potential solution. In Fiona’s LATU diagnostic writing activity she wrote, *it is not only up to the scientists to come up with new and helpful solutions to the problems in our environment but more importantly for the general community to recognise how serious these problems are and do their bit to help because otherwise the problems cannot be totally banished.* Todd also suggested people’s willingness to engage with science and make necessary changes was integral to the solution of environmental problems. In the workshop interview Todd commented, *people think of science as developing new technologies to fix environmental problems but it could be just that science discovers that the carbon dioxide from cars makes the greenhouse, so you shouldn’t drive your car. Science could fix the problem if people would stop driving their cars. You can tell people the solution but whether they act on it is another thing.*
Ingrid presented the view that science could provide the facts but it was up to the people to decide on the answer. In addition, she introduced the idea that new technologies may in themselves create political and societal problems. For example, on a workshop activity Ingrid wrote, *science is concerned with environmental issues. It may be used to help environmental preservation.* She then explained, *discoveries can lead to new technologies being develop, but they have political problems or social problems on whether to use it or not.* Later in the discussion she said, *I don’t really think science can give you the answer. It gives you the facts, but it’s really people who have to decide on the answer.*

*Science is only one part of any solution*

Participants continued to recognise the contribution scientific knowledge could make to the solution of social and environmental problems. But some suggested the realisation of science based solutions could only occur through management of social, ethical, religious and political factors. For example, Jane wrote in her LATU essay on the Kyoto Protocol, *it arose from current scientific knowledge and draws from concerns for the future of the Earth, the environment and life.* She recognised the role of scientific knowledge in the international debate surrounding the protocol but also suggested that it could only be realised by managing social influences. She stated, *the consequences of the protocol could be realised through social, ethical and political management.*

Clearly Jane did not think scientists could bring final answers to matters of public debate and in addition she suggested that science could potentially add to social tension. She stated, *science could improve debate but it could also create tension between different groups of people or between religions.* Fiona also raised religion as another dimension to the social debate surrounding the implementation of science based solutions or
endeavours. She said in the workshop discussion, *science is just one possible means of explaining things but it is not the only one, especially for people who are religious.* Tess presented an extreme view on science’s role in social debate by separating science from society. She said in the workshop discussion, *it’s a social debate, not a scientific debate. You shouldn’t really involve science. That’s like trying to solve something scientifically that’s social; that doesn’t really work.*

Governments and politics were also presented as integral to the implementation or realization of any science based solution or endeavour. It was suggested governments control the direction of science research through funding and then the implementation of its products as they made the decisions and informed the public. This view was presented by Todd in his follow up interview. He said, *science can make ways to purify gray water cheaply so we could used it on the gardens or they could research into possible bad effects gray water could have on the soil. Then the government could tell everyone to use it.* Later when discussing genetically modified products he said, *I don’t know if you can get a definitive answer there. Scientists can provide both sides of the argument and with a bit of knowledge you can work it out for yourself. Politicians have to make the decisions, scientists can’t. Politicians should get lots of scientists’ opinions.*

Newton further developed this thinking on the intersection of politics with science in his follow up interview. He strongly held the view that scientific research was influenced by politics and that the political agenda may not be in the best long-term interest of humanity. He stated, *scientific research is influenced by which way the government wants the project to run. It’s always with an outcome that the public will accept, that benefits politicians and governments.*
Hazel demonstrated sophisticated thinking about the role governments and politics could play in the achievement of sustainable development informed by science. She demonstrated awareness of the impact diverse international social conditions and living standards could have on governments’ and individuals’ willingness to make social changes called for by science in order to achieve sustainable management of the global commons. In her reading log Hazel wrote,

the author didn’t engage with the population increases occurring in the third world. Perhaps if their quality of life was improved so that there were lower infant mortality rates and they were taught about birth control, we would be able to have a more active global approach on the population problem and a sustainable future. While I accept that the first world’s standards of living are to blame for the depletion of resources I don’t think overpopulation can be resolved without ensuring that all global communities first of all are living above the poverty line and so can survive in the short term.

It was further suggested that governments and communities need to work towards the common good. However, when faced with required social change people act as individuals unprepared or unwilling to pay any social cost. Hazel wrote in her essay,

the decisions that must be made in environmental management are clear but from the perspective of society what social costs must be paid? Of the greatest concern is that people when faced with social change, will invariably behave as individuals. This is perilous when global situations like climate change require communities to work towards the common good. By adopting this mind set of an individual or even the government of a nation acting as an individual they can justify their continued and even increasing greenhouse gas emissions in the best interests of their social welfare. Hence from this perspective many individuals
would reject the target cuts put forward by science as having too great a social impact and risk on their welfare.

Hazel presented the view that individuals were not receptive to science that threatened their social privilege and had a social cost. The unwillingness of political systems and individuals to change may prevent the implementation of science supporting the sustainable management of global commons. In conclusion to her LATU essay she wrote,

the establishment of a sustainable atmosphere would require some societal change as individuals are not receptive to science that threatens their social welfare. In the short term the unwillingness of political systems and individuals to change may thwart efforts to establish successful environmental management of the global commons of the atmosphere. In the long term more intergovernmental cooperation and peoples’ realisation that the atmosphere is not an unlimited resource will force governments to make a firm choice about adapting to global climate change.

Science may not be the answer

Hazel like others raised some hesitation that science had the ability to provide technical solutions to world problems caused by the continued growth of the human population. She suggested holding such a view could even be racial arrogance. For example, in her reading log Hazel wrote, I had never considered this, which probably reflects our race’s arrogance that we are the superior life form on the planet and that our science and technology will solve many of the problems we face. She later wrote in her reading log, just because the Universe seems limitless doesn’t mean this gives us some ethical right
to exploit it as much as we can or doesn’t mean our science will always be able to triumph over its problems.

Other participants raised the potential for implemented science based solutions to have detrimental side effects or a negative long term impact. It was suggested that these solutions may be a quick fix that isn’t sustainable or could even create more problems than they solve. For example, Fiona said in the workshop discussion, scientists do develop things that aid them at the present moment and maybe in the long term but it doesn’t necessarily help society, especially the environment or pollution problems. Wendy’s comments also illustrate this view. She described science in the workshop as including environmental problems like ozone depletion, desalination and land degradation. She went on to explain, science is sometimes used as a quick fix to environmental problems. They’re not always thought about so they cause more problems. During the discussion Fiona added, using science to fix the damage we’ve already done can create more damage so you’ve got to be careful.

Science has a social responsibility

Voice was given to the idea that science has a social responsibility and as such the purpose of scientific endeavours should be critically questioned both by scientists and the general community. Some participants were clearly questioning the need for some science and the role it had in a global community. For example in the workshop Fiona said, science has consequences, moral and ethical. We should question do we genetically engineer things and should we take advantage of cloning. Tess expanded on this by saying; perhaps the more important aspect of the cloning debate is whether the technology is needed in a world that is facing an environmental crisis through the human population explosion. Similarly, Newton suggested citizens should consider the
social implications of directing funding to the current international space station. He wrote in his LATU essay, *a project of this magnitude and on going cost would surely deplete the world of the money and resources that on a sociological scale would be better used to repair the economic disaster occurring in third world countries.*

Jane later suggested in her follow up interview that scientists had a social responsibility particularly because they could influence the public’s support for and uptake of issues such as cloning and space science. She explained, *science is something people look up to because it has proved this thing and this next thing. People often take it on board and believe it.*

### 8.2 Cultural context of science: Intellectual development at a time and place

Participants demonstrated some understanding of the cultural context of science with some participants discussing the two way interaction of science with modern society. One participant, who was selected as she represented the highest level of scientific literacy, discussed in relative depth, contemporary science as representing intellectual development in modern times. Only a few participants made comments suggesting awareness of the historical context of science.

*Historical context of scientific thinking*

One participant made reference to the early philosophers of science. In the workshop Tess said, *science actually started off with philosophers asking all the questions like why does this do that or the difference between plants, animals and humans.* Tess viewed the early philosophers as creative thinkers who asked the questions which prompted scientists to search for the answers. She said, *they asked the questions and people stopped and thought, we’ll do some research and try and find answers.*
Other participants reflected over the last 100 years and suggested that the political drive for power and dominance over other nations and governments had influenced and directed scientific research. This was particularly evident during World Wars and the ‘space race’ to put the first person on the moon. For example, in the workshop Wendy said, *during wars scientists try to find something that no other country has so they could have more power over them.* Doug also suggested that research was influenced by the military and governments during war times. He said in his interview, *during war times especially science is controlled by the military and the governments. Before anything comes out it is tested by the military.* The ‘space race’ was also used as an example of how political power and the desire for domination in international relations had historically influenced scientific activity. Newton wrote in his LATU essay, *scientific activity was influenced by the space race between U.S.A. and Russia for the first man on the moon.*

*Two-way interaction between science and society*

It was suggested that modern society was shifting its view on science and its potential contribution to future development. Participants were aware that science shaped the world in which they lived and for some the technological nature of modern life made it difficult to separate science from society.

Society’s shifting conception of science and its role in development was illustrated by Fiona’s workshop comment. She said, *today’s society is shifting towards science and shifting its view about what science means and what good it can do. People are expecting scientists to be aware of the problems of the world and to know how to make a difference. Sometimes even the little things they do can lead to bigger things that make a difference.* The knowledge and technology resulting from science have clearly made a
difference but some participants perceived the difference to extend to the nature of society itself. In the workshop Wendy commented, with experiments and gaining knowledge from the world around us society changes. It was suggested that the shaping of society by science was evident in the media. Jane’s interview discussion illustrates this idea. She said, science has been of great benefit to our world at times, our society is built upon it now and it is highly influential in terms of media, medical and government.

The age of technology: thoughtful consumption or just a fashion statement?
Hazel suggested that the distinction between science and society was unclear due to the technological way of modern life. In the workshop discussion Hazel said, it is hard to see science as a distinct thing in today’s society because there is so much technology and how this is the information age where people can find out about anything they want to. Hazel was questioning the use of technology in modern society and raised its potential to mask underlying social problems. She wrote for example, in her LATU reading log,

technology was viewed more as a fashion statement or a way of experiencing the cultural world rather than a means by which to solve common human problems. This shows that the spread of technology is not egalitarian and as people seek to gain superiority in a field they may be more interested in developing technology that is harmful to humans, i.e., weaponry, rather than what is really progress. Is the technology age just a way of hiding from our problems behind supposed sophistication?
A major point of focus for participants throughout this research was the role of science in the management of environmental problems. Consistent with this focus and perhaps not surprising was Hazel’s proposition that environmental degradation was the political issue of this century. In the interview Hazel said,

I think science is traditionally relied on to solve problems which I think it is equipped for in some ways definitely but in other ways it’s more a cultural thing. It’s not going to be the solution to everything, but I read an interesting article called The Coming Anarchy and it was about how the environment, environment degradation is going to become the political issue of this century and that really interests me how science is going to play a huge role in politics so we can’t just view it as in its own niche any more. It’s become so important, so in society, science must find ways to understand how the world is changing and the implications of that whether political, social, cultural or even scientific.

8.3 **Science can reflect values and viewpoints related to society**

Participants recognised the two-way interaction of science with society. Science was seen to shape society with knowledge that led to the development of technologies, which were valued and widely used in modern developed countries. Science was also seen to be directed by society and as such it reflected the values and viewpoints of society at any given time. Funding sources, either private or government were presented as the concrete representation of what society valued and hence what type of research was supported.
Economics drives scientific research

Economic drivers were presented as the greatest influence on science in our contemporary society. Research had to be economically viable and represent the potential for commercial gain and profit. Independent companies would employ scientists that researched in a manner which achieved the company’s objectives and provided profitable findings or commercially viable products. Government funds were also perceived as being attracted by research that would be profitable. Hazel’s following interview comment illustrates the perspective that commercial applications would drive research. She said,

The direction of scientific research is increasingly determined by economics. You don’t realise how much of the funding for research comes through governments or industry which have a vested interest in it. These days you need to have commercial applications so there are going to be motivations driving the research in a certain way, particularly in biotechnology. I suppose it’s becoming more commercial because that’s the only way you’re going to get the funding. It isn’t so much about philanthropy any more.

Jane also viewed research funding as influencing the direction of science. In her follow up interview she stated, everyone has to get money together to conduct research and so government bodies strongly influence science. She also viewed social materialism or commercialism as a driving force behind research. She stated, materialism, getting the best technology the newest.

Commercial objectives determine the direction of scientific research

Companies, independent of government funding could influence the direction of scientific research by putting money into research that supported their commercial
objectives. Scientists employed by independent companies, would be directed by the company’s commercial objectives and this could influence their interpretation of evidence. Todd gave the following example in his LATU essay of a funding source possibly influencing the direction of research. *Greenpeace claims that some scientists have been bought out by large oil companies to support their arguments in the global warming debate.* He suggested that the employer’s commercial objective would determine the research findings or interpretation of evidence.

Furthermore, in the workshop discussion Jane stated her belief that money strongly influenced the direction of research. She explained, *scientists have to make money, so they’ve got to do what they can.* She also believed scientific information or research findings could be influenced by the scientist’s place of employment. For example, *with immunisation the scientists that are doing the testing are the ones involved in production so they’ve got to say it’s safe.*

**Governments’ funding of scientific research**

Participants suggested governments are also driven by economics and that they are often unable to fund research that wasn’t potentially profitable. For example, Jessica stated in her follow up interview that the *government is more likely to fund scientific research that will both produce a profit and affect a larger proportion of the population.* Jessica, like other participants, suggested that governments would also direct funding to research that was valued by the community and would impact on the greatest number of people.

In the follow up interview Todd related thinking that communities could pressure governments into providing funding for research in a particular area. For example, *the government is influenced by what the rest of the community thinks. If they really want*
something to be done (researched) they can put pressure on the government to hand out some funding for it. There was, however, evidence that participants didn’t think Governments always acted in the best long term interest of their country. Some participants perceived tension in politics between supporting research for sustainability and the desire to direct funds to high profile short term solutions that would satisfy the public and secure political power. This is illustrated by Ingrid’s workshop comment. She said, governments just want to get their countries into power, so they just use the technology anyway and not listen to the warnings of the scientists. Later in her interview she added, there’s a lot of pressure from the public in the way we’re living to do research and get the innovations. The government gets the pressure and pours money into areas that will satisfy the public.

8.4 Communicating science

Participants’ views on the importance of communicating science were mostly focussed on what they perceived to be a need to educate the public. The media was viewed as integral in this process. Some participants did, however, extend the role of communication in science to include research publications. Publishing scientific research was viewed by some as integral to the methods of science as it encouraged critical questioning, different points of view and potentially supported objectivity. Communicating science in order to educate the public

The public uptake of scientific ideas was presented as a potential limitation to science’s effectiveness and as such communicating science as a part of the solution to social problems was viewed by some participants as essential. This was illustrated by Hazel in her interview:

science can’t solve all problems. It also needs support from other areas like politics and social support. I think it’s all about science communication in that
you communicate it to a wider public and you get people to view it as part of the solution and that also makes them aware of the other factors that need to come into play as well.

Some participants suggested that communication was essential for making science applicable to the general community. The public needed to understand and find relevance in the science so that they would make lifestyle changes needed in order to sustain the environment. In her follow up interview Hazel said for example: communication is important as it enables people to see things from a scientific perspective even if they don’t have a background in science. This plays a huge role in making science applicable to the general community, getting people involved in science then getting their feedback on science. Todd viewed communicating scientific ideas as an important part of the solution to environmental problems. For example, in the interview he said, the people need to be better educated about the environment so they are more willing to agree to environmental management policies. Jane agreed that it was important for science to be communicated to the public but suggested that scientists did not always communicate clearly. In the workshop discussion she said, we don’t think they communicate very well. They should because they have to give it out to us so that we can understand what they are doing.

It was also suggested that science should be clearly communicated to the public as accurate knowledge of science could improve the economic, cultural and social well-being of the population. For example, in her follow up interview Hazel discussed the importance of communication in shifting images of science and getting it out of the laboratory and into society:
I want to go into the area of scientific communication, and I’ve been looking into that for example with the Australian group of Scientific Communications, and one of their aims I think they say, that they believe that people’s better knowledge of science can improve the economic, cultural as well as social well-being of the population. I don’t think science can survive if it keeps with this whole elitist old-boys club to use a bad stereotype, because I think it definitely does have to get out there, and I think it needs to be shown that it’s applicable because the world is becoming a lot more technological and it shouldn’t just be pigeon-holed. I’m not saying you can weave it into everything but it needs to become a lot less within its own little niche it needs to show that it’s applicable to other things as well.

Science and the media

The media was viewed as a key aspect of science communication. The media provided information to the public and contributed views to social debate. The media was also presented as a means of advertising science issues, sustainability and desirable social change. Fiona illustrated this view in her follow up interview: *science can only do so much and then it is up to us to decide what to do with it all. A lot of the media advertising, like this dam update, is just politics, it’s just trying to get people to change their ways.* Media advertising of science issues encourages individuals to engage and make social changes suggested for sustainability. In her interview Hazel made the following comments about the role of science communication in society:

> Water Corporation graphs in the newspaper show an accurate picture of where we are with water restrictions, providing some empirical facts. This proves to people that it is an important issue and that we’re trying to involve the community in water management. It says, this is the effect of what you’re doing
and shows whether you’ve met the target or not. It comes with “well done” if we’re underneath it or if we need to cut back on water. The effect is to try and get the community involved by showing them and giving them information. That way it’s not just the government saying we need water restrictions because we say we need water restrictions, it’s them being accountable as well, to the public.

However, some participants did suggest the media could present a biased view of science and scientific research. In the workshop interview Marie said,

I think the media can blow scientific work all out of proportion so there are people who don’t have an understanding of what science and technology can do, like cloning. They tend to believe what the media has given them. Whereas the people who know how it is going to help them are better informed and tend to see through the media.

This suggested that the media had a responsibility to communicate science accurately and in a manner that supported the public’s understanding and ability to engage critically with social debate. Communication should be structured so science could reach all people, even those who may not be scientifically literate. Interestingly, Hazel later responded to her interview transcript with,

A colleague said to me many people think of science as a very objective, fact-based inflexible world that we can add onto but not change, much the same way you as you build onto prior knowledge when you are studying science. His argument was that to communicate science effectively we have to keep on re-envisioning this world, beginning it from new again to reach these people who may not be scientifically literate. I think this holds true for the whole discipline.
Hazel’s studies in a double degree in Mass Communications and Chemistry coupled with her part time work as the WA Media Coordinator promoting National Science Week had clearly impacted on her level of scientific literacy and as such the depth of her thinking on science communication is exceptional.

