Communicating astrobiology in public: A study of scientific literacy

Author:
Oliver, Carol Ann

Publication Date:
2008

DOI:
https://doi.org/10.26190/unsworks/18246

Communicating astrobiology in public: A study of scientific literacy

---

PhD thesis submitted for the requirements of
Doctor of Philosophy, Science Communication

AUSTRALIAN CENTRE FOR ASTROBIOLOGY
DEPARTMENT OF BIOTECHNOLOGY AND BIOMOLECULAR SCIENCES

Carol Ann Oliver
Master of Science Communication

Supervisors:

Professor Malcolm Walter and **Professor Paul Davies**

Associate supervisor:

Professor Richard Dawkins

June, 2008

Originality statement

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at UNSW or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by others, with whom I have worked at UNSW or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.

Signed....Carol A. Oliver....

Date....25/11/08....

Copyright statement

I hereby grant the University of New South Wales or its agents the right to archive and to make available my thesis or dissertation in whole or part in the University libraries in all forms of media, now or here after known, subject to the provisions of the Copyright Act 1968. I retain all proprietary rights, such as patent rights. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.

I also authorise University Microfilms to use the 350 word abstract of my thesis in Dissertation Abstract International.

I have either used no substantial portions of copyright material in my thesis or I have obtained permission to use copyright material

Signed....Carol A. Oliver....

Date....25/11/08....

Authenticity statement

I certify that the Library deposit digital copy is a direct equivalent of the final officially approved version of my thesis. No emendation of content has occurred and if there are any minor variations in formatting, they are the result of the conversion to digital format.

Signed....Carol A. Oliver....

Date....25/11/08....

Abstract

The majority of adults in the US and in Europe appear to be scientifically illiterate. This has not changed in more than half a century. It is unknown whether the Australian public is also scientifically illiterate because no similar testing is done here. Public scientific illiteracy remains in spite of improvements in science education, innovative approaches to public outreach, the encouraging of science communication via the mass media, and the advent of the Internet. Why is it that there has been so little change? Is school science education inadequate? Does something happen between leaving high school education and becoming an adult? Does Australia suffer from the same apparent malady?

The pilot study at the heart of this thesis tests a total of 692 Year Ten (16-year-old) Australian students across ten high schools and a first year university class in 2005 and 2006, using measures applied to adults. Twenty-six percent of those tested participated in a related scientific literacy project utilising in-person visits to Macquarie University in both years. A small group of the students (64) tested in 2005 were considered the best science students in seven of the ten high schools. Results indicate that no more than 20% of even the best high school science students - on the point of being able to end their formal science education - are scientifically literate if measured by adult standards. Another pilot test among 150 first year university students supports that indication. This compares to a scientific literacy rate of 28% for the US public.

This thesis finds that the scientific literacy enterprise – in all its forms – fails scrutiny. Either we believe our best science students are leaving high school scientifically illiterate or there is something fundamentally wrong in our perceptions of public scientific illiteracy. This pilot study – probably the first of its kind – indicates we cannot rely on our current perceptions of a scientifically illiterate public. It demonstrates that a paradigm shift in our thinking is required about what scientific literacy is and in our expectations of a scientifically literate adult public. In the worst case scenario, governments are pouring millions of dollars into science education and public outreach with little or no basis for understanding whether either is effective. That is illogical, even irresponsible. It also impacts on the way astrobiology – or any science – is communicated in public.

Acknowledgements

This work has been part of a longer personal journey, encouraged by my family, friends and colleagues who supported my desire to reach this goal and beyond.

I would specifically like to thank my supervisors, Professor Malcolm Walter of the Australian Centre for Astrobiology at the University of New South Wales and Professor Paul Davies of the Beyond Center for Fundamental Concepts in Science at Arizona State University. They gracefully faced the challenge of a multiple relationship as student, colleague and friend. My thanks, too, to Professor Richard Dawkins of Oxford University who has maintained an open door whenever I visited the UK.

Unless one lives on a desert island to undertake a PhD, the other stalwarts constantly there are family. My adult son James and adult daughter Gemma, my ex-husband Barry, my sister Shirley, her husband Sam, and my Mother have provided support throughout. Thank you does not seem enough to say. I wish my Father had survived to see me undertake this work. I know he would have been thrilled.

I would also like to thank all my friends and colleagues for their advice and support. There are too many to mention, but I would like to make specific mention of Dr Seth Shostak and Edna DeVore of the SETI Institute in California, Jennifer Fergusson, Mikayla Keen, Eric Dalgliesh, and fellow students and colleagues at the Australian Centre for Astrobiology, in particular Associate Professor Simon George and Associate Professor Jeremy Bailey. I would like to thank, too, my friends and colleagues in NASA, at Arizona State University, and at the University of Glamorgan in Wales.

Finally, and especially, I would like to thank Richard Dartt, who came into my life in 2008. He reminded me of why, at the age of 58, I wanted to complete this doctorate, and encouraged me to do so.

Carol Oliver
June, 2008

TABLE OF CONTENTS

CHAPTER 4: THE PILBARA PROJECT

CHAPTER 5: METHODOLOGY

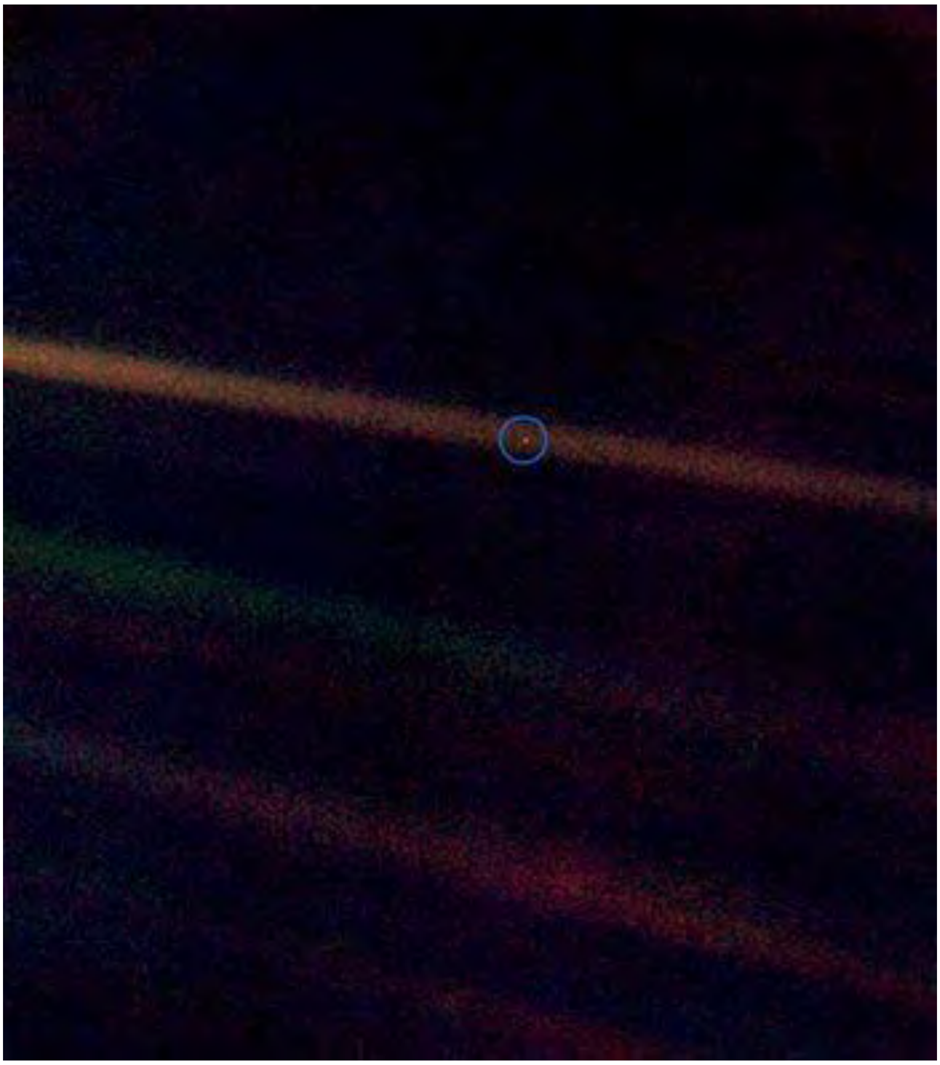
CHAPTER 6: RESULTS

CHAPTER 7: DISCUSSION

CHAPTER 8: CONCLUSIONS

"Look again at that dot. That's here. That's home. That's us"

(Sagan, 1994).



This picture of Earth was taken on 14 February, 1990, 6.4 billion kilometres from Earth across the solar system by NASA's Voyager 1 interplanetary spacecraft. Earth in a beam of scattered sunlight, picked out by the artificial blue circle, occupies a miniscule 0.12 of a pixel of the picture. Earth is home to more than 6 billion communicating humans living in a largely science-based society. How we do it is as complex as the gravitational dance that keeps us spinning around a star, itself spinning around a galaxy of at least a hundred billion other stars. Image, JPL/NASA.

Fig. 1: *A small rocky planet: Earth rise over the Moon (image: JAXA/NHK)*

Chapter 1:
Thesis overview

1.1 SCIENCE AND THE PUBLIC

As far as is known, we are unique in the universe. We are more than six billion intelligent beings, able to change our environment, and to reflect on the natural world and our place in the cosmos. We may be alone in the unimaginable vastness of space, or we might not be. Life itself may be confined to Earth's relatively thin biosphere envelope, though most astrobiologists think not. We are born, we live and we die – along with millions of other species - on a small rocky planet revolving around an unremarkable average G2 yellow dwarf star in a galaxy of a hundred billion other stars, in a universe of at least a hundred billion other galaxies. In the usually less than 100 orbits of our sun that most of us experience, we download into our cognitive hard drive a few thousand years of transgenerational learning and understanding, and integrate that knowledge in a myriad different individual human ways. It is arranged and rearranged by what Selby (2004, p20) calls our inbuilt 'biocomputer', which has no manual on programming - through the use of - the *"complex intellectual, emotional, perceptual, intuitive, and spiritual dimensions of our mental functioning."* Scientific literacy, the subject of this thesis, is like any other literacy. How scientifically literate we are, no matter how that happened, is influenced on a daily basis from macro to micro levels by life's experiences (see *Fig. 2*) – for example, home, family, friends, colleagues, work, leisure, formal and informal education, beliefs, values, motivation, social context and engagement in society (Longino, 1990; Thagard, 1994; Osborne, 2002). It is the filter through which knowledge, experience, and influencing factors are integrated into our individually unique worldviews (Wertheim, 1997) and transformed into a matrix into which we add new information and experience either consciously or subconsciously.

Noted scientific literacy researcher, Jon D. Miller (2007), addressed the question of why there had been an apparent increase in US adult scientific literacy from around 10% in 1988 to 28% in 2007. He said it reflected the complex interplay of the multiple layers that continually impact individuals in daily life. He added it was likely not one factor, but a mix of college education, work and life experiences, exposure to mass media and information technologies, and the increasing number of public science issues arising from science research and discoveries. Nevertheless, 28% is still low – the majority of the US public apparently remains scientifically illiterate.

Influences on public perception

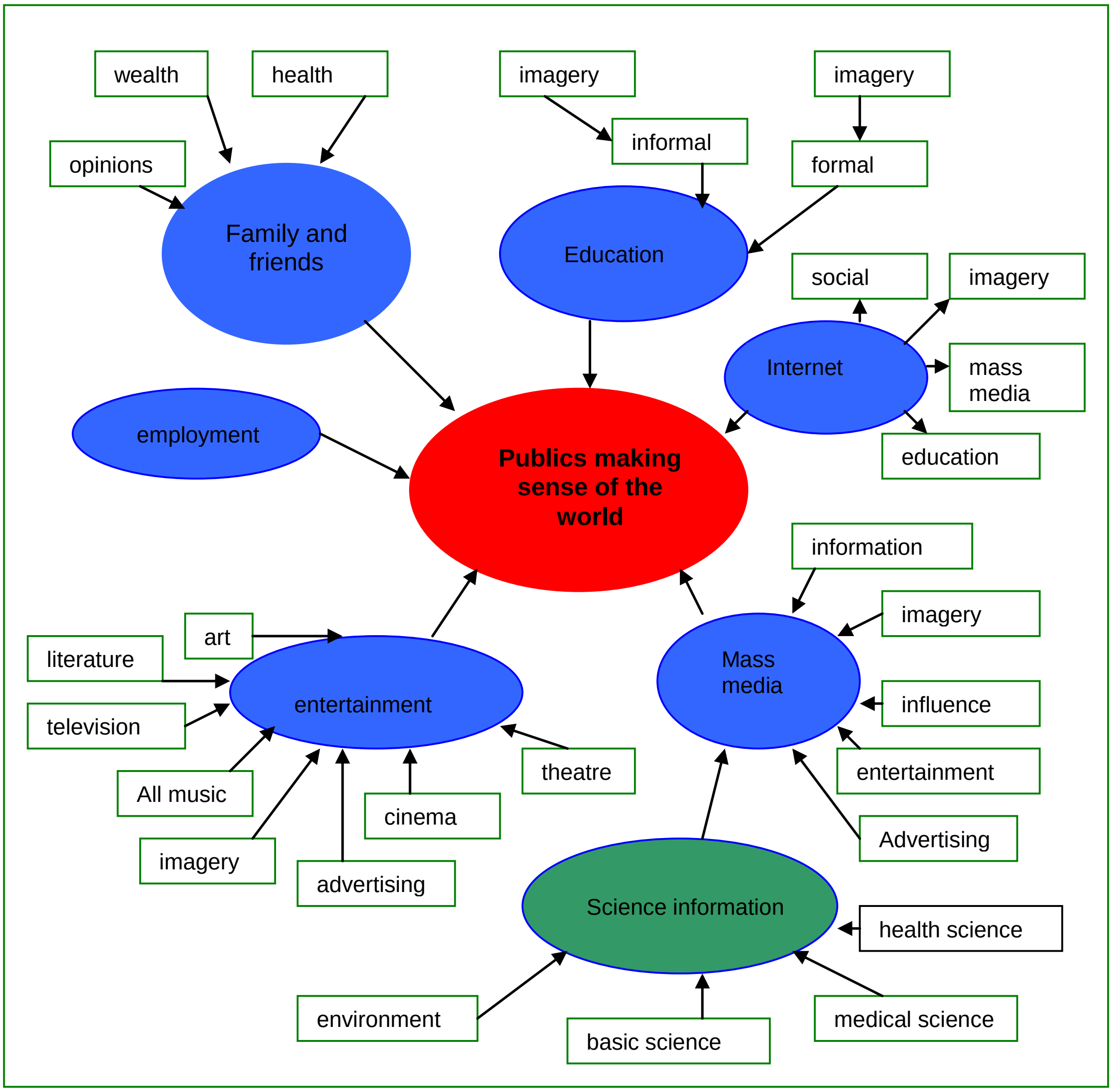


Fig. 2: *Public audiences and some of the many possible influences on the perception and integration of science information and education.*