Communication and the research process

Some participants suggested that research publications contributed to the rigor and objectivity of scientific research. Communicating research findings was integral to the methods of science. Published research could be discussed, critically questioned and interrogated from different perspectives. These ideas reflected an understanding of the dynamic nature of scientific research. For example, Newton raised in the workshop discussion the importance of communicating to the public about scientific research: *one of the purposes of scientific research is to get published, to get people thinking about it, to generate interest and funds.* Hazel further suggested in this discussion that *one of the reasons why you do an experiment and publish your findings is to try to circulate scientific knowledge, then other people can agree with you or maybe not.*

Hazel went onto suggest in her follow up interview that communication contributes to research objectivity as it encourages different viewpoints:

> communication is definitely important. In a sense that makes it more objective because it’s not just your own. You’re not just saying this is my research from your own perspective but you’re getting other people to comment on it and you can start a dialogue saying what they think about it and of course different viewpoints enable you to see it and get it as value-free as possible.
8.5 Using science to make informed decisions

Most participants showed some awareness of science’s potential role in making informed decisions. Science and resulting technologies were seen as integral to everyone’s life and as such science could provide knowledge upon which informed decisions could be made. The extent to which scientific knowledge could inform decision making was perceived by some participants as being dependent on the individuals’ prior experiences and beliefs. One participant presented the extreme view that science had little influence on her personally.

Science provides information that informs decision making

Some participants suggested science could provide information and the knowledge necessary for making informed decisions on issues generated by life in modern society increasingly shaped and directed by science. In the follow up interview Marie said, science has a role in everybody’s life. Like whether you get your children immunized or if you end up riddled with cancer and need someone to help you. I think you should question, for example the use of antibiotics and is it actually going to work for you. Even in other things like the environment. In the workshop discussion Jessica also agreed science helped her make informed decisions. For example she explained how science could inform her choice of diet: with fad diets science can tell how the body works and then say whether the diet could work. She later explained in her follow up interview how she thought science could inform the decisions she made about medical treatment:

if you were diagnosed with a disease, science could help you choose a treatment as the doctor may ask do you want surgery or medication. You would want to look at the results of people who previously had surgery or the side effects of
medication. You would need to look at the research and see if it’s worth going on medication.

*Personal beliefs determine the influence science has on decision making*

Jane could also see science as having a role in her personal life and the decisions she made. She did, however, take the view that science could not provide final answers as this was dependent on individuals’ background beliefs. She said in the workshop discussion, *it would depend on what you believe in and what kind of stance you have.* That would also affect what you decided. Hazel also agreed that personal beliefs would influence people’s interpretation of scientific information and the extent to which it informed their decisions. In the workshop discussion she said, *I think that while science can provide some idea of risk with a certain decision a lot of it would depend on your own personal beliefs and value systems. The science might be there but you may not agree with it and choose to disregard it.* Marie also raised family circumstances and social status as affecting the extent to which people would use science to inform their decisions. For example, she wrote in her LATU essay: *the attitudes to genetic engineering are dependent on a person’s family, social status and knowledge. Families who are in a situation to benefit are more likely to believe in these technologies.*

In contrast, one participant demonstrated limited awareness of science impacting on her personal life. Lisa commented in her follow up interview that she did not think science had much of a role in her personal life. She said, *not much, probably the technology we use like television.* Lisa did not view science as relevant to her and as such did not consider scientific information in decision making.
8.6 Critically evaluating science news reports

Participants frequently accepted unconditionally the research conclusion reported in science news briefs. They did not engage with the reports content in a critical manner but rather deferred directly to the report as ‘proof’ of the research conclusion. In contrast some participants did question the content of the news report. Some raised the tentative nature of research findings while others asked questions about the research methods. A few participants queried the report in relation to the research’s social context. As an extreme, one participant appeared to become increasingly disillusioned by news brief reports of science.

Uncritical engagement

Science news reports were often referred to as ‘proof’ or ‘fact’ and as such the research conclusion could be accepted unconditionally. For example on Questionnaire Two Wendy accepted the researchers’ conclusion as having being proven: I am now more certain as proven research is a definite indication that OJ helps in reducing the risk of heart disease. Tess also stated on Questionnaire One that she was now more confident in her response to the researchers’ conclusion as the news brief, in her words, attempted to give me some proof.

Some participants referred to the evidence offered by the news brief and in particular the stated statistics. For example in response to the researchers’ conclusion in the Questionnaire One news brief Doug stated, I have to assume this is so since I heard this is a scientific fact and then added after reading the brief, I am more certain as there is further impressive evidence supplied. Ingrid also focussed on the evidence offered by the news brief. She wrote on Questionnaire Two, I am now more certain as now I have heard about the research and seen the statistics.
Jane was able to identify and state the researchers’ conclusion described in her chosen news brief in the workshop. She did not, however, engage critically with the science content or described research methods but rather accepted the researchers’ conclusion because, in her words, *it could affect my lifestyle, health etc.*

**Critical engagement**

Participants who responded critically to the news brief generally asked for more information about research methods, statistics or other research in the field. Some participants did not believe one report was sufficient for accepting the research conclusion. For example, on Questionnaire Two Lisa wrote *I would probably change my mind slightly but not totally based on one report. You would need various sources to come up with the answer.* Renae expressed a similar view on Questionnaire Two: *although it says the implications of the research are significant, this is only a very small sample. More research is needed.*

Other participants did not accept the reported research conclusion as they required more information about the methods used. For example in the workshop interview Hazel said, *I would ask about the aims of the experiment, and more detail about the results. The article doesn’t give any statistics or any understanding of in fact what is going on.* Later in the follow up interview Hazel said, *I’d want to know more details of the tests they used. They use words like the effects were significant, but what do you mean by significant effects and how does it fit in with background knowledge or accepted wisdom in the field. I suppose you feel more confident if it’s backed up by other things.*
Disillusionment

Jane’s 2003 interview comments made when analysing the news briefs suggested she was becoming disillusioned with scientific research. Her response to the brief on the health benefits of oranges was, *it seems to be another headline, another proposal that people will dive into till the next great discovery is found.* Dissatisfaction with scientific method is also evident in her comment; *it seems that the scientists have to put it to the test, one test, isolated and in capsule form, of course!*

8.7 Scientific terms and concepts

Testing participants’ understanding of science terms and concepts was not an aim of this research. However, participants’ engagement with the various news briefs did provide an opportunity in which their contextual understanding of the reported science ideas and concepts could be demonstrated. Contextual understanding of science terms and concepts was viewed as important given that this research confirmed that science news briefs and the media generally were an important source of life long science learning.

*Contextual understanding of science ideas and concepts*

Science news briefs provided a concrete source of science interacting with society and a means for prompting and documenting participants’ contextual understanding of science terms and concepts. The language used in the articles was clearly the strongest influencing factor on students’ willingness to engage. For example, in the workshop Jane chose a particular news brief to discuss, as *I understood everything they were talking about.* She explained, *the other articles had lots of words I didn’t really understand.* Jessica’s choice was also based on the language. She said, *it was the language, some of it I just couldn’t understand*
The language or science terms used in the news brief were impacting on the students’ understanding of the concepts discussed. Fiona’ explanation of her choice of article illustrates this. She said, *I didn’t really understand these properly with the language. The article I chose was the easiest to understand.* This is also reflected in Ingrid’s explanation, *it was the only one I really understood. I had a basic idea of what they were doing but I didn’t understand about all those, what are they called, levels?*

It also appeared that the length of the article was influencing the students’ choice of article. Marie explained her choice of article as being based on its length. She said, *probably because of the amount of it and the size of the article.* Todd was also influenced by the length of that article but also his understanding of the language. He said *I chose this article because it was the shortest and the easiest to understand. The others had more scientific hard to understand language.* Wendy also explained her choice of news article as having been influenced by both the length and language. She said *it made sense, the language wasn’t complicated and it’s shorter.*

Only two participants stated interest in the topic as having influenced their choice of news brief. Newton explained his choice as being based on an interest in the article’s content. He stated, *I hadn’t read much on the topic; it was something new and then worthwhile to summarize. Also the language of the article was straightforward, easy to read and understand.* In the interview Hazel described her choice of article with, *it just interested me; maybe I needed sage to help me through exams. It’s something that was applicable to me.* Wendy’s personal life and interest also determined her choice of news brief: *my grandma’s got Alzheimer so I’m interested in Alzheimer. When I saw the article I was curious to see what they were talking about.*
All participants related in some way their understanding of the language in the news brief as influencing their willingness to engage with the content. It was evident that students were often unable to define or explain scientific terms used in science news reports. Their limited understanding of science terms prevented them from engaging with the reports and prevented them from considering the content in a critical manner.

Overall, the range of conceptions and the level to which they were discussed by participants reflects the diversity in their development of scientific literacy. Some conceptions are illustrative of naïve understandings of the contemporary nature of science and the manner in which it interacts with society. Others are well developed and suggest a multidimensional level of scientific literacy. This was to be expected as the participants in the focus group represented the range of scientific literacy demonstrated by responses to the pre- and post-LATU questionnaires.

It was also evident from the analysis of the focus group data that there was no obvious relationship between the time a participant had been out of school or the course they were enrolled in and their level of scientific literacy. However, it was evident that participants demonstrated their understanding of the nature of science in different ways depending on the context being considered. This supported the assumption that scientific literacy could not be determined by one context alone.

The evidence also suggested that participants’ confidence and disposition to use science as a tool for informed decision making was not only dependent on science content knowledge but also on an understanding of the nature of science. It appeared that an appreciation for the dynamic nature of scientific knowledge and research encouraged
participants to engage with learning about science and reflecting on its role in their lives. However, it was clear in this research that an understanding of the science terminology used in science news reports was a major block to participants’ critical engagement with the report’s content or considering the relevance of the science to their lives.

The following chapter brings together the converging evidence from the quantitative and qualitative aspects of this research and builds a composite picture of the participants’ developing scientific literacy.
CHAPTER NINE  DISCUSSION

The participants’ responses to the news brief and the Nature of Science Likert scale suggested trends within the group. These trends were identified in the findings presented in chapter six. The focus participants from the 2002 LATU cohort illuminated more subtle differences in perspectives and reasoning behind the responses given in the questionnaire. The LATU 2001 and 2002 cohorts are similar as they are sequential and include over three hundred students. The University’s intake process was consistent across both years and no changes were made to the course structure or enrolment criteria. This similarity in the cohorts allowed findings from the focus participants, as described in chapters seven and eight to give depth to the discussion of the questionnaire data and provide evidence for inferring some reasons for the general trends observed in participants’ development of scientific literacy.

The headings used in this chapter to organize the discussion of trends, represent the dominant themes that emerged during the analysis of the quantitative and qualitative data. These themes became evident when the data sources were converged and viewed through the framework of scientific literacy. In addition, these themes emerged out of the qualitative data and assisted in the evaluation of the framework itself.

9.1 Nature of science

The following trends were identified in the responses from the total group of 2001, 2002 and 2003 participants to the Nature of Science Likert scale. Firstly, participants mostly used the ‘agree’ or ‘disagree’ categories rather than ‘strongly agree’ or ‘strongly disagree’. This is evidenced by the category frequencies displayed in Table 6.11. These frequencies suggest that the majority of participants did not have strongly developed
views on most items. Secondly, on eight of the ten items more than fifty percent of the participants answered in a way that was consistent with a contemporary, socially located view of the nature of science. The two items that less than fifty percent of participants agreed with were: *scientific knowledge has been tested but should not be accepted as unquestionable truth* and *science is based on a dynamic ever changing body of knowledge*. These overall trends in participants’ responses were consistent across all subgroups which included gender, time out of school, course of enrolment and science background.

The comparison of the pre-LATU and post-LATU responses of the 2001 sub group of participants showed that there was overall a statistically significant shift in their responses towards a socially located perspective of the nature of science. This shift occurred over the time in which they were studying in the university foundation unit, *Life and the Universe* and it is likely their experiences in this unit would have contributed to their increasing contemporary view of the nature of science. LATU’s use of science fiction as the vehicle for driving students’ learning would have contributed to the observed shift in participants’ conceptions. The short stories included in the reader and discussed in tutorial groups highlighted the role of imagination in science and enabled the participants to consider scenarios not possible within the rigid boundaries of empirically directed scientific work. Tutorial-based discussion of the unit’s collection of short stories facilitated thinking about the consequences of past and current science actions and the ethical and moral implications of science. These discussions highlighted that science was a human endeavour and as such did not offer simple solutions.
This shift was not, however, consistent for all subgroups or all items. Mature age students made a greater shift than school leavers and participants with any science background shifted closer to a socially located view than those with no science background (Table 6.16). The two items on which participants made a significant shift were scientific knowledge has been tested but should not be accepted as unquestionable truth and scientists study a world in which they are a part and as such their work is not objective or value free. There was also a significant shift but in this case backwards towards a more empirically located view on the item science is based on a dynamic, ever changing body of knowledge.

The following discussion of trends within participants’ responses to each item on the nature of science Likert scale is based on the total group of participants. A particular focus is given to the Pre and Post-LATU subgroup for the items on which there was a significant shift. The focus group is then used to illustrate and deepen the discussion of the major trends identified.

Science and creativity

The group generally viewed creativity and imagination as an integral part of the scientific process. Only 2% of the participants from the total population disagreed with the statement, creativity and imagination play an important role in science. The large percentage (56.9%) of participants strongly agreeing with this statement may have been contributed to by the timing of the questionnaire’s completion in the LATU program. Participants completed the questionnaire in the week 2 LATU tutorial. This followed the first lecture titled The Dream. This lecture addressed the role of creativity and imagination in science and the writing of science fiction. The lecture summary, included in the unit’s reader, opened with the following statement. The practice of science must
always be done with enough intuition, enough imagination to allow the scientist to be
to dream where no one has gone before. Statements of this
nature could have made an impression on the participants and influenced their response
to this item on the Pre-LATU questionnaire.

The focus group participants primarily viewed creativity and imagination as essential in
finding new ways of solving problems, conducting experiments and developing new
products. This perspective was consistent with the dominant view of creativity in
science held by the primary science education students surveyed by Murcia and Schibeci
(1999). The greatest proportion of respondents in this earlier study suggested creativity
was needed for designing research and experimental procedures.

Furthermore, there was a relatively small number of respondents, approximately 5% in
the Murcia and Schibeci (1999) study, who did not accept that creativity had a role in
science as it was based in factual research. This view was also evident amongst a few
focus participants in this current research, who stated for example, the ideas that many
scientists have are limited to evidence and experimentation. There was little or no
evidence in the responses from either research studies that participants understood the
role of creativity and imagination in the development of abstract theories or scientific
models.

Science and its methods
The participants were aware to some extent that there is not just one scientific method,
as 53% of participants agreed or strongly agreed that there is not a set of fixed steps that
scientists always use which leads to scientific knowledge. The Rasch analysis, however,
showed that this was the second most difficult item for participants to accept. There also
appeared to be some contradiction in thinking amongst the 47% of participants who thought scientists did follow fixed steps in experiments as this assumption contrasts with the dominant participant view that creativity and imagination are integral to the development of new and innovative procedures for experimentation. This contradiction would suggest that many participants had limited understanding of scientific methods and the contribution of creativity to scientists’ work.

Focus group participants’ discussion of scientific method illustrated this limited understanding. Their discussion of science investigations included procedural terminology such as hypotheses, observations and evidence but this terminology was often left undeveloped. Participants made minimal meaningful applications of terminology to experimental situations and there was a general lack of understanding about controlled experimentation. Only a few participants related the need to control variables when designing a scientific investigation and even fewer participants provided examples that included a control group. This trend was consistent across all sub-groups and, in particular, there was no statistically significant difference between participants with a science background and those with no science background. These findings were again similar to those reported in the Murcia and Schibeci (1999) study in which 67% of respondents did not accept that there was one set of fixed steps that scientists always follow but when asked to discuss research procedures described in a news report only 19% showed any awareness of test and control procedures.

The LATU group project on planning a science investigation was a learning experience focussed on the methods of science and controlled experimentation. It required students to consider the need for experimental controls, to analyse and synthesise data, draw conclusions and make suggestions for ongoing future research. Participants had the
opportunity to use their learning later to assist in their analysis and interpretation of science news briefs and for proposing strategies for testing reported research conclusions. There was, however, minimal evidence of knowledge gained from the experience being transferred to these contexts. They did not appear to make connections between the scientific processes and principles learned to their application in everyday, real life examples of scientific research. Participants’ responses on the questionnaire suggested they were no more likely to engage critically with news reports of scientific research as a result of their LATU experience. There was, however, a range of views in the participants as illustrated by the focus group. A few focus group participants were able to propose a controlled experiment to test a reported research conclusion, as illustrated by Fiona who wrote, *have one group exposed to high levels, another to medium and a control with no exposure. Have the same conditions surrounding each group.*

*Science and objectivity*

A strong perception of scientists’ work being affected by their background, personal beliefs and values (item 6) was evident amongst the group, as 91.4% of participants agreed or strongly agreed with this statement on the Likert scale. However, when required on another item to consider the statement that scientists study a world in which they are a part and as such their work is not objective or value free (item 3), 37.8% of participants disagreed. Again, there appears to be some contradiction in the thinking of some participants. It would seem logical to assume that if you accept that scientists’ beliefs and values could affect their interpretation of evidence then you would also recognise that there are limitations to claims of science being objective. It is possible that contradictions in participants’ thinking on these two items could be due to their own experiences and prior learning about science. Science is often presented in school based
science programs and texts as ‘objective’. Doug’s interview comment supports this. He said *science has been done objectively throughout the years, textbooks and experiments with each step- methods, aim, and procedures.* Accepting the assumption that science is objective as a learned ‘rule’ may have resulted in some participants applying the concept out of context and without careful thinking. This may have led participants to accept that science is objective and value free despite recognising that scientist interpretations could be affected by their background, prior beliefs and values.

The focus groups comments and discussion about objectivity in science tended to centre on the methods of science and the rigour of scientific experiments. This is illustrated by Hazel’s definition of science which was, *objective, reasoned, interested observation and discovery of all things pertaining to the world around us.* She later explained, *they [scientists] are meant to be objective with data and measurements; they try to be objective by going through a scientific method.* The focus group participants generally viewed science as more objective than other disciplines due to its empirical nature, demand for evidence and requirement that experiments be replicable.

However, the pre and post comparison of the Likert scale responses showed that over the course of the research, participants become increasingly aware of a subjective element in science. The percentage of participants agreeing that scientists study a world in which they are a part and as such their work is not objective or value free increased from 54% to 74% (Table 6.18). This statistically significant shift in the participants’ view about objectivity in science towards a more socially located position was demonstrated by all focus group participants, except for Doug and Newton. The focus group participants generally became increasingly aware of subjectivity in science due to research ideas and design, observations, interpretation of evidence and the drawing of
inferences being affected by a scientist’s personal perspective which is built up by their prior knowledge, beliefs and values. Marie’s comment illustrates this perspective of subjectivity in science: *scientists aren’t always objective as they work to find what their company wants them to find. Their values and beliefs would also affect their work, what they want to see so they try to find it.*

The topics addressed in the LATU lectures would have contributed to the participants’ developing understanding of the nature of science. The lecture series dealt with a range of themes derived from the problems facing the Earth because of overpopulation. These themes include the Terraforming dream, the Physical and Biological Universe, Pressure for change, Terraforming Earth and Resources for change. The lectures explicitly challenge positivist views of objective and value free science offering technical solutions to the Earth’s problems.

*Science and societal values*

It was also evident that participants viewed science as an integral part of society and so it could reflect societal values and viewpoints. This conception, held by 57.9% of participants, would have contributed to their awareness of a subjective element in science and hence questioning of the assumption that science is objective. However, the focus group participants provided limited examples of societal values impacting on the direction of scientific research.

A few focus group participants made general references to the potential influence governments and politics could have on science. Newton’s comment in his follow up interview was an example of the general nature of the comments made. He said *scientific research is influenced by which way the government wants the project to run.*
It’s always with an outcome that the public will accept, that benefits politicians and governments.

Economics was presented as the strongest social factor driving scientific research. On the nature of science Likert scale, 92% of all participants accepted that the bodies supplying funding could affect the direction of scientific research. All focus group participants expressed the view that government and private sources of funding for scientific research were driven by a desire for profitable findings or commercial products. Jessica’s interview comment captured this dominant view: *the government is more likely to fund scientific research that will both produce a profit and affect a large proportion of the population.*

It was suggested in the final LATU lecture theme (Macey & Lyons 1998) that the enormous success of scientific developments over the last 300 years had resulted in the development of common misconceptions in the community. For example, *the general community has the feeling that science and technology can supply solutions to all of the problems that we face and that basically all problems are just economic problems that science and technology are capable of solving if given sufficient money* (Macey & Lyons, 1998, p. 305).

This misconception was prevalent amongst the focus group participants and despite having been addressed specifically in this lecture, continued to be evident in their follow up interviews.
Science and truth

Some participants accepted that scientific knowledge had been tested but should not be accepted as unquestionable truth. There was, however, a range amongst the focus group participants in the degree to which this statement was accepted. Views ranged from science offering evidence to support ideas to scientific knowledge being tentative as repeated research could falsify claims. Yet the majority of all participants, 58.5% viewed science as being based on tested truths. Wendy’s interview quote illustrates this dominant view: *through experiments a theory can be proven or not. When it’s proven it becomes scientific knowledge, after numerous tests and experiments it’s definitely true.* Participants like Wendy, generally demonstrated a lack of awareness of the limited nature of scientific methods and the tentative nature of scientific research findings.

Similarly, Murcia and Schibeci (1999) found that scientific knowledge was largely accepted as truth by most of the participants in their study. Responses to their questionnaire suggested that science was perceived as *a process in which the truth about the world was discovered* and that *scientific knowledge could be accepted as truth if there was sufficient research evidence to support it.* Furthermore, a dominant conception was that science was a *study of the world, a search for and discovery of knowledge.* This suggested these participants perceived science as based upon an accumulated set of facts and is therefore a relatively static discipline.

The conception of science as a static accumulation of knowledge was also prevalent amongst participants in the current study. The Likert scale item stating: *science is based on a dynamic, ever changing body of knowledge* was only accepted by 35% of all participants. These participants would have been unable to accept science as dynamic and changing as they also perceived science as being based on facts or unquestionable
truths discovered about the world. The focus group illustrated the view that science is static in nature with comments such as *science has been like a growing body of information that you sort of build onto.*

It was evident in the pre to post-LATU comparison that there was a statistically significant shift amongst participants towards a socially located conception of the tentative and questionable nature of scientific knowledge. Over the LATU study period, there was a 5% increase in the number of participants accepting that scientific knowledge has been tested but should not be accepted as unquestionable. This change was statistically significant but perhaps not educationally significant as the more socially located conception of the nature of science did not transfer to engagement with the science news brief. There was no significant improvement in the criticalness of participants’ engagement with the news brief post-LATU (Table 6.4).

*Science and informed decision making*

The Nature of Science Likert scale showed that 93.6% of all participants accepted the idea that the spreading of scientific information is important to the progress of science. Discussion with the focus group participants revealed that they clearly accepted this statement as they viewed communication as integral to providing ongoing science education. Communicating science ideas and developments to citizens was presented as a precursor to community support of scientific initiatives. Todd’s comment illustrates this dominant view: *the people need to be better educated about the environment so they are willing to agree to environmental management policies.* It appeared that the focus group participants generally accepted that science contributed important information and ideas that could assist citizens in making informed decisions. There was, however, a variable degree to which science was perceived as influencing public debate. Focus
group participants mostly accepted that science contributed important knowledge and ideas to public debate but 60.4% of all participants did not accept that science would contribute the final answer. Similar participant conceptions were evident in the Murcia and Schibeci (1999) study. The majority of their participants also viewed the spreading of scientific information as important to the progress of science and 52% agreed that science could seldom bring final answers to matters of public debate.

_Life and the Universe_ lectures and workshops provided examples of theme based science learning. The students encountered teaching and learning experiences which challenged their current thinking, connected to the world in which they lived and facilitated their own inquiry and construction of understanding. Effective pedagogy coupled with unit materials that explicitly addressed the nature of science and its interaction with society and are presumed to have contributed to the development observed amongst participants’ conceptions of the nature of science.

In contrast, the findings also suggested that participants continued to have limited understanding of the dynamic changing nature of scientific knowledge and of scientific processes or scientific methods. They had naïve understandings about the aims and limitations of science. Misconceptions and naïve understandings like these would impact on participants’ ability to meaningfully engage with and critically question the science reported in the media.

### 9.2 Science and society: Science in the news

Science and sustainability issues are constantly reported in the media and so are important sources of lifelong learning about science. The findings from this research show that science in the media was the predominant source of science information for
the participants other than their formal education. In particular, newspaper reports were the second most frequently stated source (Table 6.2).

*Engaging with science news briefs*

In light of this finding, it is important for citizens to read and engage with the science reported in the newspaper in a constructively critical manner. They need to be able to place the information into a social context and evaluate the procedures used and the evidence offered for the conclusions presented. Understanding and critically engaging with science debates, developments or research findings reported in newspapers is an integral component of scientific literacy. In light of this assumption, the findings from this study should be cause for concern to educators.

More than 50% of the participants in this study did not demonstrate the ability to critically engage with science reported in the news (Table 6.4). Most participants were unable to give reasons why the text should be accepted or reasons why it should be rejected. In the Pre-LATU questionnaire, more than 42% of the participants accepted the reported researchers’ conclusion unconditionally by simply deferring to the text or by relying with certainty on their background beliefs. There were a further 10% of participants who misinterpreted the information given in the news brief. It was also apparent that the participants’ background had no significant effect on the nature of their engagement with the news report. That is, age, gender, time out of school, science background and the course of enrolment did not have an effect on the participants’ ability to engage critically with the reported science.

Furthermore, the participants’ ability to engage critically with science news reports did not change significantly during the time in which they were studying in LATU. In fact
the number of participants engaging in an uncritical manner increased from 46% to 56%. This increase was contributed to by a much larger group of participants who were deferring absolutely to the report and stating the certainty of their beliefs based solely on more or less direct citation of the text. It was encouraging to see, however, that fewer participants (2%) continued to misinterpret the news report.

A Canadian study of 91 senior year science students by Norris and Phillips (1999) found a similar lack of critical engagement with science news briefs.

The majority of students deferred to the reports by readily accepting the statements of the reports and by implicitly trusting the authors. On only rare occasions did readers challenge the authority of the reports or the authors. The most influential factor in students’ judgments seemed to be what the reports said and not whether and why the reports should be believed (p. 325).

The daily newspaper is a concrete representation of society. The news articles it contains represent what is new, of interest or important to the general community. Participants’ lack of critical engagement with the news briefs could have been the result of their views on the role of science within society.

Participants who viewed science as providing the knowledge and technical solutions needed to solve social and environmental problems would be more likely to uncritically accept scientific research and ideas reported in the newspaper. As Wendy said, science’s role is to explain what’s happening, the basic facts to people. Alternatively, the participants who believed science could contribute information to debate but not final answers would be more likely to critically engage with the science reported in the
newspaper. Ingrid’s comment illustrates this view: *science can give you information but not the answers as answers come down to what the people believe and their values.*

A large proportion of participants who engaged uncritically with the news brief deferred absolutely to the content of the news brief. They viewed the report as proof or evidence for accepting the researcher’s conclusion unconditionally. It was evident amongst the focus group that participants who accepted science as based on objective facts derived from a prescribed scientific method were accepting uncritically the reported research conclusion. Wendy, for example, responded to the news brief research conclusion with: *I am now more certain as proven research is a definite indication.* This response is consistent with her conception of the nature of science. She stated in the workshop discussion: *when it’s proven it becomes scientific knowledge, after numerous tests and experiments it’s definitely true.*

*News Brief: Requests for extra information*

The most frequent request, both pre and post-LATU, for extra information were procedural in nature and within the category of research methods: 38% pre-LATU increased to 40.5% post-LATU (Figure 6.2). These participants asked how the research was designed and conducted. A common request was for more information about other possible variables that could have impacted on the findings. In addition, pre-LATU a further 10.5% asked specifically for information about the data collected and the statistics with 2% less making similar requests post-LATU.

Other requests for extra information were more socially located and suggested some awareness of the dynamic process of science and the tentative nature of research findings. Pre-LATU, 16.5% of participants recognized the need for re-testing, multiple
trials or looking at other research conducted in the area. The number of participants making requests of this type increased post-LATU by 1.5%. A similar proportion of participants, 14% pre-LATU and 18.5% post-LATU requested information regarding the social context of the research. This included questions about the reputation of the researchers and the project’s funding source.

Similar trends were identified by Korpan et al. (1997) in their Canadian study of 60 university students enrolled in an introductory psychology course. They compared requests for further information on four brief news reports of research. They found that almost all students requested information about methods, data and statistical tests used. In contrast, there was a relatively low frequency and inconsistency of requests about social context and related research. They concluded:

These findings may reflect a lack of sensitivity to the fact that scientific research takes place within a social community that can influence the selection of research questions, the interpretation of results and the acceptance of research findings and theory. This finding may reflect a lack of sensitivity to the fact that judgments about the validity of findings and conclusions depend to a large extent on consensual agreement among researchers, which in turn depends on whether a study has been replicated and on the degree to which results and conclusions fit with extant data and theory (p. 527).

Students were required in LATU to keep a reading log, which encouraged them to read widely and critically. It required them to consider the plausibility of the science concepts and the ethical implications in the materials read. The task also required that they look for links between what was read and other readings, lectures and tutorial discussions.
Students could choose from a range of reading materials including science fiction, science fact, scientific journals and daily newspapers. The findings of this research would, however, suggest this task did not improve the participants’ ability to engage with news briefs in a constructively critical manner.

### 9.3 Scientific ideas and concepts

Participants’ engagement with news briefs used throughout the research provided insights into their contextual understanding of the reported science ideas and concepts. In particular, opportunities were provided for focus group participants to demonstrate their understanding of science ideas and concepts in relation to their interpretation and discussion of science news briefs in the workshop and follow up interview. Discussion with the focus group participants showed that the language used in the articles was the strongest influencing factor on their willingness to read and engage with the reported research as illustrated by Jessica’s comment: *it was the language, some of it I just couldn’t understand.* It was evident that students were often unable to define or explain scientific terms used in science news reports. Their limited understanding of science terms prevented them from engaging with the full range of reports offered and prevented them from considering the content in a critical manner.

### 9.4 A possible source of misconceptions

Participants’ responses to the Nature of Science Likert scale and the science news briefs provided a view of their developing scientific literacy. It was evident that many participants in this current study held empirically located or undeveloped conceptions of the nature of science which led to uncritical engagement with science news briefs; this is also supported by findings in the studies by Murcia and Schibeci (1999), Korpan et al.
(1997) and Norris and Phillips (1999) The limited demonstration of scientific literacy amongst this study’s first year university participants and perhaps the participants in the earlier studies may be a symptom of the large volume of scientific knowledge included in high school curricula. Content loaded and driven curricula has often resulted in a teaching and learning focus on memorisation with little time typically been given for students to engage in a reflective or critical manner with scientific knowledge, processes, values or its interaction with society. Millar and Osborne (1998) stated that the current curriculum retains its past, mid-twentieth century emphasis, presenting science as a body of knowledge, which is value-free, objective and detached; a succession of facts to be learnt, with insufficient indication of any overarching coherence and a lack of contextual relevance to the future needs of young people. Hence real understanding and the development of scientific literacy were often replaced with the ability to reproduce memorized vocabulary and phrases that were in turn quickly forgotten.

Evidence of content driven science teaching and learning was found amongst the participants’ comments on their LATU tutor information sheets in response to the question: think back to your past learning experiences in science subjects. Describe briefly what was involved in learning in these subjects. The focus group participants’ accounts of their school science experiences, included as Appendix Eleven, illustrate learning focussed on memorising ‘facts’ or disconnected science knowledge and procedures. Jessica’s response suggested passive learning focussed on memorization: a lot of memorizing such as, parts and function of certain organs, names and symbols of the elements. Using formula, mainly in physics, such as speed and acceleration. Observation through experiments such as dissections, or mixing chemicals. Hazel, who has been identified through this research as having developed multidimensional
scientific literacy and also demonstrated continuing interest and learning in science, responded negatively when asked to reflect on her high school science experience. In the interview she said, *at high school you learn all this stuff and you wonder where the hell am I ever going to use it. It seems to be a lot of accumulation of knowledge just for the sake of it.* Comments of this nature support the assumption that compulsory science education has often been content driven and encouraging of passive learning behaviours.

Nelson (1999) has made similar observations of science teaching and learning. He stated,

> Today’s science textbooks and methods of instruction, far from helping, often actually impede progress toward science literacy. They emphasize the learning of answers more than the exploration of questions, memory at the expense of critical thought, bits and pieces of information instead of understandings in context, recitation over argument, reading rather than doing. They fail to encourage students to work together, to share ideas and information freely with one another, or to use modern instruments to extend their intellectual capabilities. Curriculums are over stuffed and undernourished. Over time they have grown with little restraint (p.15).

There appears to be a connection between overly dense, content-driven science curriculum and passive learning focused on the memorizing of science ‘facts’. The finding of this research would suggest that science learning experiences of this type would contribute to the development of misconceptions about the nature of science. A possible outcome is students viewing science as a static body of unproblematic facts that exist in nature to be discovered and learned. Memorizing facts would inhibit students’ ability to think critically about the aims and limitations of science or its interaction with
society. As a result of this, as seen amongst the participants in this research, students are unlikely to engage critically with reports of scientific research in the newspaper. Uncritical engagement with science news briefs would have a detrimental impact on their ongoing science learning and hinder their ability to make informed decisions or make sense of science developments impacting on their lives.

9.5 Reviewing the framework and indicators of scientific literacy

The framework of scientific literacy and the associated indicators at a functional, conceptual and procedural and multidimensional level were evaluated as they were used to analyse the participants’ development. The checklist of indicators was used as a tool for analysing the focus groups questionnaires, LATU work samples and the workshop activities, discussion and follow up interview. Critiquing the framework and indicators in the process generated important insights into the interaction of the dimensions of scientific literacy and its development amongst the participants.

Firstly, all indicators were present in the participants’ data at some point and with a range of frequencies. An exception was: able to memorize and restate lists of vocabulary. This would suggest such a task was not a part of the students’ experience in LATU and its value as an indicator of scientific literacy at any level would be questionable.

Secondly, but more importantly, the process of analysing the focus participants’ data using the framework and associated checklist of indicators highlighted that participants would respond differently in different contexts; that included at times demonstrating misconceptions when they had previously provided evidence of attaining the same indicator. There were examples of this occurring in every participant. The indicator
checklists suggested that participants’ conception of the nature of science and its interaction with society were linked to the context of the question or discussion.

Thirdly, multiple requests for extra information made by some participants regarding the scientific research described in the questionnaire news briefs did not support the assumption that the development of understandings in the three dimensions, science ideas and concepts, nature of science and the interaction of science with society, is hierarchal. Participants made requests at a functional level regarding science ideas or terminology and then at a multidimensional level by focussing on social aspects of the research. These participants did not provide evidence on the news brief task of understandings about broader science concepts or research procedures, yet could engage with ideas relating to the interaction of science with society.

Furthermore, it was evident that participants could demonstrate a contemporary understanding of the nature of science but with very little understanding of key science ideas and concepts. Jane, for example, scored highly on the nature of science Likert scale and engaged critically with the news brief on questionnaire one. Yet, in the interview following her completion of questionnaire two, she related being unsure of the science terminology used. Despite her multidimensional awareness of the nature of science and the interaction of science with society she had minimal understanding of scientific methods of inquiry or controlled experimentation. A case study of Jane’s development of scientific literacy over the two years of the study is included as Appendix Twelve. This case study captures the richness of her development and provides evidence of her development of socially located conceptions of the nature of science and understanding of the interaction of science with society but without the assumed fundamental base understanding of key science ideas, concepts and procedures.
These sources of converging evidence suggested that some starting assumptions underlying the analysis of students’ development of scientific literacy should be reconsidered. At the multidimensional level of scientific literacy there is a blending of knowledge from the three dimensions key science ideas, the nature of science and the interaction of science with society. However, a questionable assumption underlying this research’s analysis and also evident in Bybee’s (1997) levels of scientific literacy was that development in these three dimensions is hierarchical: specifically that lower levels of scientific literacy are focussed on science ideas or content knowledge followed by the development of understandings in the nature of science and its interaction with society.

Following intensely the development of the focus participants over a two year period allowed for a greater depth of understanding to evolve than what was gained alone from the large scale administration of the questionnaire. This experience highlighted that the development of scientific literacy was far more complex in reality than the originally proposed hierarchal levels and indicators. It was evident that the scientifically literate individuals drew on a blended body of knowledge that included an understanding of the social context, the values and assumptions inherent in science and key understandings of fundamental science ideas and concepts. This ability and disposition to think and act scientifically in order to problem solve or make sense of a situation required parallel development in the three dimensions. It is the blending of these understandings, at any level, that empowers individuals to choose and use science for making sense of their ever evolving world.

It is now proposed that the development of scientific literacy is the result of increased intertwining of knowledge and understandings in the three dimensions, which are key science ideas, the nature of science and the interaction of science with society. A rope
metaphor, shown in Figure 9.1, represents in a concrete medium, the weaving together
of knowledge in order to think and act scientifically. This contemporary model
representing the development of scientific literacy was informed by the work of Andrich
(2002b) in which he used a rope metaphor for describing the relationship between the
component strands of the Western Australian Curriculum Framework (Curriculum
Corporation, 1998). He stated:

If one considers a very thick rope, which can of course be straightened to form a
linear continuum, there are components that are made of much finer threads.
These are woven together to form a higher level component, which could itself
be a narrow (thin) rope. These relatively thin ropes are then woven together to
form a thicker rope, and this process can be repeated until one has a rope thick
enough for the purpose in hand (p. 104).

![Figure 9.1: Scientific literacy, a rope metaphor](image)

This model represents scientific literacy as interwoven threads of multidimensional
knowledge. Threads of knowledge, skills and understandings are attained by individuals
in each of the dimensions. As individuals develop they construct further ‘threads’ of
understanding that build onto what they know, thickening and strengthening their ‘rope’.