The term ‘scientific literacy’ is relatively modern. It was first suggested as a unifying theme for science education by US educator Paul Hurd in a paper entitled *Science literacy: Its meaning for American schools,* which was published half a century ago, not long after the launch of Sputnik 1 (DeBoer, 1998; Laugksch, 1999). The term was first used by James Bryant Conant in *General Education for Science* in 1952 (Bybee, 1998). The notion of scientific literacy has deeper roots – starting around 1945 with the development and use of the atomic bomb. A focus emerged on engaging students with science-based societal issues (Shamos, 1995). This movement simmered until the sudden, and unexpected, dawn of the Space Age on October 4, 1957, with the beep-beep-beep being transmitted from Earth orbit by the Soviet Union’s spacecraft. The event caused broad alarm and concern outside of the Soviet Union. It evoked a strong perception in the US that something was ‘radically wrong’ about the way science was being taught in schools (Rutherford and Down, 1995). In spite of the perception in the West, there appears to be no actual evidence of better science education or public scientific literacy in the Soviet Union, or that it had impacted the ability to get into space exploration first. Indeed being first did not hold any particular significance to the Soviet Union until the world reacted to the news. The then Soviet leader, Nikita Khruschev had been irritated by *‘Korolev’s rockets’* after some failures. On the night of the launch, Khruschev delivered perfunctory congratulations to the Sputnik team and went to bed (Siddiqi, 1997). The Soviet Union was caught by surprise by the global response to Sputnik 1. The day following the launch, Sputnik 1 rated only a few paragraphs in news briefs on the front page of the main Soviet newspaper *Pravda*. For the rest of the world it became the biggest media story since the dropping of the atom bomb, and in both cases it was science, engineering and technology based.

Science – big science – is public-sensitive: consider global warming, genetically modified foods, genetic engineering, nuclear energy, and the search for life on Mars. In 1957 a total 87% of the US public was aware of the launch of Sputnik 1. Awareness among other public audiences indicated interest was 'extraordinarily high' (Almond, 1960). In Norway 97% of the public were aware of the launch, France 96%, Austria 93% and Germany 91%, while in Canada it was 79% and the UK 74% (all measured in November 1957). The Age of Space Exploration was under way, and the Soviet Union had led the way. Fear struck the American heart – nuclear war was no longer half a world away; it was measured in minutes (Shapiro, 1997). The American public quickly 'got' what Krushchev had failed to recognise. And it was about the social implications, including the fear of scientific and technological incompetence in the US in the midst of a cold war with the Soviet Union. In stepping off our planet, science education at high school and tertiary levels, and public scientific literacy, came into sharp focus (Paisley, 1998; Carleton, 2001). While the cold war is long over, public scientific literacy remains a concern and the subject of testing and debate at both student and public levels.

The dichotomy between public response to science news and a perceived scientifically illiterate adult public plays out today. It is critical to understanding the realities of science communication. The receptivity to science among the many different types of public audience, and how to make the best use of the communication moment, rides on understanding it, whether it is on the back of research or event driven science news or a science education project. Somewhat serendipitously, public scientific illiteracy and initial lack of knowledge of satellites were documented in surveys carried out in 1957 and 1958 (Krieghbaum, 1968) that later became the benchmark for testing of public audiences from around 1979 onwards. Since then US and European public audiences have been regularly tested through government-funded surveys to understand what the level of scientific literacy might be. In the US, the National Science Foundation tests the public every two years in its Science and Engineering Indicators. In Europe, the European Community also regularly surveys the public for scientific literacy through its Eurobarometer series (see, in particular, Eurobarometer 55.2, 2001).

There is little doubt that space exploration and the modern focus on scientific literacy share a common genesis. Space continues to be inspiration in the act of raising scientific literacy. It is interesting that Australia does not measure scientific literacy among its adult public, even though scientific literacy – in common with science curricula in other countries - is the stated purpose and expected outcome of science education in Australia (Goodrum and Rennie, 2007). It begs the question: how do we know an Australian high school science education produces scientifically literate citizens? Where is the evidence? It is clearly an issue elsewhere. The US and European Union, for example, carry out adult as well as student testing. Nor does Australia have a space agency or space program of any kind, in spite of having two astronauts, Dr Andrew Thomas and Dr Paul Scully Powers, and a space science research community. Among the top 41 countries in the world as measured by Gross Domestic Product, Australia is anomalous in this regard (see *Fig. 3* for a graphic representation of spacefaring and non-spacefaring nations). For the purposes of this thesis, data were collected among Australian university students to achieve some indication of what the level of scientific literacy, as measured in the US and in Europe, might be among Australian adult public audiences.

Fig. 3: *Nations (in light and dark green) with operational space satellites in 2007- note it does not include Australia (Source: Wikipedia commons)*

1.2 LANGUAGE OF SCIENCE

A few years after the shock of Sputnik 1, C.P. Snow lamented a division between the *Two Cultures* of the arts and the sciences in his 1959 Rede Lecture in Cambridge, England (Snow, 1998). He remarked how his friends from the arts and the sciences would have difficulty talking with each other. Scientists apply an analytical, interpretive, and empirical evidence-based approach, attempting to work at the frontiers of knowledge in a valueless and fastidiously objective manner, mostly an anathema to the value-laden, opinionated literati (ibid). Snow was talking of those who walk the halls of knowledge of the arts and sciences in the kind of circles he moved in. Between the scientists and the public are the interpreters of science, such as journalists, who have their own values and needs (Hartz and Chappell, 1997). Those reporting the news are often not science journalists, viewing science through the eyes of an arts background – raising the spectre of the very division between arts and science that Snow saw more sharply in the academic environment. In spite of all of the above, it has been shown that non-expert citizens can understand and engage with science when the need arises. For example, the Cumbrian sheep farmers were able to link radioactive deposits to the nearby nuclear facility, Windscale, and argue that the contamination of pastures could not have been from the fallout from the Chernobyl disaster (Wynne, 1992). The equipment at Windscale was, subsequently, proven to be faulty. It is not known how scientifically literate the farmers were, but when scientific decisions began to affect their livelihood they became actively interested, though faced with a wall of 'science knows best'. Van der Sanden and Meijman (2008) note the Cumbrian sheepfarmers are the most remarkable case of lay knowledge being critical to scientific knowledge. It provided sound arguments as to why the engagement (or dialogue) model of science communication is more realistic than the now discredited deficit model. In the latter, the public are seen as deficient in knowledge, and in the case of the sheepfarmers *"...the communication process would probably have been more effective if there had been dialogue in which the common arguments of scientists and sheepfarmers were settled first,"* (ibid, p91).

1.3 SCIENTIFIC LITERACY

So why do Governments monitor their citizens for levels of scientific literacy? Why do international organisations carry out extensive testing of high school students in scientific literacy across up to 50 nations? Why is it important to have a largely scientifically literate public?

A key premise promulgated for the need for public scientific literacy is that we live in an increasingly science-based society. It is argued that in order to take part in that society – culturally, socially, and democratically – it is necessary to step beyond basic literacy, numeracy, and general knowledge: we must also be scientifically literate (Sagan, 1994; Paisley, 1998). The total sum of all the scientific knowledge ever gained is now estimated to be doubling every seven years (Gingrich, 2001). The proposition by Sagan (1996) that scientific literacy is required in order to be able to take part in a democracy is arguably more important now than it has ever been, particularly given global issues like climate change. Genetically modified foods, stem cell research, mad cow disease (BSE), biotechnology, and genetic engineering are among other examples where science and societal concerns meet – often in adversarial arenas. How are we to evaluate the evidence and the debates of science surrounding such issues without being scientifically literate? Surveys appear to provide further grounds for increasing public scientific literacy. For example, 45% of Europeans (Eurobarometer 55.2, 2001) and a similar number of Americans (NSF, 2006) believe astrology is scientific. More than half the American public do not believe Darwin's theory of evolution (NSF, 2006). More controversially, some believe in Intelligent Design – that evolution is explained by the intervention of a creator. How can public audiences separate science from pseudoscience, fact from fiction, evidence from belief, without scientific literacy?

Nevertheless, the challenge remains as to why scientific literacy is truly required for lay audiences. For example, would scientific literacy have *“boosted the careers of Luciano Pavarotti or Laurence Olivier?”* (Shamos, 1995, p98). But if it is essential, then what does it mean to be scientifically literate? Can it be tested like ordinary literacy and numeracy? The questions associated with scientific literacy straddle science, formal and informal education, science communication, science policy, sociology, and media studies, among other areas. This has produced a huge amount of literature on the subject. While the parameters of scientific literacy field should be clear-cut, the actual situation is that after more than half a century of debate and testing, they are not.

1.3.1 *Scientific literacy and the public understanding of science*

Scientific literacy itself raises many questions. First, there is no universally accepted definition of what the term ‘scientific literacy’ means (Shamos, 1995; Popli, 1999; DeBoer, 2000). There is broad consensus on two key aspects – content knowledge and process knowledge, but what either should be is either unspecified or not the subject of general consensus. For example, process knowledge could be deemed as concerning the ‘nature of science’, a phrase that also has no universally accepted definition. On the other hand process knowledge could refer to the scientific method taught in high schools, but challenged as not reflecting how science is actually undertaken. In addition, there is another phrase generally applied to public audiences as opposed to students: ‘Public Understanding of Science’, which is known by the unfortunate acronym of PUS, but it is also ill-defined in what it means and how it can be measured (Gregory and S.Miller, 1998).

If scientific literacy cannot be defined in a universally accepted way, is it possible to define what we ought to know in order to be scientifically literate? The disagreements rage. J.D. Miller proposes it comes down to being able to read – and understand – competing views in a media story in the science section of the New York Times (J.D. Miller, 1998). Norris and Phillips (2002) challenge that idea, demonstrating that any predilection of public scientific literacy needs a foundation of basic literacy and numeracy before any consideration of scientific literacy. H. Bauer questions measures of precisely what an individual's level of scientific knowledge should be to be considered scientifically literate. H. Bauer asks, for instance, who could justifiably claim to be able to answer in the affirmative that they have a clear understanding of DNA or radiation? *"How clear can one's understanding be when radiation needs in some cases to be described by equations for particles and in others by equations for waves?"* (H.Bauer, 1994, p2). If not either of J.D.Miller and H.Bauer's measures, then what should classify an adult as scientifically literate? Is it, for example, necessary for all to know why the leaves and grass are green to appreciate a landscape, or to know why the sky is blue to appreciate a crystal clear day? To be scientifically literate should one understand the mechanics behind the Sun's daily motion across the sky to appreciate a glorious dawn or sunset, or to know the Sun will rise in the morning and set in the evening at different times through the seasons? One in five Americans still believe in a pre-Copernican world where the Sun revolves around the Earth (NSF, 2006). H. Bauer (1994) points out that a scientifically literate person might reasonably say that none of the answers offered as choices for this latter question are correct. The frame of reference is not stated (solar system, or universe). In addition the Sun and Earth more specifically revolve around each other, the barycentre of which is just below the surface of the Sun (Bailey, pers. com., 2007). The questions used on tests for public scientific literacy also raise the spectre of where the line is between *understanding* science and *appreciating* science, as well as the varying views of what should be expected in terms of content, process and science in society knowledge.

1.3.2 *What is meant by 'general public audience'?*

Between 1998 and 2000, the NASA Marshall Spaceflight Center called together an expert panel of science journalists and others to report on best practices in science communication. Known as the R2 Report, among the conclusions was one that suggested that scientists and their managers do not have a clear idea of what they hope to achieve by communicating scientific research to the public, or understand that there *"is no such thing as a general public audience"* (Borchelt, 2001). Messages of science intended for the public understanding of science were actually aimed at encouraging audience appreciation of science – an informational exercise designed for either the public to be encouraged to support science or for managers to feel happy about column inches or space without any consideration of whether the sent message was ever received. Gregory and S.Miller concur. Scientists intent on improving the public understanding of science, are often promoting institutional profile instead – research messages ultimately aimed at public and political support for funding, or attracting students as the underlying purposes of communication, according to Gregory and S.Miller (1998). This is often not understood by the communicating scientist. The messages of science would be better served if the both the purpose of the message, and the needs of the audience it is directed at, are understood at the outset. Borchelt (2001) points out that there is nothing wrong with promoting institutional profile in the act of informing the public about science news. For mass media communication, the messages of science are mostly information rather than education. Science journalists largely do not see themselves as educators (Rensberger, pers.com., 2003). They inform – and this is a subtle, but important difference in the way the message is framed in the interaction between the journalist and the scientist.

1.3.3 THE MODELS OF SCIENCE COMMUNICATION

In the 1980s, the ‘black box’ view of public audiences was finally discredited (Gregory and S.Miller, 1998). Otherwise known as the ‘deficit’ model as noted earlier, its form was – and still is – one-way communication, scientist to the public, with the assumption the public is an empty vessel waiting to be filled with science information and education. From the 1990s onwards this tended to reverse, so the expert was seen as creating a deficit of trust (M.Bauer *et al*., 2006). This was particularly so in the UK. A more favoured model has replaced it – one of two-way communication: engagement and dialogue (Clark and Illman, 2001; Liem, 2005), though the deficit model continues to be employed by scientists and their mediators (usually public relations officers). Van der Sanden and Meijman (2008) point out that the dialogue model of two-way communication is relatively easy to achieve in public awareness or appreciation of science, but has not yet been employed in the public understanding of science. This might be because of the modalities of dialogue such as education and promotion whereas PUS is learning about and dealing with science. For example, a dialogue between patient and doctor on the treatment of asthma transfers an understanding of the importance of the use of steroids as a preventative from doctor the patient. While it is possible for a scientist to transfer understanding in similar circumstances, it is difficult to do that for an audience of hundreds of thousands, or millions. While one-way communication of science news seems like a deficit model, it is not. There is no assumption that the public is an empty vessel waiting to be filled with science education. It is simple transmission of information, with no intention beyond informing.

1.3.4 *Scientists ommunicating science*

Governments are undoubtedly concerned about apparently low levels of public scientific literacy, as evidenced by public understanding of science surveys by the US National Science Foundation (NSF, 2002, 2004, 2006) and those in Europe (Eurobarometer 55.2, 2001; Special Eurobarometer, 2005).

Scientists are therefore encouraged to communicate and engage with public audiences by governments and their institutions (Thomas and Durant, 1987; Clarke, 2001; Royal Society, 2006), though the latter often have specific goals not aimed at the Public Understanding of Science, such as funding as mentioned above, and – in the case of universities – student recruitment (Borchelt, 2001). Scientists are also increasingly required to undertake some public communication of their research by the terms of their research grants, for example in NSF funding. The process is often regarded as an 'add on after the research' rather than as part of the research, and in any case the funding provided is usually not enough for anything other than a minimal effort (DeVore, 2006). In NASA, the NASA Astrobiology Institute, in particular, requires the same of its grantees, but efforts are made to 'pool' education funding for co-operative programs between NAI members. The Australian Research Council is also increasingly concerned with communication of research to public audiences.

In spite of the increased pressure on the need to communicate, scientists do not always regard public communication with much enthusiasm. For example, scientists do not get research credit for communicating with the public and, in any case, one in five scientists in a UK survey said that scientists who engage with the public are 'less well regarded by other scientists' (Royal Society, 2006). Peer disdain for a public profile is further examined in Chapter 2 as it may also affect astrobiologist would-be communicators. One of the best known examples of peer attitude involved cosmologist and author of popular science books, Carl

Sagan. His membership nomination to the National Academy of Science was rejected, supposedly mostly because of his public profile (Poundstone, 1999). Sagan's commitment to communicating science to public audiences was seen as an 'oversimplification' of science, though the nominating scientist, Stanley Miller said that in hindsight it was 'jealousy' (Davidson, 1999). The NAS did make amends – just two years before Sagan died he was given the Academy's highest honour , the Public Welfare Medal for "distinguished contributions in the application of science to the public welfare," http://en.wikipedia.org/wiki/Carl_Sagan In spite of his Academy rejection, Sagan had a substantial scientific record with more than 100 professional papers. He was a consultant and adviser to NASA since its inception shortly after the launch of Sputnik, working on the Mariner, Viking, Voyager, and Galileo missions http://starchild.gsfc.nasa.gov/docs/StarChild/whos_who_level2/sagan.html (Davidson, 1999; Poundstone, 1999). In addition Sagan co-designed the plaques affixed to the Pioneer spacecraft as a 'message in a bottle' to any intelligent beings the tiny craft might encounter. In 1977, he was the co-producer of *Murmurs of Earth* – a disc placed on the Voyager spacecraft for the same purpose. Inspired by the Voyager 1 photograph at the front of this thesis, Sagan coined the description of Earth as a 'pale blue dot' (Sagan, 1994). Sagan had encouraged NASA in 1990 to allow its interplanetary spacecraft, Voyager 1, to take a 'family portrait' of the planets as viewed from the outer reaches of the solar system so public audiences could see what Earth looked like. The result was that from 6.4 billion kilometres away, Earth appears as a dot, and one that takes less than a pixel of the photograph – an image that took 5.5 hours to reach Earth (Sagan, 1994). Sagan used such eloquent pictures as way of engaging the public, convinced that science is *"an essential [survival] tool for any society...to be understood and embraced by the entire human community"* (Sagan, 1996 p336).

British scientist, writer, broadcaster and member of the UK House of Lords, Baroness Susan Greenfield is another fierce advocate for the public understanding of science. Nevertheless, she sees public scientific literacy somewhat differently – that audiences now understand that knowledge has power. They are taking responsibility for their own learning. Greenfield in her book *"Tomorrow's People: How 21st Century technology is changing the way we think and feel"* suggests public audiences will not wait for one-way communication science-to-the-public (Greenfield, 2004). She asserts there is a realisation among the public that scientific literacy is essential *"...if they are to contribute to the great debates that science will inspire this century"* (ibid p184). While Greenfield offers no evidence for this assertion, audience responses to scientific events – particularly in space exploration – are evident in Internet statistics. Unlike the traditional mass media, where only circulation, the number of listeners or the number of viewers is known for the whole product, the Internet can track visits to a specific story, revealing audience response. Around one fifth of the planet's population now has Internet access (Internet World Stats, 2007) with some of the highest saturation levels in the US (70.9%), Australia (57.3%), and Europe (42.9%), making the Internet a useful measuring tool in the world Greenfield sees. This is discussed further in Chapter 2.

Nobel Prizewinner Al Gore is not a scientist himself, but a politician, a former US Vice President, and one-time US Presidential candidate. Nevertheless, he has involved himself in the global warming debate in a very public way – a Hollywood film. He goes a step further than Sagan, seeking active public engagement with science to address a planetary problem. Gore ends his Academy Award-winning film about global warming, "*An Inconvenient Truth*", with Sagan's Viking 1 'pale blue dot' photograph. He uses the image to dramatic advantage, paraphrasing Sagan, "That's all we've got" (http://www.aninconvenienttruth.com.au/truth/) Gore, urges society to see the planet as a whole, and to consider the evidence that natural planetary processes are being impacted negatively – perhaps dangerously – by our use of fossil fuels. Gore's use of the medium of movies has attracted others – but has also drawn criticism that scientists generally neglect *"the common skills needed to engage with mass audiences,"* (Marris and Powell, 2006). Nevertheless, such an endeavour would take time and resource and it is questionable as to whether scientists would have either. The relevant literature on science, the media and the public is reviewed in Chapter 2.

1.3.5 *Paucity of evidence*

With pressure on scientists to communicate, how do we know that these efforts are effective? The answer is less than satisfying. A pivotal issue for the communication of astrobiology – and indeed any science – is the lack of data in relation to the effectiveness of any kind of science communication. Sless and Shrensky remarked:

> ***"…the evidence for the effectiveness of (science) communication is about as strong as the evidence linking rainmaking ceremonies to the occurrence of rain," (Sless and Shrensky, 2001)***

A conclusion of the R2 Report, mentioned earlier, was that given science is a data-driven enterprise, it is surprising science does not demand evidence of the effectiveness of its science communication (Borchelt, 2001). The reality is, though, that collecting data, beyond straightforward evaluation, is difficult, time consuming, and expensive. While researchers can acquire large sums of public funding on measuring perceived issues in relation to science and the public, *understanding* the nature of public awareness and what works to remedy the perceived issues are regarded as 'peripheral' (Stocklmayer, 2001). This is because such activity is neither science nor education and therefore falls into no broad category when applying for research funding. Stocklmayer goes on, *"The task of defining what they are doing and why they 'work' – or even whether they 'work' – is not addressed,"* (p 146). As the literature and this thesis discusses in Chapters 2, 7, and 8, it gives the enterprise of science communication a 'scattergun' texture: the unstated hope that some of the shot hits the right target.

1.3.6 *Expectations and testing*

How do we measure scientific literacy? Testing of audiences takes two forms – by the international examination of high school student levels of scientific literacy, and in surveys of public audiences.

There are two major international tests of scientific literacy in relation to high school students. These are the US Education Department's international Trends in Mathematics and Science Study (TIMSS) (Institute of Education Sciences, 2003) and the Program for the International Assessment of Student Assessment (PISA) (Organisation for Economic Cooperation and Development, 2007a). TIMSS and PISA test for different aspects of scientific literacy. TIMSS concentrates on content standards, while PISA tries to discover how well students can integrate and use the content. Both assessments compare levels of abilities between countries, so they are relative. Adult population testing for scientific literacy uses a set of assumptions about what adults should know about science. This varies in content, but there are commonly used questions and this enables some comparison between, for example, Europe and America. Therefore, while there is an expectation high school science education will produce scientifically literate citizens, the measures used to test that assumption are quite different and, arguably, are based on different expectations.

In the wider public community, a major component of the adult testing concerns the understanding of the way science works. One question that has been regularly used for this purpose since 1957 in various parts of the world is: *"What does it mean to study something scientifically?"* (J.D. Miller, 2004). The common use of the question through time, no matter what the challenges may be to its construction and analysis, provides a single benchmark as a longitudinal measure of public scientific literacy in relation to understanding the nature of science. Answers given in 1979 can be measured against answers given in 2007 (or in the case of this thesis in 2005 and 2006), and those in 1979 can be benchmarked against those in 1957. While not the same cohort, the experiences of each age group are carried through time as J.D. Miller points out (2007). The question also crosses international boundaries, being used in both Europe and the US. It is at the crux of this thesis, and further explored in the literature (Chapters 2 and 3), the results (Chapter 6) and the discussion of the results (Chapter 7).

1.4 PROJECT AIMS AND DATA COLLECTION

The key drivers of this thesis are:

(a) To provide an initial understanding of what the level of scientific literacy of Australians might be as compared to that of adults in the US and Europe.

(b) To understand whether students – tomorrow's adults – meet these adult standards at the end of their formal science education at high school.

The data were collected in high schools at a point where, at least in Australia, a student can end their formal science education at the age of 16 (Year 10). First year university students were also tested as a measure of what level of scientific literacy there might be in the Australian adult public. Whatever high school students know or understand about science from formal education is what they will step out with into the adult community. While the data collection and analysis is limited to the constraints of a single doctoral thesis, it may provide insight as to the genesis of public scientific literacy. This is further explored in Chapters 2 and 3, and in the results (Chapter 6) and conclusions (Chapter 8).

In terms of scientific literacy, what can we, or should we, expect of new young adult citizens emerging from high school? Should we eventually see an improvement on the levels of scientific literacy that have been seen in the US? What results do we get if students are tested using adult standards? What does this mean in terms of scientific literacy in general and the effective communication of astrobiology in public?

Five sets of data involving a total of 1,100 students were taken over two years in Australia and Wales with 692 fully completed surveys for a response rate of 62.9%. They were:

1. A cohort of Year 10 students (16-year-olds) from seven Sydney area high schools in 2005 participating in an education project over a whole term.
2. A another group of Year 10 students from seven Sydney high schools in 2005 over a whole term not participating in the above mentioned education project.

3. Another cohort of Year 10 students from five Sydney high schools in 2006 for a single day in the school year
4. An Australian first year university class over a whole semester
5. A cohort of mostly 16-year-olds from three high schools in Wales in 2005.

The data for this thesis were collected during the making of, in collaboration with NASA, an international astrobiology-based education project entitled *"The Pilbara Project".* The project was renamed *"LifeLab"* for its public release in April, 2007, via Cosmos magazine, which is one of Australia's leading science magazines. The project and its relevance to the thesis are explored in Chapter 4.

The first group of 87 students in 2005, from seven Sydney high schools, visited Macquarie University for three separate in-person days over a school term for the *Pilbara Project*, while another group remained at school continuing normal science lessons. The groups were quite different. The group of 87 were considered the best science students by their teachers. The (much larger) group not participating in the *Pilbara Project* represented students of all science abilities. Qualitative data were collected from the 87 using a one-way mirror and microphone system at the Macquarie ICT Innovations Centre at Macquarie University in Sydney.

A total of 21 of the 87 students also participated in interviews about their perceptions of science, as did the seven accompanying teachers. The methodology is addressed in Chapter 5, with results provided in Chapter 6.

1.5 PROJECT HYPOTHESIS

The quantitative and qualitative data were collected and analysed on the basis of adult measures of scientific literacy to test the hypothesis that:

> **The majority of Australian students may be leaving high school as scientifically illiterate as adults in the US and Europe as measured by standards applied to adults.**

A total of 1,100 students were tested in seven high schools and at first year university level in the Sydney area. A total of 692 surveys were completed. Although restrictions in the US prevented study of American high school students, this was possible in three Welsh high schools where 63 surveys were completed out of a total sample set of 80. Data were also collected from a first year Australian university class in an attempt to provide some crude measure of how scientifically literate the Australian public might be in relation to adult audiences in Europe and the US.

The findings do not necessarily imply fault with science teaching and learning, or fault with the different types of survey instrument at high school and adult levels. Rather it suggests that the lack of universally accepted definitions in common terms. These include scientific literacy, the nature of science, the public understanding of science, and the appreciation of science. The lack of agreed definitions make each a moving target. Nevertheless, current methods are the best approximation of the level of scientific literacy available anywhere, and thus a similar survey methodology is employed in spite of the limitations, as discussed in

Chapter 5. The results are analysed in Chapter 7, with conclusions and recommendations in Chapter 8.

1.6 ALTERNATIVE HYPOTHESES

The alternative hypotheses are:

1. The majority of Australian students may be leaving high school *more scientifically literate* than levels indicated in Government adult surveys in the US and Europe.
2. The majority of Australian students may be leaving high school *less scientifically literate* than levels indicated in Government adult surveys in the US and Europe

There are two sets of data in addition to the Australian high schools students: (a) High school students in Wales, and (b) First year university students in Australia. These two datasets lead to additional hypotheses:

3. Australian students may be leaving high school *more scientifically literate* than students in Wales.

4. Australian students may be leaving high school *less scientifically literate* than students in Wales.

5. Australian students may be leaving high school with a *similar level of scientific literacy* than students in Wales.

6. Australian high school students at Year 10 may be *less scientifically literate* than university students undertaking a first year university arts unit.

7. Australian high school students at Year 10 may be *more scientifically literate* than university students undertaking a first year university arts unit.

8. Australian high school students at Year 10 may have *a similar level of scientific literacy* to university students undertaking a first year university arts unit.

9. There is a fundamental problem with the question *"what does it mean to study something scientifically?"* The results, both in the public community and among high school students tested, suggest the question may not be a good guide to scientific literacy, in spite of its longevity in public testing.

1.7 RELATED RESEARCH QUESTIONS

There are five questions that impact on, and that are related to, the analysis of the results:

1. How is scientific literacy defined?

2. How is the nature of science defined?

3. What is meant by the awareness and/or appreciation of science?

4. Why is public scientific literacy important and can it be achieved?

5. What are the goals/expected outcomes of communicating astrobiology in public?

The public understanding of science - the sum of these research questions - challenges the understanding of what we mean by that phrase. If we cannot define it, we cannot measure it precisely, and we have no evidence that any activity designed for the public understanding of science is effective.

The data for this thesis are analysed in the context of how scientific literacy among public audiences has been measured since 1957. Review of the literature in Chapters 2 and 3, and discussion in Chapters 7 and 8 reveal how little is really understood about scientific literacy and the effectiveness of science communication.