The continuum of developing scientific literacy would then be represented by the
thickness of the rope. Scientific literacy at the lowest end of the continuum would
include minimal understandings in all three dimensions and would be represented by a
thin but multidimensional rope. The depth of understanding in each knowledge
dimension would increase along the continuum towards the higher levels. The depth of
development in each knowledge dimension would vary depending on the learning
experiences, interests and contexts in which individuals’ function. A scientifically
literate individual would have threads of knowledge in each domain but may have
greater depth in one of the dimensions. For example, as illustrated in Figure 9.2, a
parliamentarian who is scientifically literate would have interwoven threads of
understanding in all dimensions but due to their context, experiences and their continued
learning they may develop greater depth in their understanding of the interaction of
science and society. Alternatively, it could be expected that a science educator who is a
general science practitioner, may have even depth of understanding across all
dimensions of scientific literacy. Yet the specialist nature of a scientist’s work, such as
an industrial chemist, demands a depth of understanding about important science ideas,
concepts and procedures. The depth of development in this dimension would be greatest
but in order to be scientifically literate rather than only technically proficient they would
also have some understandings about the nature of science and the interaction of science
and society.
The rope metaphor captures realistically the complexity of developing scientific literacy observed throughout this research. It highlights the importance of a holistic approach to developing students’ scientific literacy and has a range of implications for teaching and learning in university’s multidisciplinary foundation units and science based courses.
Australian society is increasingly being shaped by science and there is an ever-growing awareness of the need for sustainable development. In this social context it is argued that it is important that all university graduates have a reasonable level of scientific literacy so they are prepared for both active citizenship and responsible professional practice. Millar and Osborne (1998) stated in the Nuffield Foundation seminar series report, Beyond 2000: Science education for the future that the aim of improving scientific literacy was a vital one if we are to create the social and political climate within which science and its products can be both appropriately valued and appropriately controlled in a democracy (p. 2012). It is evident in this report that scientific literacy has become as important as language literacy and numeracy for effective communication in a diverse range of contemporary contexts.

It is perhaps now more important than ever for educators to reflect on the scientific demands of life in the 21st century and what it means to be scientifically literate. The framework for scientific literacy proposed in this research clarified the concept and has the potential for wide application in higher education. It also proved to be an effective tool for structuring this research’s interrogation of First Year University students’ development of scientific literacy.

The rope metaphor is a realistic representation of developing scientific literacy as the outcomes of this process of interrogating university students’ scientific literacy highlighted that the development of the construct was a complex, intertwining and multidimensional process. Analyses of participants’ scientific literacy challenged the
starting assumption that development in the construct’s three knowledge dimensions
was hierarchical. There was converging evidence from both the quantitative and
qualitative aspects of the research to suggest that the students’ development of scientific
literacy was linked to, and perhaps driven by, a context. It was evident that knowledge
in only one dimension of scientific literacy was insufficient to empower students to
think and act scientifically in order to make sense of the world in which they lived. In
order for students to be scientifically literate, at any level, they had to have at least some
minimal understanding of the interaction of science with society, the nature of science
and key science ideas and concepts. In light of this, the rope metaphor proved to be a
more effective and encompassing representation of the development of scientific literacy
than the initial linear and hierarchal model illustrated in Figure 4.4.

10.1 Reflecting on the research process leading to the rope metaphor

The literature review which was the starting point of this research identified the
importance of scientific literacy for citizenship internationally and the important
transition to sustainability. For example, an international organisation, UNESCO,
viewed scientific literacy as a universal requirement for citizenship and the ability to
adapt to change (Boufaoude, 2002). The history of scientific literacy as an educational
construct was also documented through the literature review and then analysed in order
to identify common emerging dimensions.

The intersection of the history of scientific literacy with the current local, national and
global movement towards the achievement of sustainable development resulted in the
design of this research’s framework for scientific literacy. It was anticipated that this
framework would clarify the construct and increase its utility both in the research process and in broader educational contexts.

The study was focussed at the university level as scientific literacy was identified as not only a desirable characteristic of all citizens but also an attribute industry and the general community could reasonably expect from higher education’s graduates. The university unit, *Life and the Universe (LATU)* was a relevant context for the research as it was a multidisciplinary foundation unit open to, but not necessarily taken by; all first year students at Murdoch University. The unit provided an interesting context for the interrogation of students’ development of scientific literacy as it had as its central theme the development of self-sufficient and stable ecosystems; and, importantly, it was not intended as a specialist science unit but rather an introduction for all students to the issues faced by science in a continually evolving technological world community (Lyons & Macey, 2001). The multidisciplinary nature of the unit fitted with the National Council for Science and the Environment (US) recommendation that all disciplines and majors should integrate sustainability, environmental, social, and science literacy, social change skills and understanding of values into their curriculum. They suggested that universities had a responsibility to reach all students, not only those majoring in a natural science and facilitate their ability to integrate sustainability and as a part of this scientific literacy into both their professional and personal lives (National Council for Science and the Environment, 2003).

In addition, LATU was a valuable context for the research as a review of Murdoch University Foundation units conducted in 2001 indicated that these units made a strong contribution to the development of students’ graduate attributes. This University, like others nationally, views developing graduates with a well-defined set of attributes as fundamental in providing quality education. The University demonstrated through its
statement of graduate attributes its commitment to producing graduates that not only
demonstrate discipline knowledge but who also have the understanding and ability to
interweave ethical and social responsibility into their practice. The graduate attributes
illustrate the intersecting nature of social, economic and political factors shaping
professional practice and citizenship. They currently capture explicitly the literacy and
numeracy aspects of communication and implicitly the scientific literacy skills
demanded by modern life.

The interrogation of scientific literacy amongst First Year University students enrolled
internally in the foundation unit LATU was contributed by both quantitative and
qualitative methodologies. The quantitative component was a questionnaire
administered both pre and post LATU to all students enrolled internally. The
questionnaire contained two sources of information about students’ scientific literacy.
The first related to students’ engagement with a science news brief and the second was
their response to the nature of science Likert scale items. Both tasks were analysed
separately and the results were used to build a composite picture of participants
developing scientific literacy.

The qualitative part of the research began the following year with the selection of the
focus group of participants. The questionnaire was administered to students in three
selected tutorial groups as these groups were led by tutors who had committed to
assisting in the research process by collecting samples of students work. Rasch analysis
allowed the position of these students within the first sample of participants to be
determined. The focus group then represented the range of scores (logits) on the
questionnaire and also the diversity of the first year student population in terms of
gender, time out of school, course of enrolment and science background. The Rasch
analysis also verified the validity of the Likert scale as a tool for measuring conceptions of the nature of science.

Following the focus group participants over the next two years provided insights into the response patterns observed in the large scale administering of the questionnaire. The process generated a greater depth of understanding about the development of scientific literacy and highlighted a range of implications for teaching and learning at the University level.

10.2 Implications of the rope metaphor for LATU

The findings of this research suggest there is a need for scientific literacy to be explicitly stated as a desired student outcome from learning in *Life and the Universe* and generally as a university graduate attribute. Students should be informed of the importance of developing scientific literacy through unit study guides where links are made to over arching graduate attribute statements. In LATU, it is recommended that tutors be made aware of the units potential for developing scientific literacy and be given teaching and learning strategies to support students’ development. Suggested strategies could include group discussion of contemporary science issues developing from a relevant context base rather than discussion that is content driven. Tutors and students could look to the history of science and science philosophy to inform their views on current issues and possible futures.

Tutors should be encouraged to reflect on what is important, meaningful science learning that is likely to assist students in their lifelong science learning and ability to deal with the scientific demands of life in the 21st century. This would include having knowledge of fundamental science concepts, the processes or modes of scientific inquiry, the interaction of science with society and the confidence to use science as a
tool for making decisions or evaluating claims. Students should be provided with opportunities to critically engage with contemporary science contexts and consider the impact science could have on them personally, their broader community and the global community. Students should be encouraged to value their ability to learn and use science in times of need. This would include finding out the ideas and views of potential “experts” within science. This would involve reflecting on the context and identifying relevant questions that should be asked and then critically evaluating what they are told or read. Using science news briefs as a tool for learning could increase opportunities for students to engage critically with contemporary science issues. News briefs should be a required component of the unit’s reading logs.

Describing the dimensions of scientific literacy separately as science ideas and concepts, nature of science and the interaction of science with society could suggest clear divisions but this research shows that is not the case. An individual’s scientific literacy in any given situation is a blended understanding of science concepts, the nature of science and the interaction of science and society. Their level of scientific literacy and hence effectiveness of their handling of a science rich situation depends on what knowledge they have to draw from each of the dimensions. This assumes they have the confidence and disposition to engage with the science. In order to develop scientific literacy science curricula should be based on fundamental concepts developed in a socially meaningful context. Time should be given so students can meaningfully engage, practise ideas and skills; and then reflect on their learning. The teaching and learning goal should be to develop outcomes that are meaningful and useful to all individuals through out their lives.
Conceptualizing and representing the construct through the rope metaphor would suggest that the development of scientific literacy is dependent on teaching and learning experiences that provide opportunities for integrating knowledge from the three dimensions. The interaction of knowledge from these dimensions is an integral part of the development of scientific literacy and requires that students are provided with teaching and learning experiences that are holistic in nature and driven by socially relevant everyday contexts.

This research’s contemporary framework of scientific literacy would support students and tutors in critically engaging with science news briefs. It would assist them in seeing the dynamic nature of the reported science and reinforce that science is not a collection of unquestionable facts (Murcia & Schibeci, 1999). There is evidence in this research to support the assumption that newspaper reports of science can be an important source of lifelong science learning and that engaging with and critically evaluating the information and conclusions presented in such reports is an important aspect of scientific literacy. Engaging constructively with science news reports requires individuals to understand the terms used, take a critical stance and make links from the report to the broader science discipline and social context. Skilled evaluation requires among other things knowledge about the research process and how this affects the quality of the investigation (Korpan et al., 1997). Critical engagement with the report can occur in the areas of scientific methods, linking evidence to conclusions and the social context of the research. This may involve asking and answering questions on issues such as controls, sample size, kinds of data collected, possible causes and theories, sources of research funding, qualification and experience of researchers, motivation for the research and who will benefit from the findings (Murcia, 2005).
scientific literacy, Figure 4.3, would prompt thinking about science ideas and generate
discussion about the values, assumptions and methods underlying science. It should
assist in making explicit the knowledge dimensions of scientific literacy and stimulate
discussion of ethical and moral dilemmas that often arise at the interface of science with
society.

It should be noted that many of the focus participants did not transfer their project experience
and learning about the methods of science to assist in engaging critically with the news reports
of scientific research. The support and feedback provided to students by their tutors in the
development and presentation of the project plan should take into account this lack of
transference. It would be desirable for tutors to make explicit the connections and links from
the proposed plan to real reports of science. In addition given the research participants’ lack of
critical engagement with science news briefs; it would be advisable in the future to require
students to include a minimum number of science news reports.

The participants tracked through this research while studying in LATU, however,
demonstrated a statistically significant increase in their contemporary, socially located
conceptions of the nature of science. Specifically, this significant increase was on items
2 and 3. It would be reasonable to assume that this development in the nature of science
dimension of scientific literacy was, in part attributable to the teaching and learning they
experienced in LATU. The LATU experience appeared to have raised participants’
awareness of the tentative and subjective nature of science (item 2) by challenging the
common preconception that science knowledge has been ‘proven’ and can be accepted
as ‘truth’. The participants also became increasingly aware that scientists study a world
in which they are a part and as such their work is not ‘objective’ or ‘value free’ (item 3).
10.3 Implications for the University’s graduate attributes.

The findings of this research are of course limited to the group of participants but are illustrative of the need for greater attention to be given to students’ development and attainment of scientific literacy through their university education. This research suggests the integrated and blended nature of understandings contributing to the development of scientific literacy could be effectively captured within the University’s statement of graduate attributes. The contemporary framework of scientific literacy and the insights provided by the study into students’ development of the construct could be used to further inform the generic capabilities focussed in multidisciplinary university courses such as *Life and the Universe* and other science based programs.

The framework and rope metaphor for the development of scientific literacy proposed here has the potential to make a valuable contribution not only to multidisciplinary foundation units but also to the development of generic capabilities in science based courses as it highlights that to be scientifically literate a graduate requires more than just technical knowledge of science concepts and processes. It suggests this knowledge should be coupled with an understanding of the nature of science and an awareness of the relationship of science with society. A blend of these knowledge dimensions would increase graduates professional accountability as they work within a social move for sustainable development. All graduates, including our future scientists should have a greater awareness of their social responsibility and the interplay of knowledge from across disciplines in inquiry and problem solving.
The importance of scientific literacy could be reflected generally in university’s descriptions of graduates communication attribute. For example, the Murdoch University graduate attribute could read:

Communication: The ability to communicate effectively and appropriately in a range of contexts using communication literacy, scientific literacy, numeracy and information technology.

Alternatively, Table 10.1 illustrates one possible representation of the relationship of this research’s multidimensional indicators of scientific literacy to Murdoch University’s overarching graduate attributes.

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<th>Attribute</th>
<th>Description</th>
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<tr>
<td><strong>Communication</strong></td>
<td>• Critically evaluate science reports based on an understanding of the general aims, limitations and social context of the scientific enterprise.</td>
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<td></td>
<td>• Demonstrate the competence and confidence to make informed decisions relating to scientific ideas.</td>
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<td>Ability to communicate effectively and appropriately in a range of contexts using communication literacy, numeracy and information</td>
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<tr>
<td><strong>Critical and creative thinking</strong></td>
<td>• Display an understanding of the aims and limitations of scientific processes.</td>
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<td>Ability to collect, analyse and evaluate information and ideas and solve problems by thinking clearly, critically and creatively.</td>
<td>• Understands new scientific knowledge is produced as a result of creativity and imagination coupled with scientific method.</td>
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<tr>
<td></td>
<td>• Incorporate the philosophical, historical and social dimensions of the discipline into the analysis, interpretation and evaluation of</td>
</tr>
<tr>
<td><strong>Ethics</strong></td>
<td>• Show professional standards of openness of mind, honesty and take a moral and ethical approach to their profession.</td>
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<tr>
<td>An awareness of and sensitivity to ethics and ethical standards on interpersonal and social levels, and within a field of study and/or profession.</td>
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<th><strong>Social justice</strong></th>
<th>• Have some knowledge of the history of scientific ideas.</th>
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<td>An acknowledgment of and respect for equality of opportunity, individual and civic responsibility, other cultures and historical times and an appreciation of cultural diversity.</td>
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| **Global perspective** | • Shows an understanding of the cultural context of science.  
• View scientists as studying a world in which they are a part and as such their work is not objective or value free.  
• Displays an awareness that observations of the world are made from a personal perspective built up by prior knowledge, beliefs and theories. |
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<tr>
<td>An awareness of and respect for the social, biological, cultural and economic interdependence of global life.</td>
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| **Interdisciplinary** | • Makes connections within the discipline and with larger social problems and endeavours.  
• Shows an awareness of the role science takes in society. |
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<tr>
<td>A capacity to acquire knowledge and understanding of fields of study beyond a single discipline.</td>
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<table>
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<tr>
<th><strong>In depth knowledge of a field</strong></th>
<th>• Understand the nature of scientific theories and</th>
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Comprehensive and in-depth knowledge of a field of study and defined professional skills where appropriate.

- Understand that scientific knowledge has a temporary status and should not be accepted as unquestionable truth.
- Views science as progressing through continuing research and critical questioning.
- Views science as dynamic and ongoing, not a static accumulation of information.

**Table 10.1: Scientific literacy indicators matched to graduate attributes**

Specifying graduate attributes could inform students, employers and the general community of the skills and values that could be expected from a university’s graduates. This approach is perhaps a part of the continuing debate about the purpose of university education and in particular the development of people who are both employable and critical citizens (James et al., 2004; B-HERT, 2003). For example, the University of South Australia has recognised the place graduates take in society and the changing technological nature of their workplace. They describe social and technological changes as ongoing features of all employment so graduates need to be prepared for continuous learning and applying their knowledge in new ways. This is also the case in life outside paid employment as the graduate is a citizen of local, state, national, and global communities. (University of South Australia, 2001).

### 10.4 Facilitating university students’ development of scientific literacy

This research’s contemporary framework and indicators of scientific literacy could inform the development of unit objectives and learning outcomes included in students’ study guides. This would assist in communicating to students the importance of
scientific literacy for modern life and sustainable development. Educators working to facilitate student learning would also benefit from statements of unit objectives or outcomes that include scientific literacy and link to the students’ attainment of the university’s overarching graduate attributes.

Student outcome statements of these sorts should generate discussion about effective pedagogy for developing scientific literacy. To effectively assist students in their development of scientific literacy it is just as important to consider how subjects are taught as what subjects are taught. This is particularly true in higher education where the focus is often on content driven teaching and learning rather than a more holistic context driven pedagogy. The recommended reforms for higher education in the Science for all Americans, Blueprints (AAAS, 1997) includes stressing themes, connections across disciplines, collaboration and inquiry skills or habits of mind. Concentrating on the central ideas of each discipline even at the possible expense of covering content is presented as a critical element in a new agenda for higher education.

Building university educators’ awareness and understanding of the integrated nature of scientific literacy could be facilitated by this research’s contemporary framework for the concept. This framework should encourage professional reflection and collegial discussion on what is important and what constitutes relevant science learning. This would ideally lead to the broadening of teaching and learning experiences to include opportunities for students to critically engage with contemporary science contexts and consider the impact science could have on them personally, their broader community and the global community. Students should be encouraged to use science as a tool for making decisions or evaluating reported claims. They should be confident and value their ability to learn and use science for problem solving or making sense of their world.
This would include reflecting on the context, finding out the ideas and views of potential “experts” within science, and identifying relevant questions that should be asked and then critically evaluating what they are told or read.

Effective teaching for scientific literacy would include methods focussed on a constructivist based problem-solving approach that incorporates everyday relevant examples and applications of science. Fensham’s (2002) focus is on context and the relevance of curriculum materials to students’ lives. He has identified that science learning experiences should be meaningful and potentially useful to students while contributing to the development of a sense of curiosity about science. Scientific inquiry driven by real life contexts, questions and problems would provide students with opportunities to construct real and enduring understandings. Constructivism is a dynamic and interactional perspective of learning in which students are recognised as bringing prior knowledge, experiences, skills and attitudes to the learning experience (Krause, Brochner & Duchesne 2002). Engaging students with learning experiences that challenge their initial conceptions, attitudes and skills and that includes interaction with peers and the teacher should encourage students to redefine, reorganise and or replace their initial understandings with new learning. Wallace and Louden (2002) support a constructivist approach and further explain that students could become dissatisfied and turned off from their science learning if the goals of science education are remote from either the students’ everyday lives or the norms of science itself.

In order to increase the opportunity for students to develop scientific literacy, learning activities should be connected and interrelated. There is a need to make explicit the relationship between the three dimensions of scientific literacy, being the ideas and concepts, nature of science, which includes procedural methods, and the interaction of
Developing students’ level of scientific literacy takes time, as students need time to ask questions, talk, debate, read, experiment and ask more questions. They need time to experience the dynamic nature of science.

10.5 Implications for the University’s teacher education programs

Strong foundations need to be laid down in the years of compulsory science education. Primary and secondary school teachers could benefit from having a future view or an awareness of the expectations placed on tertiary students in relation to scientific literacy. With a clear future view they could build sound foundations and avoid the development of the various misconceptions and limitations identified in this study’s university students. It is important for teachers to see how the foundations they provide will be built upon.

This research has shown that developing scientific literacy requires a holistic view of science and the curriculum that drive its teaching, learning and assessment. For example, the Western Australian Curriculum Framework (Curriculum Corporation, 1998) when taken as a whole and coupled with effective pedagogy has the potential to facilitate students’ development and achievement of scientific literacy. The components of the science strand illustrate the three dimensions of this research’s framework for scientific literacy. The following links, displayed in Table 10.2, can be made when mapping the science strand outcomes of the WA Curriculum Framework against the dimensions of scientific literacy identified in this research.
<table>
<thead>
<tr>
<th>Interaction of science with society</th>
<th>Nature of science</th>
<th>Scientific terms and concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Science in Daily life:</em> select and apply scientific knowledge, skills and understandings across a range of contexts in daily life.</td>
<td><em>Investigating scientifically:</em> investigate to answer questions about the natural and technological world using reflection and analysis to prepare a plan, collect, process and interpret data, to communicate conclusions and to evaluate plan, procedures and findings.</td>
<td><em>Earth &amp; Beyond:</em> understand how the physical environment on earth and its position in the universe impact on the way we live.</td>
</tr>
<tr>
<td><em>Communicating scientifically:</em> communicate scientific understanding to different audiences for a range of purposes.</td>
<td><em>Science in society:</em> understand the nature of science as a human activity.</td>
<td><em>Energy &amp; Change:</em> understand the scientific concept of energy and explain that energy is vital to our existence and to our quality of life.</td>
</tr>
<tr>
<td><em>Acting responsibly:</em> make decisions that include ethical consideration of the impact of the processes and likely products of science on people.</td>
<td></td>
<td><em>Life &amp; Living:</em> understand their own biology and that of other living things and recognise the interdependence of life.</td>
</tr>
</tbody>
</table>
Table 10.2: Scientific literacy and the science strand of the WA Curriculum Framework

Andrich (2002a, p. 40) identified some risk in focussing on the component parts of the curriculum. He said, *there is an increasing risk of reductionism where the focus is on components at the expense of their relationships*. Teacher educators need to be aware of the impact of fragmenting science learning into a series of independent and unrelated tasks. Scientific literacy can only be achieved by integrating the curriculum’s component parts and focussing on the interrelationships between understanding concepts and working scientifically.

Science is a social activity and clearly makes a cultural contribution to the community. At the foundation of this contribution is a set of major ideas and concepts about the world in which we live, for example the particle model of matter, structure of the solar system, interconnected nature of ecosystems, cells, genes and inheritance, energy and energy conservation, life, diversity and evolution, natural and processes materials, physical and chemical changes and so on (Western Australian Curriculum Framework:
Curriculum Corporation, 1998). These ideas and concepts should be prominent within science education but focussing on in-depth detail or the ‘facts’ could be overwhelming, intimidating and even deterring from the development of a real understanding of the scientific enterprise. Millar and Osborne (1998, p. 2013) captured this view in the metaphor it is impossible to see the whole building if we focus too closely on the individual bricks. This is consistent with Nelson (1999, p. 15) where he states, it is important to identify and emphasise the most important concepts and skills, concentrating on the quality of understanding rather than the quantity of information presented.

The answer to improving scientific literacy does not rest simply in teaching more science concepts nor will it result from the development of appropriate curriculum materials alone. It is a teacher’s handling of science knowledge and curriculum materials that influence students’ development of higher order thinking and reasoning skills. The learning environment created by the teacher, their attitude to and understanding of the materials and in turn how they assess learning will impact on their effectiveness in developing scientific literacy. Achieving scientific literacy as an educational outcome would be supported by rich context driven curriculum materials and effective pedagogy, which are informed by a contemporary conception of the nature of science.

This research’s framework for scientific literacy demonstrates that science is not a collection of static facts and so teachers should be confident to model for students an interest in finding out what they don’t know and then the resulting process of finding out, critically evaluating and taking meaning relevant to the specific situation. It is
suggested that teachers will often teach as they have been taught. Hence it is important to consider the way university science education courses are constructed and presented.

Further research would be required to determine the robustness of this research’s contemporary framework and rope metaphor for developing scientific literacy in primary and secondary educational contexts. Its transferability to specialist science based courses and teacher training programs should also be investigated.

10.6 Reflecting on our prior experiences of science teaching and learning

Critical reflection on our prior experiences of science teaching and learning at all levels would for many educators highlight shifts in our thinking about the purpose and practice of science education. Historically, compulsory science education had been focussed on preparing students for future study and work in science based disciplines. However, with the growing scientific demands of life in this century our purpose has increasingly become the attainment of scientific literacy for all citizens. Reflecting on our science teaching and learning, Table 10.3 compares a traditional view of science teaching with the contemporary view presented through this research. This comparison is not intended to suggest that there are only two views of science teaching but rather, it aims to provoke reflection amongst educators on the emphasis that should be given to various practices if our goal is to teach for scientific literacy.
<table>
<thead>
<tr>
<th>Aspects</th>
<th>Science for technical proficiency</th>
<th>Scientific literacy for all citizens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science ideas and concepts</td>
<td>Content driven teaching and learning focussed on the transmission of science ideas that prioritises students’ ability to memorise and recall scientific ideas.</td>
<td>Context driven inquiry based teaching and learning that engages students with the more important and enduring science ideas that are integral to understanding and responding to an original context, question or dilemma.</td>
</tr>
<tr>
<td>Nature of science</td>
<td>The values and assumptions of the discipline are addressed implicitly in the teacher directed learning of science content and procedures.</td>
<td>The nature of science is explicitly discussed as a dynamic, human activity that progresses through critical questioning and continuous research coupled with imagination. Scientific results and knowledge are considered critically and not accepted as the unchanging foundation of science.</td>
</tr>
<tr>
<td>Interaction of science with society</td>
<td>Links are made to socially or personally relevant contexts in order to demonstrate the importance of learning sequentially developing science ideas, concepts and procedures.</td>
<td>Learning is centred in a relevant, meaningful and or everyday context in which students are motivated by a need or desire to know more. They may respond to the ethical and moral dilemmas that often arise at the interface of science with society</td>
</tr>
<tr>
<td>The students’ role</td>
<td>Students participate in learning experience that includes learning from the teachers’ input and textbooks. They complete activities that verify science</td>
<td>Students actively construct understanding. They question, inquire and learn broad science concepts that can be applied to new situations. They seek</td>
</tr>
<tr>
<td>The teachers’ role</td>
<td>Teachers present science ideas and procedures by talk, text and demonstration.</td>
<td>Teachers engage students’ interest, which can include the posing of questions and presenting of dilemmas. They introduce open-ended activities that enable students to investigate everyday or topical science issues and questions. They recognise students’ prior understanding and facilitated student centred discussion.</td>
</tr>
<tr>
<td>---</td>
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</tr>
</tbody>
</table>

Table 10.3: Reflecting on our science teaching and learning.

### 10.7 Scope and limitations of this research

This research will contribute to clarifying and making useable the concept of scientific literacy and so it has the potential to inform universities’ development of graduate attributes situated within the contemporary transition to sustainability. More specifically, it has the potential to broaden the conception of scientific literacy described in and reflected by the *Life and the Universe (LATU)* unit materials. The framework and indicators could assist in the review of the unit materials and assessment of student outcomes in scientific literacy. The students’ conceptions about the nature of science and its interaction with society uncovered through this research will provide a powerful start to constructivist teaching and learning for scientific literacy.
Notwithstanding the focus on the development of scientific literacy amongst first year university students, the applicability of this thesis is potentially much wider. The thrust of this research work is directed towards clarifying the meaning of scientific literacy within the context of sustainability and increasing the useability of the construct in teaching and learning. There is no reason in principle why the framework for scientific literacy should not be employed at any level of education, not just in higher education. Its adoption at other levels of education would be a means of conveying a more accurate understanding of what ‘science’ means and the role it plays within a society striving for sustainability. This research could guide science curriculum development and inform teaching and learning practices.

There are some limitations to the design of this research and these should be considered when generalising the findings. Firstly, there are two parts to the study as discussed in Chapter Five. The initial part of the study involved the 2001 LATU cohort and the second part involved the 2002 LATU cohort. The similar nature of these cohorts allowed 2002 participants to be considered as a subset of the 2001 group. The link between the two parts of the study was provided by the Nature of Science Likert scale. The Rasch analysis determined the location of the 2002 participants within the 2001 cohort. Ideally, however, the focus group participants would have come from the 2001 participants. In addition, the selection of the 2002 participants was not random. Random sampling was not an available option as the research process required the support of LATU Tutors. The sample was restricted to the students of the supporting Tutors. Students who represented the diversity of the cohort were approach to join the study. However, ultimately the sample represents students who were prepared to participate and stayed with the research project for two years.
In conclusion, meeting teaching and learning challenges requires a broader vision of science in the 21st century and a framework of scientific literacy that reflects this vision. The clear yet flexible framework and metaphor used in this research would aid in informing curriculum development and pedagogy contributing to a relevant science education and improved scientific literacy amongst the general population. It would encourage a broader vision of university foundation courses and specialist science education. This vision would be reflected in student centred, context driven learning that highlights connections across disciplines, collaboration and inquiry skills. A focus on these fundamental capabilities may come at the expense of covering content but university graduates could potentially be better prepared to take expert positions within the community and act as advisors to the general public. They would be active citizens who used science as a tool for thinking and acting in order to make sense of their world and for contributing to the achievement of sustainability.

It is essential to challenge students’ thinking and conceptions of the nature of science and its interaction with society in all educational settings. Teaching and learning for scientific literacy requires students to reflect on the aims and limitations of science in the attainment of a sustainable future. The concluding Life and the Universe (Macey & Lyons, 1998) lecture points to the required intellectual journey to achieve scientific literacy for sustainability. The epilogue states:

The challenge lies ahead. We started with the dream of a sustainable world in the stars, a bright future to use the cream of modern technology to escape the polluted Earth and build a new home on a terraformed planet. The dream has not died. We can still terraform a planet to develop a sustainable future for the human race but that planet must be the Earth (p. 314).
To ensure a move towards sustainable development and the survival of the planet for our children; we need to turn not only our science and technology but our imagination to address the problems of this planet (p. 316).
APPENDIX ONE

Questionnaire One

Questionnaire Two
This is not a test and there are no right or wrong answers. We would like you to express your personal views.

Before opening the booklet please answer the following questions.

1. Do you believe drinking a glass of wine daily with a meal can reduce the risk of developing colon cancer? Why do you say that?

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

2. Where do you get your information on current science issues? (Don’t include formal learning eg. University courses)

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
HEALTHY TIPPLE

New York

PEOPLE are already taking a glass of wine with meals in an effort to reduce their chances of heart disease. Now, a new study reports the fruit of the vine may also reduce the risk of developing colon cancer. Dr Anderson, associate professor of clinical medicine at the State University of New York discovered the wine link when studying several lifestyle factors influence on the development of precancerous growths called polyps. Lifestyle histories were recorded from 1,500 patients who were undergoing a screening test called a colonoscopy. It was found that 4.5% of the wine drinkers had polyps. The rate was almost twice as high in teetotalers.

3. After reading this news brief which states the researchers’ conclusion as, the fruit of the vine may also reduce the risk of developing colon cancer, Are you now more certain, less certain or equally certain of your background belief as described in question 1. Explain your answer.

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

4. Suppose this conclusion is very important to you and that you must determine whether it is a reliable one. What additional pieces of information if any, would you like to have about the researchers’ report to decide whether the researchers’ conclusion is true? Please list each point separately.

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
Indicate your level of agreement or disagreement with each of the following statements by circling one response

<table>
<thead>
<tr>
<th>Item</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Creativity and imagination play an important part in science.</td>
<td>SA</td>
<td>A</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>6. Scientific knowledge has been tested and can be accepted as truth.</td>
<td>SA</td>
<td>A</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>7. Scientists study a world in which they are a part and as such their work is not objective or value free.</td>
<td>SA</td>
<td>A</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>8. Science is based on an accumulated static body of knowledge.</td>
<td>SA</td>
<td>A</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>9. There is a set of fixed steps that scientists always use which leads to scientific knowledge.</td>
<td>SA</td>
<td>A</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>10. Scientists may, because of their background, personal beliefs and values, emphasize different interpretations of evidence.</td>
<td>SA</td>
<td>A</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>11. Even though science is an activity carried out by many different people, science hardly ever reflects values and viewpoints related to society (e.g. views on women, political beliefs).</td>
<td>SA</td>
<td>A</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>12. Scientists can seldom bring final answers to matters of public debate (e.g. nuclear power).</td>
<td>SA</td>
<td>A</td>
<td>D</td>
<td>SD</td>
</tr>
<tr>
<td>13. The spreading of scientific information is unimportant to the progress of science.</td>
<td>SA</td>
<td>A</td>
<td>D</td>
<td>SD</td>
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<tr>
<td>14. The bodies (e.g. government departments) which supply the money for research influence the direction of science.</td>
<td>SA</td>
<td>A</td>
<td>D</td>
<td>SD</td>
</tr>
</tbody>
</table>
15. Circle one: Male or Female

16. If you took Year 11/12 Science, tick the box for each course taken. Please fill in the year in which you took the course(s).

<table>
<thead>
<tr>
<th>Course</th>
<th>Yr 11 (year: )</th>
<th>Yr 12 (year: )</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td></td>
<td></td>
</tr>
<tr>
<td>biology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>human biology</td>
<td></td>
<td></td>
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<tr>
<td>physical science</td>
<td></td>
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<tr>
<td>physics</td>
<td></td>
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<tr>
<td>chemistry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>other:</td>
<td></td>
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</tr>
</tbody>
</table>

If you didn’t complete a Yr 11/12 science course, what was the last science course you took and when?

_______________________________________________________________________
_______________________________________________________________________

17. Have you completed any science course/unit at a post secondary level? Circle one: Yes or No

If yes, briefly describe this course/unit.

_______________________________________________________________________
_______________________________________________________________________

18. What is the degree program you are currently enrolled in?

_______________________________________________________________________
_______________________________________________________________________
This is not a test and there are no right or wrong answers.  
*We would like you to express your personal views.*

**Before opening the booklet please answer the following questions.**

1. Do you believe drinking orange juice daily can reduce the risk of heart disease? Why do you say that?

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________


ORANGES KEEP THE HEART DOCTOR AWAY

Atlanta

Researchers from the University of Western Ontario found when subjects with high cholesterol levels began drinking orange juice, the amount of good cholesterol HDL increased. HDL is responsible for transporting the bad cholesterol LDL out of the body. Both an increase in HDL and a decrease in the cholesterol ratio reduce the risk of heart disease.

Dr Kiosk, a research associate at the University’s Centre for Human Nutrition measured cholesterol in 25 subjects and then had them substitute orange juice for their regular beverage. They started with one glass building up to three glasses a day during the third month of the trials. It was found when cholesterol levels were measured again the average HDL cholesterol rose 21 percent and the ratio of HDL cholesterol to total cholesterol decreased by 16 percent. The implications of this research are significant as it is normally difficult to change HDL through diet.

3. After reading this news brief which states the researchers’ conclusion as, drinking three glasses of orange juice daily may reduce the risk of heart disease, are you now more certain, less certain or equally certain of your background belief as described in question 1. Explain your answer.

_____________________________________________________________________
_____________________________________________________________________
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4. Suppose this conclusion is very important to you and that you must determine whether it is reliable. What extra information if any, would you like to have about the researchers’ report to decide whether this conclusion is true? Please list each point separately.

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16. If you took Year 11/12 Science, tick the box for each course taken. Please fill in the year in which you took the course(s).

<table>
<thead>
<tr>
<th></th>
<th>none</th>
<th>biology</th>
<th>Human biology</th>
<th>physical science</th>
<th>physics</th>
<th>chemistry</th>
<th>Other:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yr 11 (year:  )</td>
<td></td>
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<td></td>
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<tr>
<td>Yr 12 (year:  )</td>
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<td></td>
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______________________________________________________________________
______________________________________________________________________
APPENDIX TWO

(i) Workshop and follow up interview activities
(ii) Workshop news briefs
(iii) Follow up interview news briefs
Workshop and Follow up Interview Activities

Activity One: What is this thing called ‘science’?
- Write in your own words what you mean by the term science.
- Develop a mind map to expand your thinking on science.

Activity Two: Draw a scientist
- Draw a picture of a scientist.
- Surround your picture with words you think describe the work of your scientist.

Questions Guiding Discussion
- Can scientific knowledge be accepted as truth?
- What factors influence the direction scientific research takes?
- Do scientists research objectively?
- Do scientists display professional standards of openness of mind and honesty with a moral and ethical approach to their work?

Activity Three: Science in the News
- Read all three of the following news articles.
- Choose one of the articles you read to answer the following
- Write a paragraph on the article explaining the research to someone who has no knowledge on the topic.
- What is the researchers’ conclusion?
- Do you agree with the researchers’ conclusion? Why or why not?
- In order to evaluate the research, what other information would you want?
- How would you test the researchers’ conclusion?

Questions Guiding Discussion
- What is the purpose of scientific research generally?
- What role do you think science takes in your life and society generally?
- What is a scientific theory?
- What place does creativity have in science?
Science in the News

Read all three of the following news articles.

Undersea clue to copper bonanza

Jeremy Roberts

THE PLAINS of western NSW might be concealing major copper and gold deposits linked in geological history to the zinc and lead found at Broken Hill, according to explorer-geologists from CSIRO.

A 52-day research expedition along the continental shelf of the Pacific Ocean has found evidence of a link between the formation of lead and zinc by undersea volcanoes and the formation of copper and gold by the same volcanoes.

If verified at other undersea volcano locations the conclusions point to an undiscovered copper and gold deposit in the Broken Hill area, co-chief scientist for the expedition Ray Binns said.

The geology at Broken Hill was formed by underwater conditions with "black smokers" volcanoes spewing out a mineral deposit of several different metals.

Dr Binns, CSIRO's chief research scientist of exploration and mining, said the expedition found evidence that the process separated the lead and zinc from copper and gold, which was deposited elsewhere.

The main thrust of the research, which is being partly funded by mining companies, was to study how mineral deposits form in volatile undersea conditions.

The team of 12 geologists from four Australian universities sought to identify "signature" in the geology of the seabed that gave clues as to where ore bodies may be found on dry land.

The expedition on the CSIRO research vessel R/V Franklin began north of Papua New Guinea and finished in the Solomon Islands, returning to Australia last month.

Dr Binns led the first half of the journey to Rabaul and said the trip was part of the ongoing exploration of the "Pacific rim of fire" in collaboration with countries including Japan, Korea and The Philippines.

Funding, by the federal Government foreign aid agency AusAID, of research collaboration and training with Indonesia will be withdrawn from June, Dr Binns said.

The mining of minerals on the sea floor was generally not done but if a large deposit was found mining companies had a range of options.

"They could scrape it off the sea floor, or shoot it, depending on how hard the material was," Dr Binns said.

Weekend Australian May 4, 2002

In-vitro soil breakthrough boost for trees, plants

By Michael Southwell

AGRICULTURE Department researchers have claimed a world first in the science of growing trees and plants in nurseries.

The new method of propagation dubbed in-vitro soil is said to have important implications for the future of WA’s native flower export market and tree-growing industries.

Department scientists found that traditional techniques for culturing plants from tissue samples in laboratories had a low success rate when the seedlings were propagated because of poor root growth.

They replaced the normal agar medium used to grow the seedlings with a sterile soil mix, with instant results.