1.8 TITLE OF THE THESIS

The doctorate was executed under the auspices of the Australian Centre for Astrobiology, initially at Macquarie University and later at the University of New South Wales, hence the title *'Communicating astrobiology in public: A study of scientific literacy'.* Though the data, results, and analysis have an astrobiology focus, the intention is to advance our current understanding of scientific literacy in the broader framework of communicating science. Any presenter or communicator needs to know the level of understanding among the audiences for which their messages are intended. Though specifically aimed at Australia because of the particular paucity of data on public scientific literacy, it is expected that the thesis will also have application in the public communication of astrobiology internationally, as well as for the whole of science.

The Australian Centre for Astrobiology is linked to a history of the field that has its beginnings in the 1950s when Nobel Laureate Joshua Lederberg led research in what he called *'exobiology'*. It has also been termed *'bioastronomy'*. Astrobiology came into its own when NASA initiated the NASA Astrobiology Institute (NAI) at the NASA Ames Research Center in California in 1996. It operates on a small staff with most of its membership resident in 16 research teams in universities and other institutions in the US. It also has two associate members, Centro de Astrobiologia in Madrid - and the Australian Centre for Astrobiology. Five other international members have affiliate membership. The NAI also hosts a series of Focus Groups. For around 18 months from 2004 the NAI had a Science Communication Working Group which drew together science communicators from all fields internationally, from science and education to media and outreach. It created a map for best practice in science communication. The Australian Centre for Astrobiology is specifically built on the proposal to integrate science communication with excellence in astrobiology research, and was the genesis of this thesis. The title of the thesis also drives an underlying broader question beyond the question of scientific literacy in its own right:

How do the preceding research questions, together with the results of the data collected, and the literature in the various related fields, impact on and define best practice in the communication of astrobiology?

The question draws on a number of fields in media, education, and outreach. The literature is reviewed in all of these fields, as it pertains to the question of scientific literacy and best practice in the public communication of astrobiology. It has the potential to draw in areas of specialisation beyond the thesis, including pedagogy, sociology, psychology, philosophy, and science itself, but these areas, if mentioned, are only briefly discussed. This is in favour of concentrating on public scientific literacy - and how it is related to the mass media, education (broadly), and outreach - to remain focussed on the communication of astrobiology in public within the limits of this thesis.

"Shakespeare, Milton, Plato, Dickens.....Darwin....None of them is known to have talked of putting in 'popular stuff'....or alluded to matters as being 'too complicated to discuss here.' If they were, they didn't discuss them there and that was the end of it."
- Advice from H.G. Wells to Julian Huxley while they wrote The Science of Life for the public (quoted in Gregory and S. Miller, 1998, p 246)

Fig 1: *H.G. Wells (Wikipedia Commons)*

Chapter 2:
Science communication

2.1 OVERVIEW

This chapter explores the science communication literature, the impact of that on communicating astrobiology in public and the almost knee jerk response to an apparently scientifically illiterate public. The dichotomy between the body of research on measuring a perceived problem of scientific illiteracy among public audiences on the one hand, and the reality of communicating through the mass media as a perceived solution on the other, is palpable. Most importantly, if we are to ask scientists to communicate their work to the public at the cost of their research time, it seems incredible that there is no demand for proof that science communication is accomplishing what governments and other institutions assume the public communication of science achieves (Borchelt, 2001). Scientists are simply expected to take it on faith that communication of their research somehow increases the public understanding of science. Science demands data, and so should science communication.

The Public Understanding of Science is the theme of hundreds, perhaps thousands, of papers concerning scientific literacy in formal and informal science education arenas and, especially, in scientific literacy among public audiences. There are perhaps dozens of books on the subject, and many popular articles too that have appeared in newspapers, magazines, and on the Internet.

The fundamental issues, outlined in Chapter 1, seem to exist in a haze of lack of definitions. These include, in particular, the Public Understanding of Science, scientific literacy and the nature of science. This fogginess exists in isolation from those who are charged with fixing the perceived problem of public scientific illiteracy – the scientists themselves and, though science journalists vehemently deny their role is to educate, the mass media as well (see Hartz and Chappell, 1997; Hargreaves, 2000, Royal Society, 2006). As a result, there is almost a collective mantra among the majority of those connected to the science communication field that the public are largely deficient in knowledge of key concepts in science, or lack understanding, awareness or appreciation of science in some way. There seems to be little understanding of what that ultimately translates to in terms of public response to science news and increased engagement in science policy. There also does not appear to be widespread use of best practice among scientists, public relations/public information officers, and communicators, for example in shaping the messages of science for a defined purpose and targeting selected audiences (see in particular Borchelt, 2001). As a result, the altruism at the base of promoting science to promote the public understanding of science appears to be largely misguided. There is a commonly held belief among researchers and Governments and other interested institutions that more science stories in the mass media – often in a 'scattergun' approach - increases the public understanding of science, but there is no evidence that this actually works. In fact, Hargreaves *et al*. (2004) have demonstrated the opposite with a six month study of the public and the mass media, firmly stating that there is "*...little evidence to support the idea that the presence of more science, scientists and science specialists in the media will increase the public understanding of science. On the contrary, a 'science for science's sake' approach seems the one least likely to generate public engagement and therefore understanding*" (ibid, p 53). The Hargreaves team also showed the importance of reiteration of the message in order to achieve at least awareness among the public of a particular science story. If there is a link between scientific literacy and response and/or engagement in science news then there is a probability it may follow the episodic nature of how particular science topics come and go because of the focus on a particular topic over many stories. The episodic nature is documented in the coverage of science in professional journals and general magazines, which was tracked over 14 years. It reveals a pattern of different periods of foci as seen in *Fig 2*. Two issues, global warming and the ozone layer are taken from a list of 23 to provide clarity. The list is quoted by Paisley (1998) from Magazine Index online. A more recent example that potentially links an increase in correctly answering a typical question on scientific literacy surveys with the episodic nature of stories and public health campaigns concerns the dangers in the misuse of antibiotics. A flow of stories about the overuse of antibiotics leading to microbes mutating into antibiotic-resistant varieties has occurred at more or less the same time as surveys recorded an increase in the number of respondents answering this question correctly – that antibiotics do not kill viruses such as the common cold. Paisley suggests that individuals can become highly knowledgeable about a particular aspect of science that affects them, their family, their work, or in society as a whole. A question might be is whether that makes them scientifically literate or not, even if they 'failed' a standard survey. An understanding of knowledge is being demonstrated, and necessarily of process too.

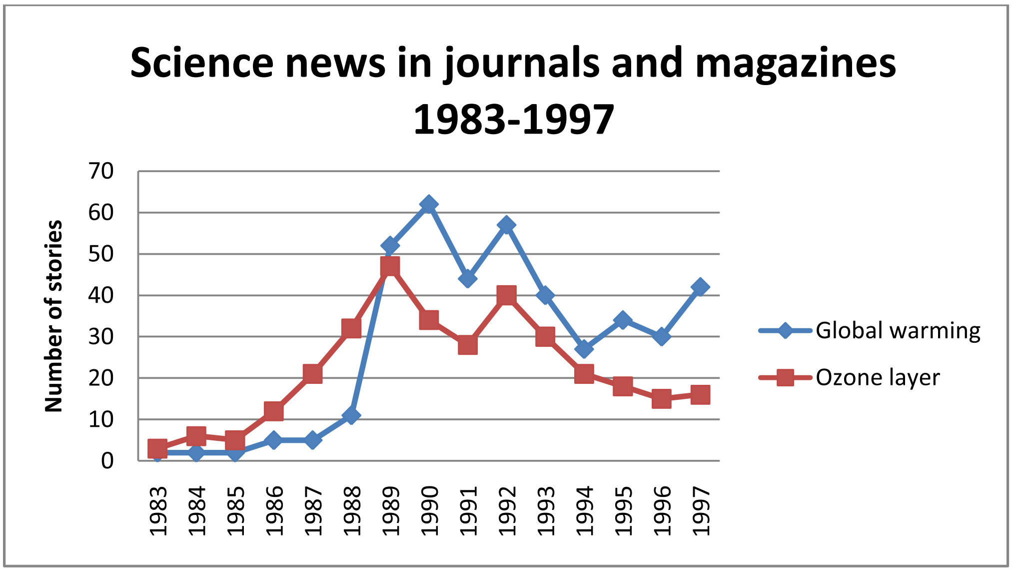


Fig 2: *Coverage of two science topics in general science journals and general magazines 1983-1997 (adapted from Paisley, 1998, p78, from Magazine Index Online)*

2.2 SCIENTIFIC LITERACY

At the centre of the debates and disagreements is measuring adult scientific literacy. The majority of the science communication field stands, in some way or another, on the perception of a scientifically illiterate public based on surveys carried out in a number of countries, but notably the US and Europe. These surveys, in general, assume that the public should know a series of at least ten basic concepts, which are typically used in the false/true/don't know multiple choice mode. J.D. Miller (2004), who has been closely involved with such surveys, maintains that the public need these constructs in order to make sense of science-based stories – particularly those that impact individuals in one way or another. He points to DNA and molecule as terms commonly used in the mass media without explanation. When tested in 1999 only 13 per cent of American adults could explain what a molecule is. J.D. Miller further argues that it is reasonable to expect when NASA spends $16 billion a year on space exploration, the public should know the structure of the solar system. He suggests such knowledge is essential to understanding stories about space science.

Recent surveys suggest the majority of public audiences in the European Union and the US do not know how lasers work or that electrons are smaller than atoms. Less than 60% know it is the father's gene that determines the sex of a baby. Only 22% of Americans know the universe began with a Big Bang and 43% accept that humans developed from earlier species of animals. Less than half the US population accepts the theory of evolution. Less than 60% of Europeans know that not all radioactivity is man-made. Most Americans and Europeans know that continents move, that the Earth goes around the Sun, and that the centre of the Earth is hot (NSF, 2006, Eurobarometer 55.2, 2001). A separate Canadian study by Einsiedel (1994) showed Canadians know the continents are moving (74.9%) and humans developed from an earlier species (58%) and that oxygen comes from plants (80.4%) but less than half know electrons are smaller than atoms (46.7%), that humans did not live at the same time as the dinosaurs (45.9%) and only 14% could say what DNA is. Respondents were asked if they understood what a scientific study is – only 16% replied that they do. *Fig 3* compares the US and Europe with China and Russia.

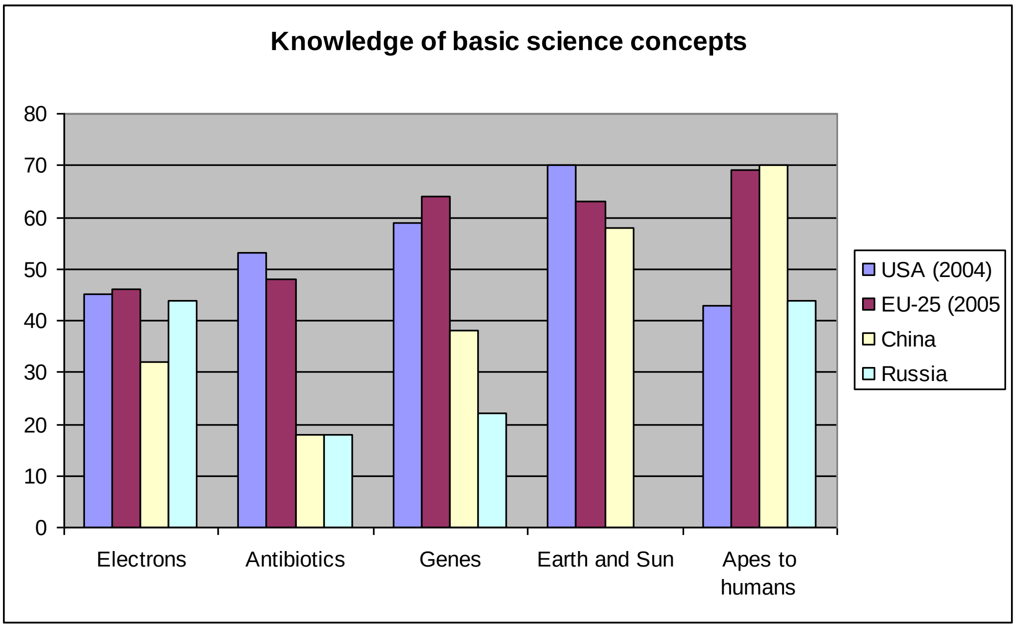


Fig. 3: *Adapted from National Science Foundation Science and Engineering Indicators, (2006), Chapter 7 Fig 7-7 showing correct responses to the following questions (Russian statistics unavailable for Earth and Sun):*

Electrons: *Are they smaller than atoms?*
Antibiotics: *Do they kill viruses?*
Genes: *Does the father determine a male or female baby?*
Earth and Sun: *Does the Earth go around the Sun or vice versa?*
Apes to humans: *Were humans the result of an earlier species?*

Fig 4: How much knowledge is enough to be scientifically literate?

Here is scientific literacy scholar Henry Bauer's summary of what could be deemed necessary, but requires a college level education for understanding as well as knowledge:

** Nature of the chemical elements: what compounds they can make and how; how they behave; liquids, solids, gases; why some solids are crystals, powders or glasses; what polymers are and why some are fibrous and others are not.*

** Organic chemistry – needed for biochemistry and physiology leading to nutrition and medication*

** Elementary knowledge of physics: light, sounds, electricity, magnetism, elementary particles and forces (because we live in a nuclear age)*

** The universe: big bang, evolution of stars and galaxies, formation of solar systems from supernova events.*

** Geology: at least an outline of the history of Earth*

** Biology: Biological evolution, know something about cells, and organisms, the chief classes of plants and animals, and how they are related to and differ from one another; processes of cellular reproduction, sexual reproduction including mutation and recombination, and how DNA enables us to understand all that; basics of developmental biology, and how nature and nurture interact to produce both similarity and variation*.

(adapted from H.H. Bauer, 1995, p9)

The National Association of Science Writers (NASW) conducted a survey in 1957, providing a benchmark study in public scientific literacy. It was run just six months before the launch of Sputnik 1 on October 4, 1957. The NASW repeated the survey in 1958. The surveys included two questions that reflected public response to science news in isolation to scientific literacy: *"Have you heard anything about launching a space satellite, sometimes called a man-made moon?* and "*From what you've heard what is the purpose of launching these satellites?"* In the first survey, 54% of respondents *(n=1,919)* reported they had not heard about satellites; but this dropped to just 8% *(n=1,547)* in 1958 (Swinehart and McLeod, 1960) indicating big science related news events do have an effect on the public. However, the general scientific literacy among the sample had *not* been impacted by the intense news coverage of the dawn of the Space Age (Kreighbaum, 1968). In other words, public audiences had absorbed the news and were able to recall the purpose of satellites, in isolation from their perceived scientific illiteracy.