"Roots that grow in this new system are more like naturally occurring root systems, compared with roots that grow in traditional agar-based systems," researcher Chris Newell said. "In-vitro soil has the potential to lower production costs by lowering plant losses, improving material handling rates and shortening propagation times.

"It integrates well with modern nursery practices, is readily available and does not require a large amount of expensive retrofitting.

Plant tissue culture is a propagation method, based on selecting elite individual plants, then cloning that individual to capture the genetic benefit of the desirable variation it possesses.

This might be a plant or tree that is fast-growing, has high fruit numbers or a desirable flower colour.

West Australian May 1, 2002

Kitchens may sink fertility

The continuing use of microwave ovens in the kitchen may be affecting women's fertility, according to an Italian study.

Women are exposed to electromagnetic fields from microwave ovens in the home and from aircraft and power lines and the use of appliances such as hairdryers and radios.

Dr Sandra Bonomi from the University of Milan, in a study of fertility in Rome, said EMF from microwave ovens may be affecting the ovaries of women exposed to it.
Follow up interview news briefs

Alcoa cancer risk ‘not higher’

By Griffin Longley

ALCOA’s Kwinana staff are no more at risk of cancer than the general population, says the Health Department.

The department finding is based on Alcoa commissioned research into the health of workers in an area known as department K58, some of whom had either died of cancer or become ill.

The study followed a recommendation by University of WA public health professor D’Arcy Holman on behalf of former workers and widows.

Department of Health executive director of population health Michael Jackson said the study was carried out independently by Monash University and UWA in response to community concerns.

“The researchers have compared the statistics of cancer risk in the refinery’s workforce with that of the general Western Australian population,” Mr Jackson said.

“And so far they have found no evidence to suggest that cancer rates among workers at Alcoa are disparate with the general population.

“Essentially, the numbers found in the Alcoa group were fewer than would have been expected, but not significantly different.

Of the 1844 men involved in the study, 64 reported cancers, compared with an expected 67.3 cancers in men of the same age in the general WA population over the same period.

Only three cancers were found among the 169 women surveyed.

Dust and workplace health campaigner Keith Woolard said the figures were no basis for the department to reassure the public.

But Alcoa’s director of WA Operations Giulio Castello said the findings did provide reassurance to the community and employees.

“The research is ongoing and will continue to give us valuable information about the workforce,” he said.

Sage, the thinking man’s herb

Nigel Hawkes

SAGE has lived up to its name by enhancing the memory of volunteers in controlled experiments.

Students at the University of Northumbria in Newcastle upon Tyne performed better on word-memorizing tests after they had swallowed sage oil capsules and the effects lasted for several hours.

Nicolle Tidestly, the lead researcher, said it was possible the herb could benefit those suffering from the first stages of Alzheimer’s disease.

“Unfortunately, our memories start to decline from the age of 36,” she said. “It is possible that sage might be used to bring you back to a reasonable level.”

Results are expected shortly from a new trial by the Newcastle team testing the effect of sage on patients with Alzheimer’s disease.

The research results would have come as no surprise to the herbalists of old, who swore by the value of sage.

The 16th-century herbalist John Gerard wrote of sage in 1597: “It is singularly good for the head and brain and quickeneth the nerves and memory."

Nicholas Culpeper, in his book The English Physician, said: “Sage B of excellent use to help the memory, warming and quickening the senses.”

The Newcastle team recruited 44 undergraduates for experiments designed to test the herbalists’ convictions.

The volunteers, whose ages ranged from 18 to 27, were given a capsule of oil of Spanish sage or a placebo and tested for memory. Those given sage capsules showed a better performance. The effects were significant up to two hours.

New hope for brain-injured

By JANE LOVBOND

A TEAM of scientists has made an extraordinary breakthrough that could lead the world in treating strokes, Alzheimer’s disease and other brain-related diseases.

The group, led by University of Tasmania neuroscientist Roger Chung, has been hailed by researchers worldwide and has published its findings in the Journal of Neuroscience.

Mr Chung and the team discovered they had unwittingly tapped into one of the brain’s oldest secrets while working on brain proteins to find a cure for Alzheimer’s disease.

“We realised we had discovered a brain protein with the ability to help the brain heal itself,” he said. “We are still working on our project, but it seems it could have a much wider application than we first thought.

“Basically, this protein could heal damaged brain cells without the need for invasive surgery or using stem cells.”

Mr Chung said it could be five years or more before a commercial treatment was available. And he said people with recent brain injuries were likely to respond more readily than those who had been incapacitated for a long time.

The team has an international patent on using the naturally occurring protein, called metalloelastin.

With these proteins normally present in the brain after trauma, Mr Chung and his colleagues are working on how to trigger the substance or produce it synthetically.

AUSTRALIAN

AUG 20TH '03
APPENDIX THREE

An example of a participant’s checklist
## Indicators of Scientific Literacy

**Name:** Marie

<table>
<thead>
<tr>
<th>Indicators</th>
<th>2002 Quest. 1</th>
<th>2002 LATU Work samples</th>
<th>2002 Workshop Comments</th>
<th>2003 Quest. 2</th>
<th>2003 Interview + Work sheets</th>
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<td>Can use scientific vocabulary in a particular activity for a specific need, i.e., defining a term on a test</td>
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<td>Can read a newspaper article and define a scientific term used</td>
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<tr>
<td>Uses scientific vocabulary but without a broader conceptual understanding in relation to the discipline.</td>
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<tr>
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<tr>
<td>Able to state examples of scientific activity or processes but without a demonstrable functional understanding</td>
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<tr>
<td>Demonstrates an understanding of the way conceptual parts of the discipline relate to the whole discipline</td>
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<td>Demonstrates an understanding of scientific concepts within a context but does not relate the concept to the discipline as a whole.</td>
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<tr>
<td>Reads science news briefs and relates the content to the broader discipline and or the processes of science.</td>
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<tr>
<td>Can use vocabulary in context or in laboratory work, i.e., making observations inferences and hypothesising.</td>
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<td>Demonstrates a functional understanding of scientific method, e.g., able to design, conduct and report on a controlled scientific experiment or investigation.</td>
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<tr>
<td>Recognises scientifically investigatable questions.</td>
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<td>Can identify, draw or evaluate conclusions from first hand data or reported science investigations.</td>
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<td>Communicates valid conclusions from first or second hand data.</td>
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<td>Multidimensional Scientific Literacy</td>
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<td>Has some knowledge of the history of scientific ideas.</td>
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<tr>
<td>Displays an understanding of the aims and limitations of scientific processes.</td>
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<tr>
<td>Understands the nature of scientific theories and the role of continuous testing and retesting that occasionally results in the discarding of new and old theories.</td>
<td>1</td>
<td>*</td>
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<tr>
<td>Understands that scientific knowledge has a temporary status and should not be accepted as unquestionable truth.</td>
<td>1</td>
<td>*</td>
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</tr>
<tr>
<td>Views scientists as studying a world in which they are a part and as such their work is not objective or value free.</td>
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<td>1</td>
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<tr>
<td>Understands new scientific knowledge is produced as a result of creativity and imagination coupled with scientific method.</td>
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<td>Views science as progressing through continuing research and critical questioning.</td>
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<td>1</td>
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</tr>
<tr>
<td>Views science as dynamic and ongoing, not a static accumulation of information.</td>
<td>*</td>
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<td>1</td>
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<tr>
<td>Displays an awareness of the concept of observations being made from a personal perspective built up by prior knowledge, beliefs and theories.</td>
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<tr>
<td>Shows confidence in scientists’ and the scientific community’s professional standards of openness of mind and honesty and their moral and ethical approach to their profession.</td>
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<tr>
<td>Shows an awareness of the role science takes in their personal life and society generally.</td>
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<td>Demonstrates a contextual understanding of science ideas and concepts by relating them to other disciplines.</td>
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<tr>
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<td>Makes connections within the discipline and with larger social problems and endeavours.</td>
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<tr>
<td>Understands the spreading of scientific information is important to the progress of science.</td>
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APPENDIX FOUR

(i) Summary of Indicators of Scientific Literacy: Conceptions
(ii) Summary of Indicators of Scientific Literacy: Misconceptions
Summary of Indicators of Scientific Literacy:

Conceptions

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<tr>
<td>Shows an understanding of the cultural context of science.</td>
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<td>3</td>
<td>14</td>
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<td>Makes connections within the discipline and with larger social problems and endeavours.</td>
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<td>Critically evaluates science news reports based on an understanding of the general aims, limits</td>
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## Summary of Indicators of Scientific Literacy: Misconceptions

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<tr>
<th>Indicators</th>
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<td>Can use scientific vocabulary in a particular activity for a specific need, i.e., defining a term on a test</td>
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<td>8</td>
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<tr>
<td>Can read a newspaper article and define a scientific term used</td>
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<td></td>
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<td>Able to memorize and restate lists of vocabulary</td>
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<td>Demonstrates an understanding of the way conceptual parts of the discipline relate to the whole discipline</td>
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<tr>
<td>Demonstrates an understanding of scientific concepts within a context but does not relate the concept to the discipline as a whole.</td>
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<tr>
<td>Reads science news briefs and relates the content to the broader discipline and or the processes of science.</td>
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<td>2</td>
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<td>Can use vocabulary in context or in laboratory work, i.e., making observations inferences and hypothesising.</td>
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<tr>
<td>Demonstrates a functional understanding of scientific method, e.g., able to design, conduct and report on a controlled scientific experiment or investigation.</td>
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<td>Recognises scientifically investigatable questions.</td>
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<td>Can identify, draw or evaluate conclusions from first hand data or reported science investigations.</td>
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<td>Communicates valid conclusions from first or second hand data.</td>
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<tr>
<td>Has some knowledge of the history of scientific ideas.</td>
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<td>1</td>
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<td>Displays an understanding of the aims and limitations of scientific processes.</td>
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<tr>
<td>Understands the nature of scientific theories and the role of continuous testing and retesting that occasionally results in the discarding of new and old theories.</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
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<tr>
<td>Understands that scientific knowledge has a temporary status and should not be accepted as unquestionable truth.</td>
<td>11</td>
<td>1</td>
<td>6</td>
<td>8</td>
<td>9</td>
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<tr>
<td>Views scientists as studying a world in which they are a part and as such their work is not objective or value free.</td>
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<td>1</td>
<td>4</td>
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<tr>
<td>Understands new scientific knowledge is produced as a result of creativity and imagination coupled with scientific method.</td>
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<td>Views science as progressing through continuing research and critical questioning.</td>
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<td>1</td>
<td>1</td>
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<td>Views science as dynamic and ongoing, not a static accumulation of information.</td>
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<td>1</td>
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<td>17</td>
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<td>Displays an awareness of the concept of observations being made from a personal perspective built up by prior knowledge, beliefs and theories.</td>
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<td>Shows confidence in scientists’ and the scientific community’s professional standards of openness of mind and honesty and their moral and ethical approach to their profession.</td>
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<td></td>
<td>3</td>
<td>8</td>
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<td>Shows an awareness of the role science takes in their personal life and society generally.</td>
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<td>2</td>
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<td>Shows an understanding of the cultural context of science.</td>
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<tr>
<td>Makes connections within the discipline and with larger social problems and endeavours.</td>
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<tr>
<td>Understands the spreading of scientific information is important to the progress of science.</td>
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<tr>
<td>Demonstrates the competence and confidence to make informed decisions relating to or involving scientific ideas.</td>
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<tr>
<td>Critically evaluates science news reports based on an understanding of the general aims, limitations and social context of the scientific enterprise.</td>
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APPENDIX FIVE

(i) Question 3: Pre-LATU responses

(ii) Question 3: Post-LATU responses
**Question 3: Pre-LATU responses.**

The distribution of the responses in each category generated for question 3 is shown below. The frequencies are shown as a percentage followed by the number in brackets.

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<th>Science background</th>
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Question 3: Post-LATU responses

The participants’ post LATU responses to question 3 were classified into the same categories used for the pre LATU data. The distribution of the post responses is shown in Table A5.2. The total number of participants was 166. Two participants did not respond to this question so the total number of useable responses was 164.

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<th>Course</th>
<th>Gender</th>
<th>Time out of school</th>
<th>Science background</th>
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<td>0 (0)</td>
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<td>0 (0)</td>
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<td>11 (7)</td>
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<td>10 (9)</td>
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<td>10 (9)</td>
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APPENDIX SIX

The statistical summaries of each subgroups pre and post-LATU response to question 3.

(i) Gender
(ii) Time out of school
(iii) Course
(iv) Science background
### GENDER

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<th>Uncritical 1 % (n)</th>
<th>Critical 2 % (n)</th>
<th>Total % (n)</th>
<th>Mean</th>
<th>Independent t-test</th>
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<td>44.5 (34)</td>
<td>47.5 (36)</td>
<td>100 (76)</td>
<td>1.39</td>
<td>.635</td>
<td>t=.516 p&lt;.607</td>
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<td>Female</td>
<td>12.5 (11)</td>
<td>41 (36)</td>
<td>46.5 (41)</td>
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<td>1.34</td>
<td>.693</td>
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<td>Post-LATU Male</td>
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<td>46 (35)</td>
<td>51.5 (39)</td>
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<td>1.49</td>
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<td>t= 1.918 p&lt; .057</td>
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### TIME OUT OF SCHOOL

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<th>Time out of School</th>
<th>Other 0 % (n)</th>
<th>Uncritical 1 % (n)</th>
<th>Critical 2 % (n)</th>
<th>Total % (n)</th>
<th>Mean</th>
<th>Independent t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-LATU Mature</td>
<td>12 (4)</td>
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<td>39 (37)</td>
<td>100 (95)</td>
<td>1.28</td>
<td>0.647</td>
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<tr>
<td>Post-LATU Mature</td>
<td>6 (2)</td>
<td>45.5 (15)</td>
<td>48.5 (16)</td>
<td>100 (33)</td>
<td>1.42</td>
<td>0.614</td>
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<table>
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<td>Dependent t-test</td>
<td>Dependent t-test</td>
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</tr>
<tr>
<td>t= 0.197</td>
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</tr>
<tr>
<td>p&lt; 0.845</td>
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Note: There were 36 participants answering question 3 who were unspecified in time out of school and as such they were not included in this analysis and summary.
### COURSE

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<th>Critical 2 % (n)</th>
<th>Total % (n)</th>
<th>Mean SD</th>
<th>Independent t-test</th>
</tr>
</thead>
<tbody>
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<td>Pre-LATU Matched</td>
<td>Science</td>
<td>8.5 (8)</td>
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<td>100 (95)</td>
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<td>.644</td>
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<td>45.5 (29)</td>
<td>100 (64)</td>
<td>1.32</td>
<td>.691</td>
<td></td>
</tr>
<tr>
<td>Post-LATU</td>
<td>Science</td>
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<td>100 (95)</td>
<td>1.36</td>
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<tr>
<td>Non-Sc</td>
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<td>37.5 (24)</td>
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<td>1.44</td>
<td>.540</td>
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<table>
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<th>Science-based Dependent t-test</th>
<th>Non-science Dependent t-test</th>
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</thead>
<tbody>
<tr>
<td>Pre-LATU</td>
<td>t= -.418 p&lt;.677</td>
<td>t= -.275 p&lt;.784</td>
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<td>Post-LATU</td>
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Note: There were 5 participants answering question 3 who were unspecified in course and as such they were not included in this analysis and summary.
### SCIENCE BACKGROUND

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<th>Uncritical 1% (n)</th>
<th>Critical 2% (n)</th>
<th>Total 100% (n)</th>
<th>Mean SD</th>
<th>Independent t-test Compared to No Sc.</th>
</tr>
</thead>
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<td>47 (8)</td>
<td>41 (7)</td>
<td>100 (17)</td>
<td>1.29</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Biological</td>
<td>21.5 (8)</td>
<td>38 (14)</td>
<td>40.5 (15)</td>
<td>100 (37)</td>
<td>1.18</td>
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<tr>
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<td>Physical</td>
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<td>44.5 (12)</td>
<td>51.5 (37)</td>
<td>100 (72)</td>
<td>1.063</td>
<td>t= -1.098 p&lt;.275</td>
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<tr>
<td>Post-LATU</td>
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<td>6 (1)</td>
<td>59 (10)</td>
<td>35 (6)</td>
<td>100 (17)</td>
<td>1.29</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Biological</td>
<td>0 (0)</td>
<td>54 (20)</td>
<td>46 (17)</td>
<td>100 (37)</td>
<td>1.46</td>
<td>t= -1.061 p&lt;.294</td>
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<tr>
<td></td>
<td>Physical</td>
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<td>52.5 (20)</td>
<td>45 (17)</td>
<td>100 (38)</td>
<td>1.42</td>
<td>t= -.773 p&lt;.443</td>
</tr>
<tr>
<td></td>
<td>Phys.&amp; Biol.</td>
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<td>58.5 (42)</td>
<td>40.5 (29)</td>
<td>100 (72)</td>
<td>1.39</td>
<td>t= -.660 p&lt;.511</td>
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</table>

<table>
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<tr>
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<th>Biological Dependent t-test</th>
<th>Physical Dependent t-test</th>
<th>Both Phys &amp; Biol Dependent t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-LATU</td>
<td>t= 0.0</td>
<td>t= -1.709</td>
<td>t= -0.404</td>
<td>t= 1.062</td>
</tr>
<tr>
<td>Post-LATU</td>
<td>p&lt; 1.0</td>
<td>p&lt; 0.096</td>
<td>p&lt; 0.689</td>
<td>p&lt; 0.292</td>
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</table>
APPENDIX SEVEN

(i) Question 4: Pre-LATU responses

(ii) Question 4: Post-LATU responses
Question 4: Pre-LATU responses

A total of 63 participants made requests for information that fitted 2 categories while 6 participants made requests fitting into 3 categories. In contrast 9 participants did not respond and as a result the total number of requests for information was 296.