The 1957/1958 surveys also generated a benchhmark question *"What does it mean to study something scientifically?"* In 2006 the US National

Science Foundation reported that only 23% of Public Understanding of Science survey respondents knew what it meant to study something scientifically (NSF, 2006). J.D. Miller (2007) reports the figure a year later as 28%. In the UK, a similar study in 2002 revealed only 14% of respondents could give a minimally acceptable answer to the same question (Evans *et al*., 2002).

Did Galileo take science on faith?

Galileo did not have any experimental way of determining the hypothesis that the Earth revolved around the sun. He inferred it from observations of the planets and of the four largest moons orbiting Jupiter.

At the time of his writings none of the following tests could have been done because they had yet to be discovered.

1. The movement of Foucault's Pendulum

2. Keplar's laws of planetary motion

3. Stellar parallax

Fig 5: *The conclusions of a private discussion between physicists Dr Michael Duff and Dr Paul Davies, and the author, Arizona, 2008*

While a largely scientifically illiterate public is generally accepted across the literature there are those that challenge it such as H. Bauer (1994) and Shamos (1995). Shamos points to the lack of defining exactly what it means to be a scientifically literate citizen, while H. Bauer is equally dismissive of assumptions made about what scientific literacy is. He also attacks the scientific method as being little more than worksheet school science rather than how scientific research gradually builds a solid, but always tentative, database of our understanding of the natural world. Shapin (1992, p28) also dismisses the *"fables about the scientific method so beloved of textbook writers".* He says the *"methodological fairy tales"* give rise to the belief the scientific method sorts out good from the bad, or that it can ultimately confirm or discard information in the way a scientist interrogates the natural world. It does not reveal the *"contingency and revisability of scientific judgements"* or the different interpretations of the same evidence. Jenkins (2007) is also highly critical of the scientific method because of its formula-like nature – hypothesis, data collection, analysis, interpretation, and conclusion. He says it does not represent how the sciences are undertaken in terms of peer review and scientific debate, nor the cultural or creative context in developing ideas that lead to discoveries. Neither does it reveal scientific thinking of the kind that challenges a commonsense point of view, for example the perception that heavier objects fall faster than light ones and the Sun goes around the Earth – apparent views that confront the public every day. In addition, it takes no account of different methodologies used in different sciences, or the world view of each of the disciplines. For example astronomy and biology are time directional, whereas for physics and chemistry, time is just another controllable variable. Even within the sciences there are differences in approach, for example organic chemistry where there are modellers and experimentalists constantly in tension (George, 2007). Hazen (2002) suggests scientific illiteracy is not confined to the public. A survey of 24 PhD physicists and geologists showed only three could explain the difference between DNA and RNA, a basic concept in molecular biology. Oliveira (pers.com., 2008) concurs, citing a colleague from the life sciences who could not name the planets of the solar system.

More seriously among the public is the belief factor: where science is apparently seen by the public as to be believed or not in the same way as one might have religious faith rather than its empirical evidence-based nature. In the US the majority of the public do not 'believe' in the theory of evolution (NSF, 2006) – note how poorly the US performs on the evolution question in *Fig 3.* There have also been controversies and challenges on attempts to teach Intelligent Design as an alternative theory to evolution (see Dover decision, 2005). To a certain extent the idea that science is a belief system is promulgated by mass media following normal practice of giving equal weight to different interpretations of a story rather than weighting according to a view based on peer reviewed scientific research. An example of this was media weight applied to a single researcher who claimed there was a link between the UK triple vaccine for Mumps, Measles and Rubella (MMR) and autism. The scientifically unbalanced reporting subsequently led to substantial resistance among parents in allowing their children to be vaccinated - in spite of the weight of the evidence that showed the vaccine was safe (Hargreaves *et al*., 2004).

Yet another issue is in what the public believe and how they interpret the evidence available to them (see the Climate Change box, *Fig. 6* for example) and sometimes an apparent lack of ability among public audiences to distinguish between credible and less credible evidence (Stootman, pers.com., 2008). Other researchers debate the meaning of scientific literacy, but generally include at least some form of content knowledge and process knowledge though there is disagreement on what content should be and what the nature of science

BELIEF AND GLOBAL WARMING IN PUBLIC

Robert is an intelligent, average American with an interest in science. He does not believe global warming is anthropogenic - the result of human activity –but that it is a natural planetary process and that we make no contribution to that process.

His friend Kevin (also American) provides him with an Internet 'NewsMax' story that global warming itself may not be happening, quoting the US National Oceanographic and Atmospheric Administration (NOAA) that there had been very cold weather of late in various parts of the world and lost ice at the poles was returning. Robert refuses to watch "An Inconvenient Truth" because it has been produced by a politician. He has strong political views.

An Australian SBS story is offered in which Tim Flannery, author of The Weather Makers, *provides similar account to that of Al Gore showing carbon dioxide levels well above planetary cycles over hundreds of thousands of years, and describes the impact we are having on our planet. Robert and Kevin are asked to comment on it. Robert still maintains his world view given the evidence available to him. Kevin replies that Flannery is a palaeontologist. If he had a need of medical attention he would not consult a meteorologist. Why should we consult a palaeontologist about global warming?*

(Fata, pers.com., 2008) Fig 6

Note: NewsMax is an Internet news site with breaking news on American politics and provides a digest of top news stories actually is. For example, see Thomas and Durant, 1987; Durant, 1993; Lewinstein, 1997; Paisley, 1998; Popli, 1999; Laugksch, 1999; Hodson, 2005. More recently there have been studies that extend the commonly used concepts of previous scientific literacy surveys into areas of current interest. These include nanotechnology, genetically modified plants and animals, ecology, and infectious diseases (J.D. Miller, 2007). Miller uses cohort sampling from previous surveys, matching age groups through time, to extract longitudinal data that otherwise would not be available. Although not the same respondents, they are representative of specific age groupings. From these studies of US data he demonstrates an increase in adult scientific literacy from 10% in 1988 to 28% in 2005 (ibid). Miller also demonstrates that the number of tertiary science courses taken is the strongest predictor of scientific literacy in the US – the only country where all university students are required to take a year of science courses as part of their general education. The US is not alone in recording increases in scientific literacy. Between 1992 and 2005 an increase was observed in almost all European countries with Belgium, Germany, Iceland, Luxembourg and the Netherlands recording double digit increases, though still not raising the statistics to the level of the majority of adult public audiences in Europe being considered scientifically literate.

The surveys record an increase in scientific literacy by the measures applied. No study has been done to understand the effect, if any on greater public participation in a democracy and in scientific policymaking, contributing to the economic health of a nation, being able to evaluate evidence and define science from pseudoscience, making better informed consumer choices, or in producing a populous that is culturally and socially more enriched by scientific literacy. It would be difficult if not impossible to measure these aspects, but the point is that there is no direct causal evidence of a link between scientific literacy as measured by careful survey research and the actions of citizens in relation to science in the community.

A question could be posed as to whether scientific literacy is any more desirable than at least 41 other types of literacy from technical, historical and mass media to sexual and consumer, and of course including basic reading, writing and numeracy literacy (Paisley, 1998). In 2006 the National Geographic Education Foundation surveyed a representative sample of the US population and found the majority could not find Iraq, Iran, Saudi Arabia or Israel on the map. An even greater percentage – more than 75% - could not find Afghanistan. Nor did the majority know the border between North and South Korea was the most heavily fortified in the world. This is in spite of American involvement in these countries, sometimes in a war situation, and being the subject of stories in the print and electronic media on a regular and persistent basis. Is this any more, or less, important than scientific literacy? Susan Jacoby (2008) in her book *'The Age of American Unreason'* sees a general decline in knowledge, including scientific knowledge. She blames an instant gratification society in which individuals rely on information being at their fingertips via the Internet rather than being aware of the subtleties of political and other debates. Also in 2006 less than half the American public read any kind of work of fiction including 'bodice-breaking romances' and detective novels. Only slightly more than half of the public read a non-fiction book during 2006. Jacoby despairs of what she calls a dumbing down of knowledge. The problem in Australia is that for such things as scientific and geographic adult literacy, it simply is not known whether the literacy levels are any worse or any better than in the US or, indeed, anywhere else in the world.

Other recent literature suggests at least a tentative emerging direction in the mediation between science and the public. The sciences are no longer simply out there in society, but an integral function of our daily lives. In 1959 C.P. Snow lamented a fundamental division in communication between the academic worlds of science and the humanities and thus the impact on public audiences. Snow took no account of the potential of television to communicate science to the public, and of course did not foresee the Internet. Since then, the opportunity for the negotiation and mediation of science in the public arena has burgeoned and blossomed through emerging communication technologies. M. Bauer *et al*. (2006) chart the eras of public scientific illiteracy from the 1960s onwards, the Public Understanding of Science movement from 1985 onwards, and science in society from the 1990s onwards, now against this backdrop of an information-rich society. Nevertheless, the playing field has changed while the original game that takes it almost on faith – that the public are largely scientifically illiterate by any measure – is still being played. The sciences have split into more and more specialisations, while the public have had access to more and more information and communication. The latter are both seeking scientific knowledge using new communication technologies such as the Internet (see NSF, 2006). They are also demanding interpretation of that knowledge, for example self-diagnosing a health issue and quizzing their doctor. Between the sciences and the public are a myriad of science communication specialists. Van Dijck (2003) encapsulates and predicts the new landscape succinctly:

> *"Just as the bipolar professional identity of scientists and artists has splintered into a kaleidoscopic range, the binary opposition between scientists and non-scientists has equally dissolved into a continuous palette of participants."*

The majority of the literature implies division into three broad cornerstones – researchers, governments, and the scientist-science journalist relationship. All three largely represent the entire field of the public scientific literacy and the Public Understanding of Science *as it was*. Little of the literature, like C.P. Snow's lecture not taking account of the increasing access to television communication, considers the realities and best practices of communicating science into today's communications hi-tech, information-rich, public domain. Nor does it largely take account of the rapidly changing political, cultural and social landscape that has emerged in concert with science becoming a physical part of everyday life – from computers and cell phones to reading our genome and vaccinations for cervical cancer. Neither does the literature, with some exceptions, take account of engagement in science and influence on public perceptions of science through entertainment in box office hits like The Cell, Gattaca, and AI (Artificial Intelligence), or television series such as Star Trek, where fans globally delight in picking up scriptwriters on scientific accuracy (Van Dijck, 2003).

No research has yet produced convincing data that it is possible to even get close to understanding the effectiveness of science communication in today's environment - let alone prepare high school students to become scientifically literate citizens. Apart from surveys of the Public

Understanding of Science - that are criticised for their assumption of a public deficient in science knowledge and process – and some good, but relatively small-scale, research projects - there are no data on this broader nature of links between public scientific literacy and a causal effect on the public domain. This is true even in past environments. Neither are there substantial data on the effectiveness of science communication initiatives (see for example Pringle, 1997; Borchelt, 2001; Stocklmayer *et al.,* 2001; and Sless and Shrensky, 2001, Burns *et al*., 2003).

2.3 COMMUNICATION WITHIN SCIENCE COMMUNICATION

The contributors to the scientific literacy, Public Understanding of Science, and science in society literature come from diverse fields – scientists, science communication researchers, educators, psychologists, sociologists, historians, and journalists, among others. The three cornerstones of the field, (researchers, governments, and the scientist-science journalist relationship) barely overlap.

The first cornerstone is a body of research relating to scientific literacy in the public domain (for example, Withey, 1959; Durant *et al*., 1989; J.D Miller, 1998, 2004, 2007). The second is an area of reports and data collection (mostly government and institutional reports and public surveys) that tends to accept the majority opinion of the first – that public audiences are largely scientifically illiterate. This body of literature also generally makes the basic assumption that increasing the public understanding of science - and to some extent, by default, the appreciation of science - via the mass media is a key way of addressing the issues perceived in the first cornerstone (for example, Bodmer, 1985; House of Lords, 2000;

Office of Science and Technology, 2001; British Association, 2002). In the third cornerstone are scientists, political scientists, journalists, and educators. They largely accept or assume either directly or indirectly that at least public audiences are, indeed, largely scientifically illiterate and/or that there are issues in the public communication of science that need to be addressed (see J.D. Miller, 1998, 2004, 2007; Gregory and S. Miller, 1998; Durant *et al*., 1989; Triese and Weigold, 2002; Hargreaves, 2004; M. Bauer *et al*., 2006). The central concept is in addressing the uneasy relationship between scientists and journalists (Friedman *et al*., c1986; Nelkin, 1995; Hargreaves, 2000; Hartz and Chappell, 1997) and in understanding best practices in science communication (Borchelt, 2001; Stocklmayer *et al*., 2001; Weigold, 2001; Triese and Weigold, 2002), but largely do not consider the reality of the reception of any messages about science.

There is a surprising *independency* rather than an *inter-dependency* between the three cornerstones. The result is there is little evidence one cornerstone informs the other, so the results of research have not translated into a largely scientifically literate public. There is a basic issue that hamstrings all efforts to understand the relationship between the sciences and the public: the wealth of painstaking and thoughtful research appears to do little in the way of informing either science communication policies or practices (Gregory and S. Miller, 1998) even when science communication researchers attempt to bridge the gap between theory and practice (S.Miller, 2003). What is happening? Why do we see inertia in the route from research to practical communication of science in public?

A basic function of successful communication is in knowing the audience, and in each of the three cornerstones, the primary audience is known. None of these primary audiences overlap. In cornerstone one, the primary audience are other researchers in scientific literacy – an example being in the paper *Mapping variety in public understanding of science* (M. Bauer and Schoon, 1993) and J.D. Miller's response to it in the same year, in which the parties debate methodologies. Researchers in the field widely cite each other with often insightful commentaries and some data collection – for example J.D. Miller *et al's* paper on what audiences learn from television (2006b). Such debates and research papers tend to mimic the processes involved in pushing back the frontiers of knowledge in science. Nevertheless, unlike science, they do not appear to influence or inform outside of the field – it seems confined to the research field itself without practical application.