<table>
<thead>
<tr>
<th>Category</th>
<th>Tot pop. % (n)</th>
<th>Course</th>
<th>Gender</th>
<th>Time out of school</th>
<th>Science background</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Science % (n)</td>
<td>Non-Sc % (n)</td>
<td>Male % (n)</td>
<td>Female % (n)</td>
<td>Sch. Leaver % (n)</td>
</tr>
<tr>
<td>Social context (m)</td>
<td>14 (41)</td>
<td>11 (20)</td>
<td>16.5 (19)</td>
<td>19.5 (27)</td>
<td>9 (14)</td>
</tr>
<tr>
<td>Ongoing research (m)</td>
<td>16.5 (49)</td>
<td>17 (30)</td>
<td>16.5 (19)</td>
<td>21.5 (30)</td>
<td>12 (19)</td>
</tr>
<tr>
<td>Research methods (cp)</td>
<td>38 (112)</td>
<td>39 (69)</td>
<td>37 (42)</td>
<td>33 (46)</td>
<td>42 (66)</td>
</tr>
<tr>
<td>Data and stats. (cp)</td>
<td>10.5 (32)</td>
<td>13 (23)</td>
<td>8 (9)</td>
<td>6.5 (9)</td>
<td>14.5 (23)</td>
</tr>
<tr>
<td>Clarifying article (f)</td>
<td>12 (35)</td>
<td>11 (19)</td>
<td>12.5 (14)</td>
<td>12.5 (17)</td>
<td>11.5 (18)</td>
</tr>
<tr>
<td>Off-task (f)</td>
<td>9 (27)</td>
<td>9 (16)</td>
<td>9.5 (11)</td>
<td>7 (10)</td>
<td>11 (17)</td>
</tr>
<tr>
<td>Total</td>
<td>100 (296)</td>
<td>100 (177)</td>
<td>100 (114)</td>
<td>100 (139)</td>
<td>100 (157)</td>
</tr>
<tr>
<td>No response</td>
<td>(9)</td>
<td>(3)</td>
<td>(5)</td>
<td>(4)</td>
<td>(5)</td>
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</table>
Question 4: Post-LATU responses

Post LATU participants’ requests for extra information were classified into the 6 categories used for the pre LATU data. There were 6 participants who did not respond to this question. In addition, 39 participants made requests fitting 2 categories and 1 participant made a request fitting into 3 categories. Hence for the total population number of responses is 201

<table>
<thead>
<tr>
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<th>Tot pop. % (n)</th>
<th>Course</th>
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<th>Science background</th>
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<td></td>
<td></td>
<td>Science course % (n)</td>
<td>Non-Sc course % (n)</td>
<td>Male % (n)</td>
<td>Female % (n)</td>
</tr>
<tr>
<td>1. Social context (m)</td>
<td>18.5 (37)</td>
<td>20 (24)</td>
<td>17.5 (13)</td>
<td>25 (25)</td>
<td>12 (12)</td>
</tr>
<tr>
<td>2. Ongoing research (m)</td>
<td>18 (36)</td>
<td>15.5 (19)</td>
<td>20.5 (15)</td>
<td>19.5 (20)</td>
<td>16 (16)</td>
</tr>
<tr>
<td>3. Research methods (cp)</td>
<td>40.5 (82)</td>
<td>43.5 (53)</td>
<td>35 (26)</td>
<td>32.5 (33)</td>
<td>49 (49)</td>
</tr>
<tr>
<td>4. Data and stats. (cp)</td>
<td>8 (16)</td>
<td>6.5 (8)</td>
<td>9.5 (7)</td>
<td>6 (6)</td>
<td>10 (10)</td>
</tr>
<tr>
<td>5. Clarification of article (f)</td>
<td>11 (22)</td>
<td>13 (16)</td>
<td>9.5 (7)</td>
<td>12 (12)</td>
<td>10 (10)</td>
</tr>
<tr>
<td>6. Off-task (f)</td>
<td>4 (8)</td>
<td>1.5 (2)</td>
<td>8 (6)</td>
<td>5 (5)</td>
<td>3 (3)</td>
</tr>
<tr>
<td>Total responses</td>
<td>100 (201)</td>
<td>100 (122)</td>
<td>100 (74)</td>
<td>100 (101)</td>
<td>100 (100)</td>
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<tr>
<td>No response</td>
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<td>(1)</td>
<td>(5)</td>
<td>(0)</td>
<td>(6)</td>
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APPENDIX EIGHT

The statistical summaries of each subgroups pre and post-LATU response to question 4.

(i) Gender
(ii) Time out of school
(iii) Course
(iv) Science background
### GENDER

<table>
<thead>
<tr>
<th>Data Q4</th>
<th>Gender</th>
<th>Functional % (n)</th>
<th>Conceptual/Procedural % (n)</th>
<th>Multi-dimensional % (n)</th>
<th>Total % (n)</th>
<th>Mean</th>
<th>SD</th>
<th>Independent t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-LATU</td>
<td>Male</td>
<td>20 (15)</td>
<td>43.5 (33)</td>
<td>36.5 (28)</td>
<td>100 (76)</td>
<td>1.173</td>
<td>.742</td>
<td>t=1.558 p&lt;.121</td>
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<tr>
<td></td>
<td>Female</td>
<td>15.5 (13)</td>
<td>68 (57)</td>
<td>16.5 (14)</td>
<td>100 (84)</td>
<td>1.01</td>
<td>.567</td>
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<tr>
<td>Post-LATU</td>
<td>Male</td>
<td>18.5 (14)</td>
<td>41 (31)</td>
<td>40.5 (31)</td>
<td>100 (76)</td>
<td>1.22</td>
<td>.741</td>
<td>t=1.918 p&lt;.057</td>
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<td>Female</td>
<td>13 (11)</td>
<td>63 (53)</td>
<td>24 (20)</td>
<td>100 (84)</td>
<td>1.11</td>
<td>.602</td>
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**Note:** There were 35 participants answering question 4 who were unspecified in time out of school and as such they were not included in this analysis and summary.

### TIME OUT OF SCHOOL

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<th>Functional % (n)</th>
<th>Conceptual/Procedural % (n)</th>
<th>Multi-dimensional % (n)</th>
<th>Total % (n)</th>
<th>Mean</th>
<th>SD</th>
<th>Independent t-test</th>
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</thead>
<tbody>
<tr>
<td>Pre-LATU</td>
<td>Mature</td>
<td>15.5 (5)</td>
<td>44 (14)</td>
<td>40.5 (13)</td>
<td>100 (32)</td>
<td>1.273</td>
<td>.719</td>
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<td>100 (93)</td>
<td>1.01</td>
<td>.620</td>
<td></td>
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<tr>
<td>Post-LATU</td>
<td>Mature</td>
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<td>47 (15)</td>
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<td>59 (55)</td>
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<th>School leaver</th>
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<tr>
<td>Post-LATU</td>
<td>-0.618</td>
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Note: There were 35 participants answering question 4 who were unspecified in time out of school and as such they were not included in this analysis and summary.
### Data Q4

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<th>Independent t-test</th>
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<td>2 % (n)</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>21.5 (20)</td>
<td>100</td>
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<td>37.5 (23)</td>
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<td>1.21</td>
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Note: There were 5 participants answering question 4 who were unspecified in course and as such they were not included in this analysis and summary.
### SCIENCE BACKGROUND

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<th>Conceptual/Procedural 1 % (n)</th>
<th>Multi-dimensional 2 % (n)</th>
<th>Total % (n)</th>
<th>Mean SD</th>
<th>Independent t-test Compared to No Sc.</th>
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<tr>
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<td>53.5 (8)</td>
<td>26.5 (4)</td>
<td>100 (15)</td>
<td>1.06 .680</td>
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<tr>
<td></td>
<td>Biological</td>
<td>11 (4)</td>
<td>50 (18)</td>
<td>39 (14)</td>
<td>100 (36)</td>
<td>1.27 .652</td>
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<td>Physical</td>
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<td>47.5 (18)</td>
<td>34 (13)</td>
<td>100 (38)</td>
<td>1.139 .723</td>
<td>t=-.358 p&lt;.722</td>
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<td>Phys. &amp; Biol.</td>
<td>19.5 (14)</td>
<td>63.5 (45)</td>
<td>17 (12)</td>
<td>100 (71)</td>
<td>.972 .609</td>
<td>t=.527 p&lt;.600</td>
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<tr>
<td>Post-LATU</td>
<td>No Science</td>
<td>20 (3)</td>
<td>46.5 (7)</td>
<td>33.5 (5)</td>
<td>100 (15)</td>
<td>1.13 .743</td>
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<td>Biological</td>
<td>14 (5)</td>
<td>55.5 (20)</td>
<td>30.5 (11)</td>
<td>100 (36)</td>
<td>1.17 .655</td>
<td>t=-1.061 p&lt;.294</td>
</tr>
<tr>
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<td>Physical</td>
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<td>37 (14)</td>
<td>39.5 (15)</td>
<td>100 (38)</td>
<td>1.16 .789</td>
<td>t=-.773 p&lt;.443</td>
</tr>
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<td>Phys. &amp; Biol.</td>
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<td>60.5 (43)</td>
<td>28 (20)</td>
<td>100 (71)</td>
<td>1.17 .609</td>
<td>t=-.660 p&lt;.511</td>
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<table>
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<th>Physical Dependent t-test</th>
<th>Both Phys &amp; Biol Dependent t-test</th>
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</thead>
<tbody>
<tr>
<td>Pre-LATU</td>
<td>t= 0.00</td>
<td>t= 1.044</td>
<td>t= 0.00</td>
<td>t= -2.239</td>
</tr>
<tr>
<td>Post-LATU</td>
<td>p&lt; 1.00</td>
<td>p&lt; 0.304</td>
<td>p&lt; 1.00</td>
<td>p&lt; 0.028</td>
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</tbody>
</table>
APPENDIX NINE

Multiple requests for extra information in question 4.
Multiple requests for extra information in question 4 pre- and post-LATU.

Note: Participant responses highlighted in red do not demonstrate a linear and hierarchical development from category 0 through to 2. This includes 8 pre-LATU participants’ responses and 6 post-LATU responses.

<table>
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APPENDIX TEN

Profile of focus group participants
### Profile of focus group participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Background</th>
<th>2002: Selection</th>
<th>2003: Following up</th>
</tr>
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<tbody>
<tr>
<td><strong>Jessica</strong></td>
<td>Jessica was a school leaver who had studied Human Biology, Physics and Chemistry in Year 12. She was enrolled full time in a Bachelor of Science in Biomedical Science. Her units for the year included, Life and the Universe, Introduction to the Human Body, Principles of Vertebrate Biology, Introduction to Developmental Psychology, Cell Biology, Biostatistics, Chemistry for Biological Science and Introduction to Psychology.</td>
<td>Likert scale score: 13/30 Logit: 0.883 She responded to the news brief in a manner, which suggested she was at a functional level of scientific literacy. She wrote, <em>the conclusion still only says it may reduce the risk. It hasn’t been proven yet.</em> Her requests for extra information could indicate some developing conceptual/procedural indicators. This included, ages, gender and family history of patients.</td>
<td>Likert scale score: 19/30 Logit: 1.124 Jessica had continued with full time studies in Biomedical science. She again made a functional response to the news brief. She said, <em>without the knowledge that OJ contains HDL, I would be less likely to believe it reduces heart disease risk.</em> Her requests for further information were again at a conceptual/procedural level. She included for example, diet, age, sex, race, family history, exercise programs and smoking/non-smoking.</td>
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<tr>
<td><strong>Lisa</strong></td>
<td>Lisa was a school leaver who was enrolled part time in a Bachelor of Science, majoring in mathematics and statistics. She completed year 12 part time over two years and studied chemistry and human biology. Her 1st year university program included LATU, Fundamentals of Mathematics, Applied Mathematics, Statistical data analysis and Introduction to Accounting.</td>
<td>Likert scale score: 14/30 Logit: -0.371 Her responses to the news brief suggested she had a functional level of scientific literacy with some conceptual/procedural level indicators developing. She requested information regarding variables in the reported research that could influence the findings. She asked, <em>what lifestyle history was recorded, diet, exercise, gender and age.</em> She did not completely accept the researchers’ conclusion commenting that there was however, <em>some evidence to support it.</em></td>
<td>Likert scale score: 16/30 Logit: 0.013 Lisa had continued with her part time studies but had enrolled as an external student. She appeared to engage more critically with the news brief. She said, <em>I would probably change my mind slightly but not totally based on one report. You would need various sources to come up with the answer.</em> Her requests for extra information were again mainly procedural but now also included a multidimensional indicator. She listed, <em>raw statistics, how was the test carried out and the experience of the researchers.</em></td>
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<tr>
<td><strong>Newton</strong></td>
<td>Newton was a male mature age student enrolled in Sustainable Development. This was his first experience of tertiary study. He had no other formal science</td>
<td>Likert scale score: 15/30 Logit: -0.183 His responses to the news brief suggested he had a functional level of scientific literacy. He made limited requests for information in</td>
<td>Likert scale score: 16/30 Logit: 0.013 Newton has continued with second year courses in Sustainable Development. His engagement with the science news brief continued to</td>
</tr>
<tr>
<td>Name</td>
<td>Education and Employment Background</td>
<td>Likert Scale Score</td>
<td>Logit</td>
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<td>Wendy</td>
<td>Wendy was a school leaver who had studied Year 12 Human Biology. She was enrolled full time in a Business degree program. Her units for the year included Life and the Universe, Legal Process, Australian Government, Law, Justice and Social Policy, Injury and Compensation and Legal Writing.</td>
<td>15/30</td>
<td>-0.183</td>
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<tr>
<td>Roy</td>
<td>Roy is a mature age student who studied year eleven physics in 1979. His previous employment had been in telecommunications. He was enrolled full time in a Bachelor of Commerce. His first semester units were Life and the Universe, Economics, IT and Computer Science.</td>
<td>17/30</td>
<td>0.216</td>
</tr>
<tr>
<td>Todd</td>
<td>Todd was a school leaver who had studied Biology and Physics in year eleven and twelve. He had enrolled full time in Environmental Science.</td>
<td>17/30</td>
<td>0.429</td>
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</table>

In order to evaluate the science research news report, Roy asked, are polyps formed from a build up of fatty acids and does greater consumption of wine further decrease cancer risk. He did not engage critically with the news brief and his comments suggested he could have a functional level of scientific literacy. For example, I suppose it could be done but only for medical purposes. His requests for extra information included, see if Dr Anderson is a doctor or Associate Professor, where he got his figures from and more information about polyps. Wendy did, however, make conceptual and procedural requests for extra information in order to evaluate the research. For example, studies in eating, drinking and smoking habits of a larger proportion of the population. Wendy had continued full time with studies in business. Again she was uncritical in her engagement with the news brief. She accepted the researchers conclusion based on the article. She said, I am now more certain as it is proven by research. Her requests for extra information would also suggest a functional level of scientific literacy. She asked for, information on individual subjects, more facts and figures and information on HDL and LDL. Roy had transferred to an Arts Degree program and was studying part-time. He stated being more certain of his background reaction after having read the news brief but did not give any reason for this. His requests for extra information were again functional in nature and diverged from the stated conclusion. He asked what sprays and insecticides they have used in growing the oranges and what type of oranges. In addition he asked, what qualifications the researchers have. Todd has continued with full time study in Environmental Science. His response to the news brief suggested he was working at a conceptual/procedural level of scientific literacy.
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Scientific literacy score</th>
<th>Likert scale score</th>
<th>Logit</th>
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<tbody>
<tr>
<td>Renae</td>
<td>Renae was a school leaver who had studied Year 11 and 12 Human Biology. She was enrolled full time in a Bachelor of Psychology. She wrote on her tutor information sheet that she was considering continuing with her studies to the Doctoral level. She also stated being interested in environmental issues such as ozone depletion and how these could affect humanity.</td>
<td>18/30 Logit: 0.429</td>
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<td>Marie</td>
<td>Marie was a mature age student who had studied Year 11 and 12 Human Biology in 1992/3. She was enrolled full time in Primary Education. Her previous work had been in customer service. Her unit enrolments for the year included Life and the Universe, Principles of Language and Literacy, Cultural Mathematics, Introduction to Developmental Psychology, Introduction to Teaching, Introduction to Science and Australian Environmental Issues.</td>
<td>18/30 Logit: 0.429</td>
<td>18/30 Logit: 0.429</td>
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<td>Tess</td>
<td>Tess was a school leaver who had studied Year 11 and 12 Human Biology.</td>
<td>19/30 Logit: 0.651</td>
<td>19/30 Logit: 0.651</td>
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<tr>
<td><strong>Year 11 Human Biology and Chemistry and again Human Biology in Year 12. She was enrolled full time in a Mass Communications Degree. Her first semester units included Life and The Universe, Media Industries, Introduction to IT and Law Justice and Social Policy.</strong></td>
<td><strong>Her response to the science news brief suggested she was working at conceptual/procedural level of scientific literacy. She asked for more information on, colon cancer, wine composition, polyps, other variables tested, and the variables kept the same in the study.</strong></td>
<td><strong>Tess had continued with full time study in Mass Communications. She stated on the questionnaire that she was now more confident in her response to the researchers’ conclusion as the news brief attempted to give me some proof. Her requests for further information included other diet changes, lifestyle changes and other factors that can remove LDL or HDL.</strong></td>
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<td><strong>Fiona</strong></td>
<td><strong>Likert scale score: 19/30 Logit: 0.651</strong>&lt;br&gt;Her response to the news brief could suggest she was working at a conceptual/procedural level of scientific literacy with multidimensional indicators developing. She referred to the data contained in the report to support her acceptance of the researchers’ conclusion. She wrote, 4-5% of wine drinkers had polyps but the rate was twice as high in teetotallers. Her requests for extra information included, other articles from other researchers on the same topic, the background of the researchers, what other things have they researched and do they have a good reputation.</td>
<td><strong>Likert scale score: 22/30 Logit: 1.378</strong>&lt;br&gt;Fiona had continued her part time study in Biological Science. She stated finding the researchers’ conclusion quite interesting but I’m still not convinced 100%. Her requests for extra information included, other research methods into heart disease, what has been found out previously, how long was the study, what was the health of the participants, their ages, work, stress levels, previous diet, hereditary conditions, was the test done at a specific time interval.</td>
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<td><strong>Doug</strong></td>
<td><strong>Likert scale score: 20/30 Logit: 0.883</strong>&lt;br&gt;In response to the researchers conclusion in the news brief he stated, <em>I have to assume this is so since I heard this is a scientific fact</em> and then added after reading the brief, <em>I am more certain as there is further impressive evidence supplied.</em> His requests for further information suggested some conceptual/procedural level indicators and included, more surveys within a bigger sample population and further health implications.</td>
<td><strong>Likert scale score: 14/30 Logit: -0.371</strong>&lt;br&gt;Doug continued with full time study but changed his enrolment to Communications Management. He stated being more certain of his background reaction after having read the news brief as <em>I now have reliable statistics.</em> However, more independent research showing the same results would better persuade me. His request for extra information included, more tests conducted, having it published in a reputable medical journal and having it televised on the news.</td>
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| Jane          | Jane was a female school leaver enrolled full time in a Primary Education course. In addition to Life and the Universe (LATU) she was enrolled in Different Histories, Cultural Mathematics, Principles of Language, Introduction to Science, Introduction to Teaching and Turning Points in History. She attended an alternative primary school where she described experiencing many science lessons scattered throughout. Her TEE studies were completed at a mainstream school and included year eleven and twelve Human Biology. | Likert scale score: 20/30 Logit: 0.883 She engaged critically with the news brief and her comments suggested she had a developing multidimensional level of scientific literacy. She challenged the report asking, how can this document be true? Sure the experiments seem reliable but I'm still not convinced. She asked for, more indepth explanations about the reports content. | Likert scale score: 21/30 Logit: 1.124 Jane had transferred her enrolment to another university that offered education units more consistent with her views on non-traditional schooling and her preference for Steiner schooling. Her engagement with the science news brief was at a functional level. She related being unsure of the meaning of the terminology used. Her request for further information was limited to the type of orange juice used and did not include any consideration of the research methodology. For example, is it freshly squeezed orange juice. |
| Ingrid       | Ingrid was a school leaver who had studied Biology and Chemistry in Year 11 and 12. She was enrolled in a Bachelor of Environmental Science. Her unit enrolments for the year included Environmental Biology, Statistical Data Analysis, Introduction to Chemistry, Life and the Universe, Introduction to Environmental Science, Chemistry for Environmental Science, Australian Environmental Issues and Introduction to Marine Biology. | Likert scale score: 21/30 Logit: 1.124 She commented agreeing more strongly with the stated researchers’ conclusion as, at least now I have some background information on it. She did not engage critically with the news brief’s content. Her requests for more information suggest she could be at a conceptual/procedural level of scientific literacy. She wrote, more information on the screen test, how the patients had been chosen, more statistics. | Likert scale score: 20/30 Logit: 0.883 Ingrid had continued with full time studies in Environmental science. Again she did not engage critically with the reported research. She wrote, I am now more certain as now I have heard about the research and seen the statistics. Her requests for extra information included, the background of the subjects, whether they are healthy or had a history of heart disease in their family. How significant the percentage rise of HDL’s was. |
| Hazel        | Hazel was a school leaver who had studied Year 11 and 12 Chemistry and Physics. She had spent 6 months of the previous year as an overseas exchange student. She was enrolled full time in a double degree in Mass Communications and Chemistry. Her response to her interview transcript was influenced by her part time work promoting National Science Week as the WA | Likert scale score: 21/30 Logit: 1.124 Hazel was accepting of the reported conclusion as it had been proven through research. She stated, it has been proven through research that drinking a glass of red wine daily can reduce the risk of developing some cancers. In | Likert scale score: 23/30 Logit: 1.645 Hazel had continued with full time study in a double degree in Mass Communications and Chemistry. Her response to her interview transcript was influenced by her part time work promoting National Science Week as the WA |
Communications and Chemistry. Her unit enrolments for the year were Life and the Universe, Applied Mathematics, Chemistry for Physical Sciences, Media Industries, Chemistry Laboratory Techniques, Media Research Methods, Physics and Writing for the Media. On her tutor information sheet she commented, *I hope to leave the university a more aware and informed person, understanding my social responsibilities and my place in the wider community.*

addition she stated, *the credibility of the researcher helps in my accepting of this research. She requested, other life style factors, history of cancer in the family, was it just a localised area study and what sort of wine were the participants drinking. Her comments and requests for further information suggested she was working at a conceptual/procedural level of scientific literacy with developing multidimensional indicators.*