In cornerstone two is the wealth of data of surveys and reports. The surveys on public scientific literacy are subject to some challenge on the assumptions made, as mentioned, and therefore the efficacy of the results. Both the reports and the surveys are largely sponsored by Governments and institutions, for example Eurobarometer 55.2, (2001), Special Eurobarometer (2005), NSF (2002, 2004, and 2006). Science communication researchers classified under cornerstone one often lead the survey and report work. For example, J.D. Miller led the Public Understanding of Science statistics in the National Science Foundation's biennial Science and Engineering Indicators for a number of years and Hargreaves has twice been supported by the Economic and Social Research Council (Hargreaves, 2000; Hargreaves *et al.,* 2004). The primary audience in cornerstone two is essentially the promoting body: it is an attempt at gaining a picture of the issues, but not necessarily the solutions, for example Special Eurobarometer (2005) the Science and Technology Engineering Indicators (National Science Foundation 2006).

The primary audience in the third research/policies cornerstone are communicating scientists and science journalists. One of the most comprehensive reports in this area, *"Worlds Apart"* (Hartz and Chappell, 1997) underscores the theme of the literature – the uneasy relationship mentioned above between scientists and science journalists. One claim the report makes in common with other research is that the failure in good communication between scientists and science journalists ultimately impacts the scientific literacy of the general public, though there are no data that demonstrate that relationship. Again this tends to be generated in the field by members of either audience for one or both audiences, but largely without reference to the first two cornerstones. Nevertheless, changes in the public uptake of communication technologies, such as the Internet, may be reducing the importance of the relationship between scientists and science journalists as this thesis is being written. The numbers of science journalists appears to be declining. Prominent universities in the US reported in 2007 fewer numbers of journalists wishing to specialise in science as newsrooms reduce the numbers of journalist overall (Jennings, 2007). The NSF (2002, 2004) reports most respondents in its biennial survey of the public understanding of science turn to the Internet for specific science information rather than other forms of media (see *Fig. 8*).

In a sense there is a fourth cornerstone - scientific literacy in the formal education environment in the direct, practical way. This generates a field of both separate literature and publications, for example *Science Education* and the *International Journal of Science Education.* The following chapter is devoted to this latter field, which is almost an outlier to the wider question of public scientific literacy. Nevertheless, the two together – public scientific literacy and scientific literacy at high school – impact on each other. It is an important aspect at the heart of the data presented in Chapter 5. Can we show that by using the measures of scientific literacy in the adult world, that students about to leave high school science education are no better or no worse than what is found in the adult environment? In other words, do we generate the picture of high levels of public scientific illiteracy by producing young adults without the skills to meet those tests (whether the testing is faulty or not)?

The lack of definition of scientific literacy challenges the generally held perception that high school science education should first and foremost produce scientifically literate citizens (see Goodrum and Rennie, 2007, as the Australian example). If we are to accept that statistics such as those produced by the US National Science Foundation (2002, 2004, 2006) and the European Community (Eurobarometer 55.2, 2001; Special Eurobarometer, 2005) do reflect a largely scientifically illiterate public extending back through 50 years of research and measurement in both the education and science communication fields, then why do the public remain largely scientifically illiterate? Why do initiatives in high schools internationally not appear to have any effect on changing that situation in the adult public domain? Or is it that expectations among adult public audiences implied in the measurement process are different to the expectations of students at high school?

2.4 LESSONS FROM HISTORY

There is little doubt the political, social and cultural landscape in 1957 provided the frame of reference and context that created the non-overlapping cornerstones we see today. It appears that these three areas gained impetus almost immediately, but went in three different directions and set the foundations for what is seen in today's environment. The concerns about student and public scientific literacy happened in a very different world that had neither the widespread television access nor the ubiquity of the Internet. It was an era deep in the winter of a Cold War between the then superpowers – the United States and the Soviet Union. The beginning of the Space Age spurred deep concerns that the Soviet Union was more technologically advanced than the US and that scientific literacy, or a lack of it, was the basic reason (Kreighbaum, 1968; Paisley, 1998) although there was no foundation for believing either. It is not to say that there was no concern before 1957 on public scientific literacy or on the communication of science, only that it lacked focus. The *popularisation* of science has been around for millennia, suggesting there has always been an interested public audience as we still see today and reported regularly by the scientific literacy surveys. There is a dichotomy between persistently reported high levels of interest in science at the same time as low levels of scientific literacy.

The history of public interest in science is long. Herodotus (c.484-425) gave what might be the first public geological explanation of the formation of Egypt. There are many scientists throughout civilisation in the past two millennia who have sought to make their work publicly accessible – Galileo, John Herschel, and Charles Darwin among them (Gregory and S.

Miller, 1998). In the depths of the Victorian gas-lit winters in London, self-taught physicist and chemist Michael Faraday engaged with children at Christmas at the Royal Institution by weaving the stories of science discovery and acquisition of knowledge around *'The Chemical History of the Candle'* . Faraday drew on the children's perceptions of a simple candle to see in the light an essence of the nature of science. *"Nothing is too wonderful to be true if it be consistent with the laws of nature"* (words of Faraday, reported by Day, 1999). Delivery of the still popular Christmas Lecture at the Royal Institution in London remains as one of the most prestigious prizes in UK science communication – the Faraday Prize, and given by well-known modern day scientists including Carl Sagan before his death in 1996. Unfortunately, even less is known about the impact of such science communication efforts than is available in the modern arena.

There is some evidence of a closer relationship between science and the humanities prior to Snow's lamentations. In 1833, for instance, the word 'scientist' was coined by polymath William Whewell at the request of the poet Coleridge (Snyder, 2006). Science fiction has also engaged public audiences over the centuries, mixing literature with science to make sometimes surprising scientific predictions. For example, fairly accurate data regarding the two moons of Mars, Phobos and Deimos, appearing in Swift's Gulliver's Travels 150 years before they were discovered by Asaph Hall in 1877, though in 1610 Kepler had predicted their existence (Nemiroff and Bonnell, 1995).

The recognition of the importance of public scientific literacy began earlier than the flashpoint of Sputnik 1 that led to a rethink in science education. In the early 1950s, for example, the Executive Committee of the American

Association for the Advancement of Science changed the purpose of the AAAS to one more oriented towards the public understanding and appreciation of science, and that the methods and nature of science *"...be better understood by Government officials, by businessmen, and indeed by all the people."* But the shock of Sputnik shook the foundations of confidence in the ability of the US to meet the challenges of the Soviet Union in the context of the Cold War between the superpowers. The launch of Sputnik 1 rocket-propelled science, science education, public interest in science and the public understanding of science initiatives into a new era in the US (Shapiro, 1997; Weigold, 2002) and elsewhere together with the modern day repercussions. In education, critics who had been pushing for 'back to basics' in science education got the reforms they wanted (Bybee, 1998). A new approach dawned in science education, at least in the US. Students were presented with *"coherent, integrated, conceptual wholes"* rather than *"...collections of fragments"* in science and mathematics lessons (DeBoer, 1998). Science news, and the public demand for it, exploded. The number of science stories in print, radio, and television increased, but the sophistication decreased, the latter because of the lack of experienced science writers (Bishop, Council for the Advancement of Science Writing, date unknown). In spite of all this activity and funding, no substantial changes were recorded in the public engagement with science because of any increases in scientific literacy.

2.5 KNOWLEDGE TRANSFER

As shown in Chapter 1, the processes of transfer of new knowledge from the lab into the public domain are far from simplistic. The idea the brains of public audiences are empty vessels, waiting to be filled with information, has long been discredited (Gregory and S. Miller, 1998), but is still regularly employed in that manner in the communication of science into the public domain (Borchelt, 2001). This is subtlety different from a public reading, listening, and watching, science news to fill their minds with information they are interested in. The subtlety is in what they are perceived to be deficient in – basic knowledge or the news. Is the scientist communicator teaching or informing? It is an important difference. The one-way communication of using the media to *teach science* in the public domain is largely discredited, but it is the most efficient way to communicate *science news* to the public. The expected outcome changes from increasing public scientific literacy to informing. This shift in perception allows the scientist to construct his or her communication with the media appropriately. In any case, science journalists do not see their job as one of science education, but one of informing. They seek to find the story and to convey it to the public.

Two-way public engagement is more suited to exercises designed for that purpose, such as the Australian Government's annual Science Week. However, such efforts as these are generally aimed at the awareness or appreciation of science, with the objective of improving public attitudes towards science and science policy, rather than public scientific literacy. Nevertheless, this approach has its own difficulties since there is no established link in the literature that demonstrates a public that loves science is a public that supports and engages in science policy issues. Data collected by Durant *et al.* (1989) indicate measures of public attitudes towards science *"are poor predictors of specific attitudes on particular science policy issues"* (Ziman, 1991 p103), and that other values come into play on any particular issue such as religion or politics (Evans and Durant, 1995). On the other hand, the number of editorial column centimetres in newspapers and magazines is often used to measure the amount of science reported in the mass media that is ultimately aimed at raising the profile of an institution (Borchelt, 2001). One pertinent question is whether the column centimetres devoted to science actually reach the audience. Publication is no guarantee of message delivery. Highfield (2000), a science reporter on the London *Telegraph*, says he has to justify his existence every day. *"Every day, my news editor compares my stories, angles, and intros with those in the other nationals (newspapers)."* Boyce Rensberger, a former *New York Times* and *Washington Post* journalist, agrees. His motivation is not to sell newspapers as a scientist once hissed in accusation at him, but to cull the best of the science stories crossing his desk in the hope of getting them into the scarce column inches or minutes of airtime (Rensberger, 2000). Wynne cautions that science itself is 'the elephant in the room' of the public understanding of science. *"What is the science which we are supposing people experience and sense...?"* (Wynne, 2007, p21). Without critically examining the elephant "*...we cannot properly conduct relevant research on publics in relation to science."*

Such findings and assertions are orthogonal to arguments put forward from both those researchers who advocate a more scientifically literate public, based on content and process knowledge, and curmudgeons such as H. Bauer (1994) and Shamos (1995) who question the efficacy of the terminology.

2.6 THE INTERNET: MOVING THE GOALPOSTS OR ANOTHER GAME ENTIRELY?

There appears to be a subtle difference between reporting science through the needs-driven and admitted value-laden eyes of journalists (Nelkin, 1995) and the delivery of science via the Internet and emerging new technologies such as podcasting and Second Life. The increasing availability of Internet access in the US coincides with a rise in the number of NSF survey respondents (NSF, 2002) reporting the Internet as their primary source of science information (see *Fig. 6*). At the same time a drop is seen in television and radio being named as the main source of science news. The Internet rises above all other sources when a respondent is seeking scientific information (see *Fig. 7*). This field alone suggests that the science communication landscape, in which researchers view the scientific literacy of adult populations, is changing rapidly.

It is difficult to make direct comparisons between nations on Internet usage for science and technology information and specific information. The following charts, *Fig. 7* and *Fig. 8*, compare statistics in the US between 2002 and 2004 that indicate a trend seen elsewhere in the world – the growing importance of the Internet as a public research tool when seeking specific science information and, to a lesser degree, as a primary source of science news.

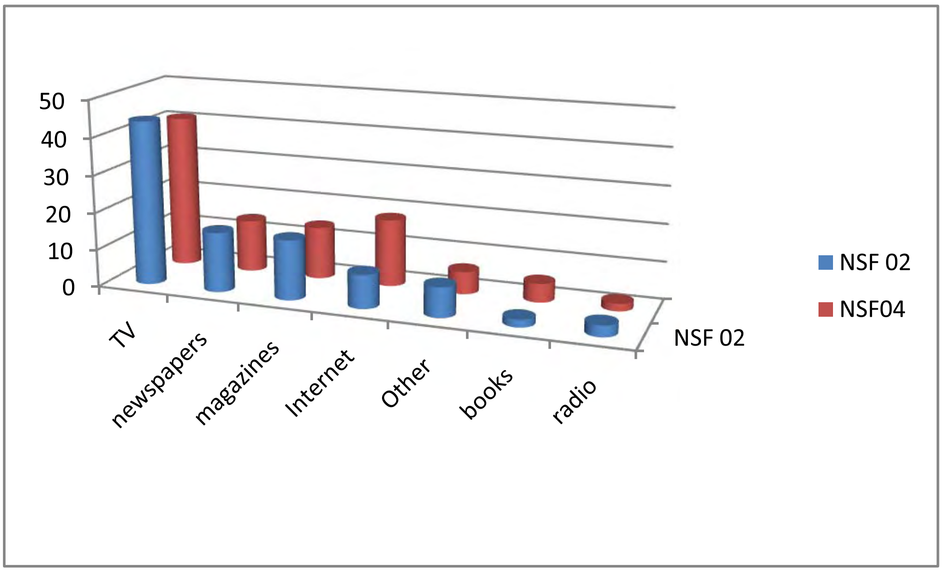


Fig. 7: *Where Americans got their science and technology news in 2004 compared to 2002. (Compiled from National Science Foundation Science and Engineering Indicators, 2004 and 2006).*

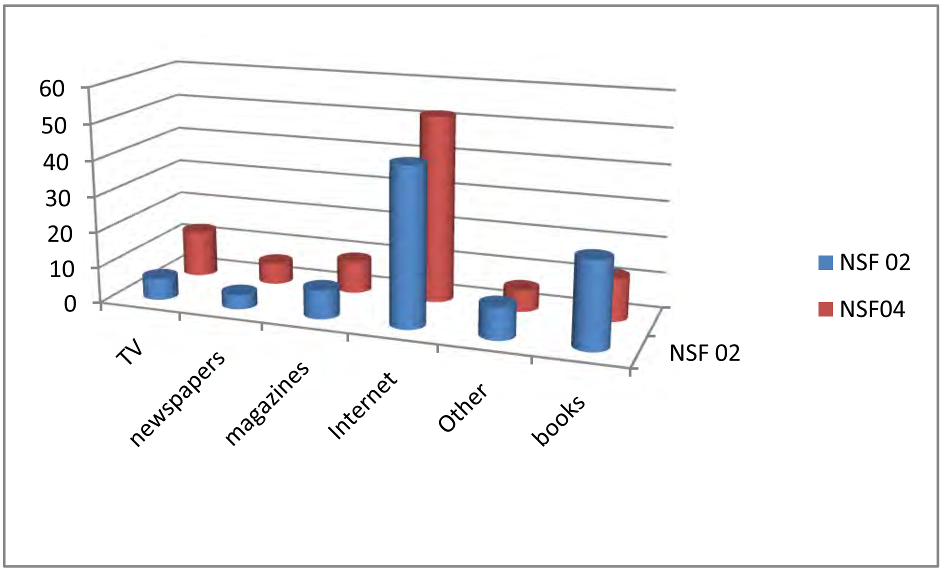


Fig. 8: *Where Americans sought specific information on science and technology in 2004 compared to 2002. (Compiled from the National Science Foundation Science and Engineering Indicators, 2004 and 2006).*

The demand for science on the Internet is also evidenced by the number of science-based websites, including those of major news organisation around the world as seen by the more than 150 current sites listed at http://www.openquestions.com/oq-news.htm#general . Australia's ABC radio website gets special mention as one that attempts to reach its traditional audiences through the Internet as well as radio, embracing such technologies as the increasingly popular podcasting.

The growth in science-based websites and the usage correlates well with the National Science Foundation surveys that have recorded increases in the choice of the web for specific science information from 24% of respondents in 2002 to more than 50% in 2006 (NSF, 2006). At the same time a drop is seen in television and radio as a primary source of science information. It also matches increases in numbers using the Internet from 580 million worldwide in 2002 (Nielsen NetRatings, 2003) to more than a billion in 2006 (Internet World Stats, accessed November, 2006). The 17 billion hits on the NASA portal in 2004 in response to the successful landings and work of the Mars Exploration Rovers, *Spirit* and *Opportunity*, equated to 1.6 billion web page visits (Mahone and Mirelson, 2004). A hint of this wave of interested audiences utilising the Internet to access science information surfaced seven years ago when far fewer were connected to the Internet. For example, the lower levels for Pathfinder and the Hubble Space Telescope compared to the Mars Exploration Rovers should be read in the context of far fewer people being connected to the Internet prior to 2000. The Internet also provides information about *who* is visiting a site as well as numbers. A NASA analysis of the hits in the first month on the rovers' site indicated 25% of the visitors were high school students and teachers (Jacobs, 2004).

A key finding from a study by Treise *et al.* (2003) suggests the Internet can identify audiences most likely to be interested in science. The authors of the study found a strong correlation between interest in science and seeking science information on the Internet. The respondents in the study were also likely to make judgements on credibility of the information based on address (.gov and .edu) rather than author. However, site attractiveness and comprehensiveness of information come into play with more experienced Internet users. NASA, in particular, has a high credibility rating among public audiences even though the media have had misgivings at times (Nelkin, 1995). This suggests the Internet is an emerging tool in science communication towards understanding the needs of audiences. Christian and Kinney (1999) report that the mass media use statistics from their web sites as a rough measure of what interests their audiences. It is worth noting most news websites have science and technology pages, perhaps reflecting that knowledge of what interests the public.

Science journalists admit the Internet is changing the landscape of science communication, but as yet it is not understood what the impact on science information is or will be (Triese and Weigold, 2002). It is *"the media as they are becoming"*, not as they are (Hargreaves, 2000).

2.7 COURTING DISASTER IN A SCIENCE BASED SOCIETY?

While scholars and others wrestle with a definition of scientific literacy, there are motivators in society that seem to make scientific literacy apparently an imperative. For example, a study among 400 US trial judges (Gatowski *et al.*, 2001) demonstrates surprising weaknesses. It shows that although almost all of the 400 judges surveyed placed importance on falsifiability and error rates as an important guideline in evaluating scientific evidence presented in the courtroom, most had no clear understanding of what either meant (see *Fig. 9*). This held true even after researchers went back to the judges to test whether they had understood the questions relating to these two aspects of evaluating evidence.

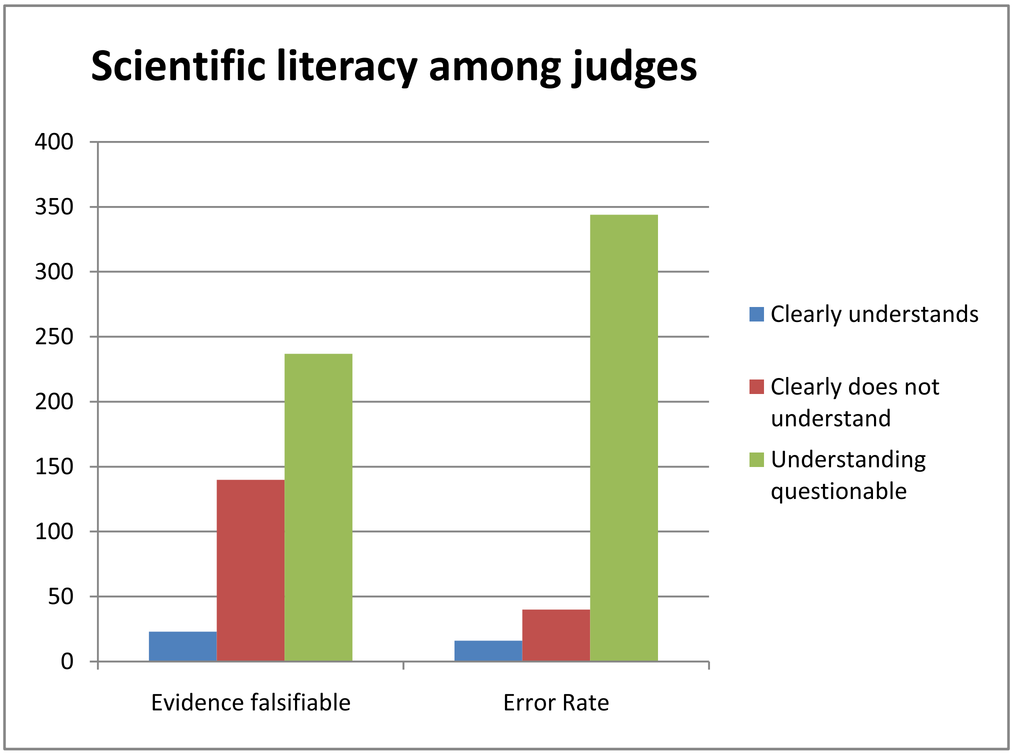


Fig. 9: *Data constructed from Gatowski et al., 2001, pp 445-44*

2.8 THE 20% SOLUTION

Shamos (1995) believes it is impossible to attain general scientific literacy among the adult public and that another approach is required. He poses the questions of what the chances are of getting at least one scientifically literate person who has been randomly selected from a normal population. According to Shamos, if 5% of the population is considered scientifically literate, then there is a 46% chance of one scientifically literate person on the jury – roughly one out of two juries. At a scientifically literate rate of 10%, the chances increase to 72% - but at a scientifically literate rate of 20% that rises to a 93% chance. Shamos therefore proposes that schools focus on students who show an interest or aptitude for science (which will include the future scientists and engineers) thus guaranteeing (theoretically) that 20% emerge from high school scientifically literate (ibid, p194). This increases the chances dramatically of at least one person being scientifically literate in randomly picked jury. According to J.D. Miller the US now has a scientific literacy rate exceeding that (J.D. Miller, 2007). Therefore, while there may be issues concerning the scientific literacy of judges, a defendant can now have a reasonable expectation that at least one person on the jury will be scientifically literate. Nevertheless, most European nations are still below the 20% level (J.D. Miller, 2006).

2.9 SUMMARY

The literature establishes that with the best measures currently available, adult audiences in the US and Europe are still largely scientifically illiterate, despite recent increases in scientific literacy in the US. According to most scholars, scientific illiteracy means public audiences lack knowledge of basic science concepts and cannot provide a minimally acceptable answer to the question *"What does it means to study something scientifically?"* Some scholars suggest such metrics are misleading because they are built on a deficit knowledge approach – respondents are required to know and understand a set formula of basic scientific constructs. Alternative evidence is difficult to obtain – for example in knowing which science news stories an individual will read, watch or listen to and then how that is integrated (if indeed it is) into the individual's world view. A multitude of values come into play such as religion and politics together with a wide variety of preconceptions about science.

There is also no agreement on what scientific literacy actually is, though many groups, institutions, governments and education systems aim to attain it. With no definition, it makes it difficult to evaluate whether formal and informal education programs work, or whether the efforts of scientists are being misdirected by reaching for a goal when they are really communicating another – such as *"we do great research here – come study with us".* Evaluation of the long term effectiveness of science communication of any kind is time consuming, expensive, and difficult. Funding is concentrated on identifying and measuring the perceived problems, rather than addressing the effectiveness of techniques developed and applied to the issues (Stocklmayer, 2001).

Australia remains a mystery in relation to levels of scientific literacy among the adult public. Some indirect studies have been carried out, such as an investigation of the effects of museum attendance in Western Australia and CSIRO's two surveys in 1997 and 1999 on Australian public attitudes to science (Rennie and Williams, 2002). Evaluation data for events such as Australia's Science Week do not provide information on scientific literacy among public audiences.

Scientific literacy surveys generally form excellent, painstaking, research but (a) use a set of basic assumptions about what the public should know, and (b) do not show that even if the results are a true reflection of the state of public scientific literacy that there is any link to how it addresses any of the typical reasons given as to why we need a scientifically literate public. This is not to say that scientific literacy is not desirable or is irrelevant. What is true is that science communication research does not provide a proven link between scientifically literate citizens and the reality of adult public audiences operating in and responding to a society that is increasingly science-based. For example, there was swift public reaction to the launch of Sputnik 1 and an increase in public knowledge about satellites as demonstrated by the 1957 and 1958 NASW surveys. Nevertheless, the increased knowledge did not impact on increasing scientific literacy between the two surveys. Science in society is a complex issue that impacts on science education and outreach, and on the scientists who spend valuable research time communicating to public audiences. It is essential to understand - and have to proof of - how to do that effectively. Fruitful initial steps seem to be to (a) attempt to establish whether there is a gap between formal high school science education and the adult public audiences, albeit with the assumptions built into the surveys, and (b) attempt an initial understanding of the rapid and multiplying impact of new and emerging communication technologies on astrobiology – and science in general – in public. It may be that the wrong questions are being asked.

Nevertheless, the challenge may remain however scientific literacy is viewed. Carl Sagan wrote in his last book before he died that a scientifically literate public was *"…an absolutely essential tool for any society with a hope of surviving well into the next century with its fundamental values in tact – not just science as engaged in by its practitioners, but science understood and embraced by the entire human community. And if the scientists will not bring this about, who will?"* (Sagan, 1996, p336).

The public, as a key stakeholder, should have access to science research and its discoveries expressed in everyday language. However, it is not yet clear to what degree that requires public audiences to have prior knowledge of science and how it works. It is especially not clear as to whether the motivations in communicating science are understood by those who urge more science in the mass media, or by those required to do the communicating: the scientists themselves. The apparent disconnect between theory and practice in science communication (S.Miller, 2003) may be, at least in part, responsible. Most of all, with no agreed definition of scientific literacy it is difficult to see how any measures applied to its measurement have an broad general meaning (see Irwin and Michael, 2003, pp19-32).

"Successful 21st Century societies will be swift to exploit new knowledge, adopt innovative ideas and harness advantageous technologies. For this Australia must be science literate, as well as having basic literacy and numeracy."

Prime Minister's Science, Engineering and Innovation Committee, Education Working Group report (2003)

Chapter 3

Scientific literacy and science education

3.1 OVERVIEW

This chapter examines the influence of interest in science and education level in predicting whether a student will be scientifically literate. These two aspects may be a factor in creating science attentive adult audiences (J.D.Miller, 1986). The international testing of the scientific literacy of students is also reviewed and is compared to adult testing.

3.2 CORRELATION OF EDUCATION AND ADULT INTEREST IN SCIENCE

A number of studies have suggested that the key factor in receptivity to scientific information is interest (Miller, J.D, 1986, 1998) and that is linked to the level of education (Nisbet et al., 2002).

These studies have shown that interest in science is strongly influenced by interest at school, indicating scientific literacy as an adult does have early roots. Ishii (2002), for example, confirms this view with a Japanese study involving 2,146 adults. 79.8% of those who liked science at school also had an interest in space exploration, compared to only 49.6% of those who disliked science at school. New scientific discoveries interested 85.3%of those who had been interested in science at school compared to 53.3% for those who disliked science at school. There was also a strong correlation between science television program viewing and interest in science at school – 40.9% among the science interested against 13.7% among those who disliked science at school. However, the dislike of science is in stark contrast to passing science tests, where Japanese students gain high test scores yet Japan's science literacy among its adult population is well behind that of France, the US, Finland and Sweden (ibid).

J.D. Miller concurs that the higher the level of education, the greater likelihood of adult scientific literacy. He suggests an almost doubling in scientific literacy to 28% of the US public is due in part to a policy that requires all US university students to take at least one year of science as part of their general education. A New Zealand study supports this view. It shows a strong relationship between education and interest in science, identifying six distinct groups. The group with a high level of interest - 25% of respondents – were also the most highly educated and in high remuneration positions. Another 18% with 'average' levels of education have an interest in science, but also *"a somewhat naïve view of science*". However a highly educated group, consisting of 16% of respondents, showed less interest in science and technology and the benefits to society. They were likely to be in business roles and 25% of this group had some formal science training. The remaining groups – a total of 41% of respondents - had little to no interest in science (Hipkins et al., 2003)

Other studies, such as the NSF's science and technology indicators (2002) and another in-depth survey by the European Union of all its member states (Eurobarometer 55.2, 2001), also show a correlation between level of education and a knowledge of basic science concepts. The NSF survey states, *"A strong, positive relationship exists between the number of correctly answered questions and level of formal education, number of science and mathematics courses completed , and attentiveness to science and technology."*

There are other indications of the positive relationship between education, interest and scientific literacy. The set of two NASW surveys in 1957 and 1958, noted in Chapters 1 and 2, also found a relationship between the less educated and having little idea of the purpose of satellites even though they were exposed to the same media coverage of Sputnik 1 as those who could demonstrate knowledge of satellites (Swinehart et al., 1960).

The 2005 *'Europeans, Science and Technology'* Special Eurobarometer also shows a strong relationship between interest in new scientific discoveries and education level. Among the 30% of Europeans saying they were very interested in new scientific discoveries, more than 40% were highly educated and/or in managerial positions.

Yet, even in a high level education environment, preconceived ideas confound Harvard graduates when asked to explain the simple basic scientific concept of the seasons. An 18-minute film of interviews with the graduates and their teachers shows many of those interviewed could not give a reasonable explanation of the seasons. *A private universe: Misconceptions that block learning* was produced in 1989 by Matthew H. Schneps of Project STAR, a curriculum program then under development at the Harvard-Smithsonian Center for Astrophysics (Sky & Telescope, 1989).