Media Coordinator. She wrote, *the experiences of this role have certainly improved my scientific literacy, they have also made me more aware of how science is communicated in the mass media and changed my perspective somewhat from observer to participant. Hazel critically engaged with the news report. She wrote, probably equally certain as the people tested had high cholesterol levels therefore the conclusion seems aimed at a particular group not necessarily the whole population. Her requests for extra information included, where their findings fit in with other research, sample size and representation of sample, future directions for research and is there more involved research that this study has led to.*
APPENDIX ELEVEN

Focus group participants’ experience of school science
<table>
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<tr>
<th>Name</th>
<th>School science experience: Think back to your past learning experiences in science subjects. Describe briefly what was involved in learning in these subjects.</th>
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<tbody>
<tr>
<td>Newton</td>
<td>Human biology, reproduction, veins, arteries and the heart. Learning within the bounds of the structures of formal science.</td>
</tr>
<tr>
<td>Jane</td>
<td>There were many science lessons scattered throughout primary school. In high school I did Human Biology. What was involved was a lot of understanding rather than learning because each piece easily fit into the next if you could understand.</td>
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<tr>
<td>Lisa</td>
<td>N/A</td>
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<tr>
<td>Todd</td>
<td>N/A</td>
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<tr>
<td>Roy</td>
<td>All hands on experiences</td>
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<tr>
<td>Jessica</td>
<td>A lot of memorizing such as, parts and function of certain organs, names and symbols of the elements. Using formula, mainly in physics, such as speed and acceleration. Observation through experiments such as dissections, or mixing chemicals.</td>
</tr>
<tr>
<td>Doug</td>
<td>N/A</td>
</tr>
<tr>
<td>Tess</td>
<td>School science involved text book learning with little practical work. It was the learning of basic practices, procedures and principles. There was little expansion or application of concepts learnt.</td>
</tr>
<tr>
<td>Renae</td>
<td>Learning scientific equations. Carrying out scientific experiments in the lab.</td>
</tr>
<tr>
<td>Ingrid</td>
<td>Commonly in learning experiences in science subjects the majority of lessons would be spent copying down overheads or taking notes from textbooks. In the weeks preceding an exam we would receive revision sheets to do in class or at home.</td>
</tr>
<tr>
<td>Wendy</td>
<td>Lower school science was quite simple, giving a basic simple introduction. But as I did a TEE science I experienced a more in depth learning process about the human body. Completing assignments, tests and conducting experiments. There was hands on experiences for example cutting up liver and eyes.</td>
</tr>
<tr>
<td>Fiona</td>
<td>Reading from textbooks and notes that were given in class and learning this material relatively closely. The practical side of things included experiments and field work to reinforce what we’d learned.</td>
</tr>
<tr>
<td>Marie</td>
<td>Learning was in the way of labs (experiments), readings, revision exercises, research, listening and note taking, videos and visual. Our science teacher kindly brought in her placenta- a vision not forgotten!</td>
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<tr>
<td>Hazel</td>
<td>Learning in high school science subjects the objectives were achieved mainly through 4 hours of lessons per subject each week and a comprehensive textbook. Very rarely did we have to look outside the text and particularly in year 12 the majority of our study time was</td>
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spent reviewing past TEE papers so that we would come to recognise the types of questions they asked. In terms of teaching we most often had contact with only one person, our class teacher, to ask for help or teach us new methods.

Hazel later added in her interview, at high school you learn all this stuff and you wonder where the hell am I ever going to use it. It seems to be a lot of accumulation of knowledge just for the sake of it.
APPENDIX TWELVE

Case study: ‘Jane’
Case Study: “Jane”

Introducing Jane
Jane was a female school leaver enrolled full time in the first year of a Primary Education course. In addition to Life and the Universe (LATU) she was enrolled in the units titled Different Histories, Cultural Mathematics, Principles of Language, Introduction to Science, Introduction to Teaching and Turning Points in History.

She attended an alternative primary school where she described experiencing many science lessons scattered throughout. Her TEE studies were completed at a mainstream school and included year eleven and twelve Human Biology. She described her learning in this subject as involving a lot of understanding because each piece could easily fit into the next if you could understand. She anticipated gaining deeper science knowledge through participating in LATU. Illustrating this, I really want to broaden my own understanding of the theory’s and scientific knowledge in the past and present.

Why Focus on Jane?
Jane was selected as a Focus Student as her responses on the initial Questionnaire suggested she had a developing multidimensional level of scientific literacy. She scored 20/30 on the Likert scale and engaged critically with the news brief. She challenged the report asking, how can this document be true? Sure the experiments seem reliable but I’m still not convinced. Her requests for more information were functional in nature as she only asked for clarification of the article’s content. She requested more in depth explanations rather than information regarding the science content of the news brief.

Questionnaire responses
Jane’s responses to the Likert scale items suggest she views scientific knowledge as tentative and dynamic in nature. She accepted that scientists do not have one fixed method that always leads to scientific knowledge. It appears she views creativity and imagination as integral to the process. It was also apparent she viewed scientists’ work as potentially influenced by individuals’ background; personal beliefs and values. She also agreed that funding bodies could effect the direction of research. In addition Jane
seemed to have some awareness of the limitations of science for bringing final answers to matters of public debate and she agreed the spreading of scientific information was important to the progress of science.

In contrast to these contemporary conceptions of the nature of science she accepted that scientists research in an objective manner and as such their work would hardly ever reflect the values and viewpoints of society. This perspective of scientific objectivity contradicts with her responses to the other scale items.

**LATU Work samples**

It was evident in Jane’s reading logs and diagnostic exercise that she understood the science terms and concepts being raised. She stated, *I found my human biology studies a great use in this story, as the terms were quite explicit.* She effectively summarised both fiction and non-fiction science materials. In all cases she identified the researchers’ conclusion or thesis and summarised the main points. In her discussion of the materials she was generally analytical and made connection within the discipline and across disciplines. She often explored social implications of the science contained in the readings. For example, *what about the future, from these readings I have become more aware of the importance of biodiversity in our fragile and so important ecosystem.* She also seemed to recognise that science may offer knowledge with some potential for addressing environmental problems but it’s effectiveness could be dependent on the social context and the way the knowledge was utilized. She stated, *It (fictional technology for controlling weather) would be a great solution for our Earth’s problems. It would be a gift but who ever had control could abuse it.*

An awareness of the interaction of science with society was also evident through out her essay on the Kyoto Protocol. For example, *Kyoto Protocol’s importance is vital. It arose from current scientific knowledge and draws from concerns for the future of the Earth, the environment and life.* She recognised the role of scientific knowledge in the international debate surrounding the protocol but also suggested that it could only be realised by managing social influences. She stated, *the consequences of the protocol could be realised through social, ethical and political management.*
In the LATU mid-semester exam Jane identified all the key points in the included newspaper article. She produced a meaningful summary that showed understanding of its science content. This was achieved by making connections between the science concepts included in the article. She also showed some appreciation of the role of the research in building scientific knowledge. She stated, *although at the moment it all seems like something out of a science fiction novel, experiments are proving worthy.*

Furthermore, her short answer response to the role of science fiction in science suggested she viewed scientific method as devoid of creativity. She viewed fictional writing as a way of expanding this evidence bound approach to research. She stated, *the ideas that many scientists have are limited to evidence and experimentation so science fiction’s role is to expand the imagination and the possibilities.*

*Workshop activities and discussion.*

Her perspective of scientists’ work being focussed on evidence and experimentation was again present in her activities and discussion during the workshop. Jane’s drawing of a scientist included 5 stereotypical indicators. These included male, unkempt appearance, facial hair, eyeglasses and symbols of knowledge. She later explained knowing that her representation of a scientist was stereotypical but that she believed that was still the norm. In response she said, *it’s just how I see it.* Surrounding her drawing was a description of scientists’ typical personality and behaviour. Her description included *smart, practical, busy learning all the time, intensely interested* and that work *takes over their life.* In discussion she also added that a scientist was *somebody who is really passionate about what they do.*

Consistent with the view that scientists are focussed on experimentation was her description of science as the *study of how things happen and what they are made up of.* She described the purpose of science as being to *discover and explain natural and man made things* through a prescriptive method. She explained that scientific work was, *a rigid form due to hypothesis, experimenting and conclusions that rely on statistics and number evidence.* When discussing her response she added that the scientific knowledge produced was not fact but rather evidence. She explained, *its hard to imagine they can do these sorts of things, its just proof I think.* Later in discussion Jane added that science required creativity in order to *drive it forward, other wise its just*
going to get too stale. It appeared she viewed this forward progress as possibly only limited by money. She stated, *I guess money would be a definite limitation.*

Later in discussion she added believing that money strongly influenced the direction of research. She explained, *scientists have to make money, so they’ve got to do what they can.* Jane believed scientific information or research findings could not always be trusted as they may have been influenced by the funding source or the scientist’s place of employment. For example, *with immunisation the scientists that are doing the testing are the ones involved in production so they’ve got to say its safe.*

Jane appeared to link the purpose of science to a social context. She related that it resulted in the *creation of new things and saves lives (medicine).* However, she viewed the potential benefits of scientific discoveries as dependent on the use they are put to. She stated science *has the potential to be extremely dangerous, for example, the atomic bomb.* It was clear in discussion that Jane did not think scientists could bring final answers to matters of public debate and furthermore science could potentially at to social tension. She stated, *science could improve debate but it could also create tension between different groups of people or between religions.* Jane could also see science as having a role in her personal life and possibly influencing her decision-making. Again she took the view that science could not provide final answers but rather that *it would depend on what you believe in and what kind of stance you have. That would also affect what you decided.*

It was also evident in discussion that she generally viewed scientists as honest, moral and ethical. She stated, *we do rely on them. They have a big responsibility to uphold.* Jane also held the view that it was important for scientists to communicate with the public but holds the opinion they don’t do this very effectively. For example, *we don’t think they communicate very well. They should because they have to give it out to us so that we can understand what they are doing.*

Interestingly, Jane chose the news brief *Kitchens may sink fertility* to discuss, as she *understood everything they were talking about.* She explained that the other articles had lots of words she didn’t understand or really comprehend. Her description of the research reported in the fertility news brief, was clear, contained the key points and
suggested an understanding of the main science ideas. She was able to identify and state the researchers’ conclusion and also related the tentative nature of the findings. She stated, *the exposure might impair female reproductive potential*. She did not, however, engage critically with the science content or described research methods but rather accepted the researchers’ conclusion because, in her words, *it could affect my lifestyle, health etc.*

Subsequent requests for more information about the research were for greater depth in the content of the article. For example, *more detailed reasons about electromagnetic frequency and what it does to tissues*. Jane made a limited procedural level request for information about the research design. She asked, *what and how experiments have been conducted to come to this conclusion*. She later related the need for repeated research and multiple trials in order to test the researchers’ conclusion.

*Developing scientific literacy*

Jane’s tutor related having found it difficult to evaluate her level of scientific literacy, as she was quiet in the tutorial and *not always forthcoming with ideas*. She believed Jane was, *not always a critical thinker* and suggested she was working at a functional level. In contrast, the questionnaire, LATU work samples and workshop discussion provided a forum in which Jane openly discussed her views about science. It was evident that her level of scientific literacy was dependent on the context in which she was working and at times she did take a functional approach. It was also apparent that she had a greater understanding of key ideas and concepts from the biological sciences. However, her conceptions of the nature of science and its interaction with society were not subject specific. Focussing on these dimensions allowed her to demonstrate various multidimensional indicators of scientific literacy.

*Following up in 2003*

Jane transferred her enrolment to another university that offered education units more consistent with her views on non-traditional schooling and her preference for Steiner schooling. She explained having gone back to relearn about her own school experience and that she was developing very different views about education. Her goal was to complete her education degree and gain employment in a Steiner school.
She related in the 2003 interview that over the previous 12 months she had taken a significant journey in her intellectual development. She explained that while doing science for the TEE the focus had been on *learning the facts and getting the ground and structure on how everything worked*. Her university experience had been more about understanding things for herself and having her own views. She said it had been about *growing into your own person*.

*The questionnaire and written activities*

Jane’s responses to the Likert scale in 2003 suggested she had developed a stronger acceptance of the tentative nature of scientific knowledge and the influence of scientists’ background and personal beliefs on their interpretation of evidence. Her view on science reflecting values and viewpoints related to society had changed and was now consistent with a contemporary perspective of the nature of science. In contrast she had shifted to a less contemporary perspective on two items. She accepted that science was based on a static body of knowledge and that science could bring final answers to public debate.

Jane’s 2003 description of science had discovery as a central and connecting theme. She stated, *science is a way of thinking, a structure that leads to the discovery of how material things occur*. She again focused on scientific method stating that science *works with observation, conjecture, experiments, set steps to discovery*. Jane also clearly described science interacting with society. For example, *science has been of great benefit to our world at times, our society is built upon it now and it is highly influential in terms of media, medical and government*.

In addition, Jane included the following explanation of the purpose of scientific research, *it’s purpose is to know and be more knowing of how the material world works, how the basic elements form*. She went on to explain feeling that science was *fickle* and *humans could not encompass everything*. She related thinking *discoveries never really link* and that *science is at times isolated and narrow minded*.

Jane’s interest in Steiner schooling was reflected in her 2003 drawing of a scientist. She split her drawing, having on one side a stereotypical representation and on the other an
image she labelled as her own. She labelled the person as Rudolf Steiner and drew a well-groomed, male wearing everyday clothing. It appears she views this person working in a more holistic manner than her stereotypical scientist. She included the following descriptions of his work. *Studies nature unfolding, studies materials in their environment and conscious of the outer world but mindful and inquisitive of other.* It seems she had broadened her image of scientists as previously she had accepted the stereotypical view.

Her engagement with the science news brief in the questionnaire and on the activity sheet included during the interview was at a functional level. In response to the brief, *Oranges keep the heart doctor away* she related feeling uncertain about the validity of the research and that she was unsure of the meaning of the terminology used. Her request for further information was limited to the type of orange juice used and did not include any consideration of the research methodology. Her requests for more information on the research described in the brief, *Sage the thinking man’s herb* was also limited. She wanted more information about the sage and the observed memory improvement. Again there was no request for information regarding research procedures. Jane went on to explain she would not repeat the same controlled experiment to test the researchers’ conclusion. Instead she proposed to *gather all the information of sage from old knowledge and try it for myself.* She did see using the placebo as a way of attaining accurate information. She wrote, using the placebo seems to be a way of getting an exact evaluation but you would have to interview each person to get into their senses.

The comments made by her when analysing the news briefs suggested she was becoming disillusioned with scientific research. Her response to the brief on the health benefits of oranges was, *it seems to be another headline, another proposal that people will dive into till the next great discovery is found.* Dissatisfaction with scientific method is also evident in her comment, *it seems that the scientists have to put it (sage) to the test, one test, isolated and in capsule form, of course!*

*The Interview*

In contrast to her views on the rigour of scientific method Jane expressed in the interview that she did not believe anything could ever be tested again in exactly the
same by. Hence the findings of any research were limited. She explained, *I don’t believe anything can ever be tested again and get exactly the same results so it can be one truth but not the whole truth.* She expanded this view to include that findings from research cannot be accepted as truth due to the influence researchers’ backgrounds could have on their interpretations. She did not accept that science was objective or that scientific research could be conducted in a totally objective manner. She stated, *I don’t think anything can be truly objective, everybody has a view, always unconscious, its always interpretation.* Jane also related viewing creativity as important to the progress of science. She explained that *there has to be a little spark of creativity, like an inspiration to continue.* She viewed this as important as science was structured and hence restricting. She said, *science could be quite restricting in terms of having the right scientific knowledge, words and power on how to put it out into the world.*

Jane also viewed research funding as influencing the progress and direction of science. She stated, *everyone has to get money together to conduct research* and as such government bodies strongly influenced science. She also viewed social materialism or commercialism as a driving force behind research. She stated, *materialism, getting the best technology the newest.*

Furthermore, she raised the idea that scientists can be narrow minded and not always forward thinking enough to foresee the possible uses of their discoveries. She gave as an example, the development of the atomic bomb. She said, *it doesn’t come across as being very open-minded and looking beyond what is being studied or looking out to the real world and seeing what’s going to happen.* Jane did not believe it was the scientist who had been immoral or unethical but rather the people who used the scientific knowledge to build the atomic bomb. She explained *it may not be the scientists that haven’t been moral; it’s just how it’s been dealt with outside of that and taken advantage of.* She did add, however, that she expected scientists to look to the future and consider the possible implications of their work. She stated, *you can’t predict the future but just have a consciousness of what you are doing.*

It was evident that Jane felt scientists had a social responsibility particularly because they could influence the public’s up take of issues such as sustainable water management. She explained, *science is something people look up to because it has*
proved this thing and this next thing. People often take it on board and believe it. She did not, however, accept that scientists could provide the solution to a shortage of drinking water as again this was affected by the publics’ uptake of the knowledge. She stated, *I think people would have to do that with the help of scientific research and everything.*

**Concluding level of scientific literacy**

Jane continued in 2003 to demonstrate multi-dimensional indicators of scientific literacy. She was particularly aware of the interaction of science with society. She also made functional level requests for information about reports of scientific research. She did not engage with the scientific procedures contained in the news briefs. This functional level approach was also evident in 2002. The most significant change, however, had been in what appeared to be an increasing negativity or scepticism about science methods.
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