3.3 INTERNATIONAL TESTING FOR STUDENT SCIENTIFIC LITERACY

3.3.1 *Differences between the surveys*

There are two key international surveys that test the science learning performance of students internationally as mentioned briefly in Chapter 1. One is the United States Department of Education Trends in International Mathematics and Science Study, and the other the Organisation of Economic Cooperation and Development's Program in International Student Assessment. The Australian Government's Department of Education, Science and Training outlines what it sees as differences between the two surveys.

http://www.dest.gov.au/sectors/school_education/publications_resources/schooling_issues_digest/perf_aus_schools/why.htm
Australia participates in both, and performs well. It should predict a good performance when students are tested against adult measures, but as the results will show, this is not necessarily the case.

TIMSS, according to the Australian Government, covers science content and performance expectations – specifically in understanding simple information, solving problems and using science processes. On the hand, PISA's scope includes recognising questions, identifying evidence, and drawing conclusions in understanding scientific processes, has a strong emphasis on scientific concepts, and places science in the context of everyday living.

3.3.2 *TIMSS results*

In 2003 the United States Department of Education (2004) tested students internationally across 46 countries in what equates to Years 3 and 7 in Australia (Grade 4 and 8 in the US). While Australia scored well above the average of 473 in science literacy in the 2003 Trends in Mathematics and Science Study, and on a par with the US at 527, it was well below Singapore at 578 and the six other countries scoring 552 to 558 (Japan, Estonia, Hong Kong, Republic of Korea, and Chinese Taipei).

Assessment was by multiple choice and constructed response questions using problem solving and inquiry tasks. These were designed to test a student's understanding of formulating questions and hypotheses; designing investigations; collecting data; representing, analysing and interpreting data; and drawing conclusions and developing explanations based on evidence.

3.3.3 *PISA 2006 results*

During 2006 more than 400,000 15-year-old students in 57 countries – that account for more than 90% of the world's Gross Domestic Product - participated in the Organisation for Economic Cooperation and Development's Program for International Student Assessment on science literacy. Australia performed above the OECD average and was significantly lower than only three other countries – Finland, Hong Kong-China, and Canada.

Nevertheless, the Australian Council for Educational Research (2007) points out that these figures masked figures Australia should be concerned about. This includes 15% of students who fell below a scientific literacy baseline set by the OECD. Other statistics reveal 40% of Australia's indigenous students, 27% of remote area students and 23% of students from the lowest socioeconomic quartile in Australia also performed below the OECD baseline. By contrast, Australia was one of only five countries to have at least one in seven students reach the top two levels of scientific literacy (Organisation of Economic Cooperation and Development, 2007b). The figures are based on testing of 14,170 students from 356

schools from July to September, 2006. In spite of this good performance in comparison with other nations, Finland stands out as being in a class of its own at the top of the scale as it has in past surveys, and worthy of a study in its own right.
The OECD (2007a) tests for:

- Science knowledge and uses that knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based solutions within science related issues.
- Understanding of the characteristic features of science as a form of human knowledge and enquiry
- Awareness of how science and technology shape our material, intellectual and cultural environments
- Engagements in science related issues and with the ideas of science as a reflective citizen

A key question about assessment of scientific literacy is “what is being measured?” Is it synonymous with the open response process of science question used in adult surveys: *“what does it mean to study something scientifically?”*

After each survey some questions are made public as examples of the way students are tested. Others are retained for future use to retain consistency in the next triennial survey. The questions address some or all of the following and are assessed at six levels of difficulty, six being the highest:

- Identifying scientific issues
- Explaining phenomena scientifically
- Using scientific evidence

A range of ideas and concepts are tested through themes – in the 2006 survey this included questions related to genetically modified crops, acid rain, the greenhouse effect, the Grand Canyon, the Mary Montague (18^{th} Century smallpox vaccination) and sunscreens. Advanced students would be able to tackle interpreting complex, unfamiliar data, while less able students might be able to demonstrate knowledge, to some degree, of experimental design. Important aspects of science are assessed, including critical thinking, reasoning and construction of evidence-based arguments. The question is whether this is reflective of actual science. That is a matter of debate beyond the scope of this thesis.

3.3.4 *Summary of surveys vs. thesis hypothesis*

The hypothesis is that, in spite of this testing, and Australia's good results, students are largely not able to answer the same question asked of adults when assessing the understanding of science. Whether it is the right question, or is assessed in the wrong way is moot – it is what is used to largely gain a perception of scientific literacy among adult audiences and to provide persuasive evidence that there is a problem among the adult public. There is also a corollary concern. The Australian Council for Education Research's PISA report (2008) begins with the line under 'Policy Issues', *"Australia is well placed to continue its tradition of producing top* *quality scientists."* Experience in universities suggests otherwise, at least in terms of numbers of top quality scientists, albeit for perhaps different reasons other than the ability or otherwise of being able to pass science literacy testing significantly well.

3.4 SUMMARY

Research indicates a strong relationship between interest in science and level of science education. Testing of scientific literacy is carried out by the US Department of Education and the OECD. Australia performs better in the OECD's PISA statistics that those of TIMSS, performing about the same as the US but well below top scoring nations. Both surveys found a 'considerable disparity' between Australia's highest performing science students and the lowest (Department of Education, Science and Training, 2006) and that only 13.5% of Australia's workforce has science, engineering or technology (SET) skills against 15-20% for a number of European countries including the UK and Germany.

Fig. 1: *Views from the Pilbara Project (Image: Geoffrey Bruce, NASA)*

Chapter 4:

The Pilbara Project

4.1 OVERVIEW

In 2004, the Australian Centre for Astrobiology (ACA) initiated a *Virtual Field Trip* (VFT) to the Pilbara in Western Australia with the Macquarie ICT Innovations Centre (MICTIC) and NASA. The project was aimed at students nearing the end of their high school science education. The Pilbara contains the best, earliest evidence of life on Earth at 3.43 billion years old, though the interpretation of that has been controversial. As such it provides a site of scientific interest, and the opportunity to open students to an authentic science research experience, a combination considered to be needed in effective learning strategies in science education (Kubicek, 2005).

The objective of the *Pilbara VFT* was to use a suite of immersive, multimedia tools to engage students in ‘science in the making’ during a real field trip. It is difficult, if not impossible, for teachers to replicate authentic science experiences in the classroom (Rahm *et al.,* 2003). Chinn and Malhotra (2000) argue that such classroom inquiry-based activities are qualitatively very different from real science. It is intended to engage high school students in science as is undertaken as opposed to the worksheet high school science presented as a formula ‘hypothesis-data collection-analysis-conclusion’ scientific method characterised by Jenkins (2007). School science is isolated from the social structures within science such as knowledge of the literature, exchange of views, peer review and publication of research. School science has also been challenged by a number of scientists for not being reflective of how these techniques are actually employed as part of the scientific enterprise (for example, H. Bauer, 1994; Shamos, 1995). The data collection for this thesis included evaluating the effectiveness of introducing high school students to an authentic science experience. The results and discussion appear later.

The *Pilbara VFT* serves both as a standalone *VFT* and a linking tool for three existing NASA tools: *World Wind*, a dynamic globe interface that allows 3-D views of the Earth, planets and moons; *What’s the Difference?*, a student programmable interactive database and electronic journal, and *Virtual Lab,* which allows access to Scanning Electron Microscope (SEM) images down to less than the width of a human hair, and to a Light Microscope. There is also an associated Wiki website to provide a rich, searchable database to support all aspects of the project, including the sharing of lesson plans between teachers.

The literature indicates that the use of multimedia allows students to gain essential background knowledge in a time-efficient manner as they grasp higher level understandings of science not otherwise possible within the high school science curriculum. This strategy is based on research that suggests that such multimedia resources, by increasing visual impact, can improve scientific understanding. For example, Huppert *et al.* (2002) investigated the impact of a biology simulation on high school students' academic achievement and their science process skills. The findings reflected those found in the *Pilbara VFT* - that students in a simulated learning environment exhibited more complex and integrative reasoning than might otherwise be expected (Oliver *et al.,* 2006a). Similarly, the Huppert *et al.* simulation was found to benefit students with low reasoning abilities in particular, enabling them to cope with learning scientific concepts and principles which require high cognitive skills. Trindade *et al.* (2002) also found that visual modes of presentation aid understanding of concepts and processes. In order to realise their full potential, however, simulations need to be interactive (Baggott La Velle *et al.,* 2003). The interactivity includes the capacity for students engaged in science-based projects to make predictions, test hypotheses and receive instant feedback to develop their investigative and higher order thinking skills, as is made possible in the *Pilbara VFT (*Oliver *et al.,*2005, 2006b*)*

The prompt for the *Pilbara VFT* was a previous astrobiology project – also in association with NASA - with 24 high school students from ten high schools (Oliver *et al.,* 2004). The students worked with scientists at the

ACA who were undertaking a mission with colleagues at NASA's Johnson Spaceflight Center to 'black smokers' – hot springs – deep in the Atlantic and Pacific Oceans. The opportunity arose by invitation from film-maker James Cameron for his movie *"Aliens of the Deep"* for scientists to join him onboard the Russian research vessel the *Keldysh* for mini-submersible dives on a number of the locations to carry out experiments. These 'black smokers' spew sulfurous plumes from the ocean floor at hundreds of degrees and at extremely high pressure in constant complete darkness, yet complex life thrives there, including fish and crustaceans. The challenge for the high school students was to develop an experiment to be carried out by scientists aboard the *Keldysh*. They developed the project over 12 weeks, later returning to the ACA to observe the results. Written and verbal evaluation indicated that engagement with scientists had changed perspectives within the group about science and how science is done. Most changed their choices of science subjects for their last two years at high school, while others decided not to finish science in Year Ten, and three other students indicated they would be considering taking at least some science at tertiary level.

How could the 2003 'black smoker' experience be achieved with a larger group - with perhaps thousands to tens of thousands of students and their teachers? Could it be done in a way that would cross national boundaries and cultures beyond Australia, for at least the US and UK? How could the effectiveness be assessed? What would be considered 'effective', and what ultimate outcome would we look for? Implicit in these questions is the expectation of most high school science education curricula: to produce scientifically literate citizens.

4.2 RELEVANCE TO THE THESIS

Part of the innovation of the *Pilbara VFT* was the decision to address questions related to the implications of the project in relation to scientific literacy via this thesis, as well as the effectiveness of the project in addressing a gap between real science and school science. Data were collected in the form of entry and exit surveys from both project and non-project students in 2005, and again in 2006 from a larger group, but project students only. Qualitative data were also collected using a one-way mirror system into the classroom at the Macquarie ICT Innovations Centre, which is also equipped with microphones in the classrooms. All the data collected formed part of a larger dataset, described in Chapter 5.

The areas chosen for the project – the Pilbara region and Shark Bay areas in Western Australia - are of strong astrobiological interest, thus addressing the title of the thesis: *Communicating Astrobiology in Public.* While the Pilbara contains the most ancient evidence of life on Earth, the salty Shark Bay – also in Western Australian - provides a home to the modern analogue of living stromatolites. Both the Pilbara and Shark Bay sites have implications for searching for life on other worlds – particularly in what we might look for - and in understanding the origin of life on Earth. The students participating in testing of the project were the sample groups for this thesis, together with control groups not participating in the project.

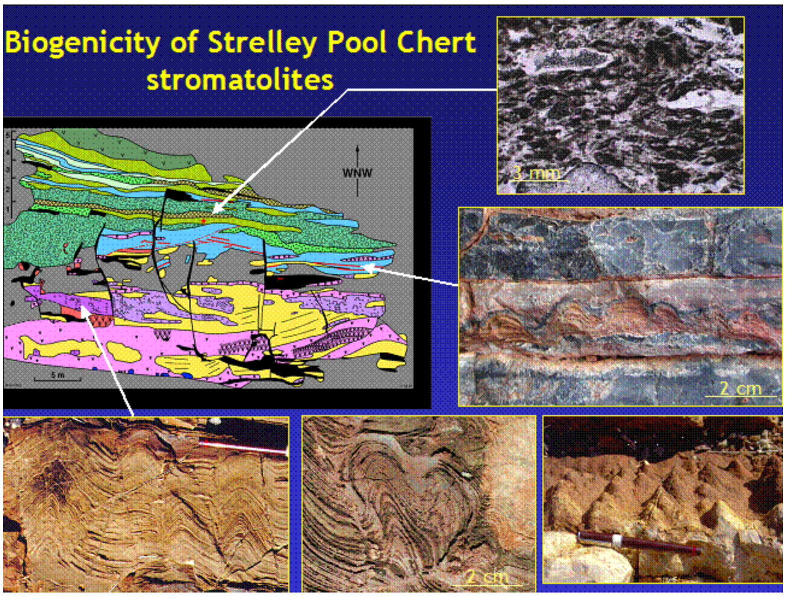


Fig. 2: *Squiggles in the rock: Life traces or just shapes made by Earth processes? (Picture: Martin Van Kranendonk)*

4.3 PARTNERSHIPS

The following were involved in the extended collaboration: Australian Centre for Astrobiology (ACA), the Macquarie ICT Innovations Centre (MICTIC), NASA Learning Technologies (NLT), the NASA Astrobiology Institute, NASA Headquarters, NASA Goddard Flight Center, NASA Kennedy Space Center, the Beckman Institute (University of Illinois, US), the Geological Survey of Western Australia, the SETI Institute (US), and the University of Glamorgan (UK).

The Australian Federal Government provided an Australian Schools Innovation in Science, Technology and Mathematics (ASISTM) grant of $119,500 that enabled development of the project.

4.4 DESIGN

There were questions within the project intimately linked to both the design and the usability for primary target audiences – high school students and high school teachers, and a secondary audience – the public. A key question, for example, was how to use technology to deliver the kind of experience gained when students and their teachers meet face to face with scientists and their research.

The *Pilbara Project* fuses technology, astrobiology, science education, and science communication skills from three continents to produce the *Pilbara VFT*. It is designed to be a resource, rather than curriculum-bound, to provide the best possible insight into science in action coupled with the greatest flexibility and longevity in the formal and informal education environments.

The intention of the *Pilbara VFT* is primarily for it to be adapted by teachers for their specific and subject needs for students aged 15-17, but also to be used by students and public audiences in multiple ways, including just simply for the pleasure of learning, much as is intended by television documentaries.

4.5 CREATING THE *PILBARA VIRTUAL FIELD TRIP*

A team of educators and communicators from the ACA, MICTIC, NLT, and the University of Glamorgan, accompanied 30 international geologists, microbiologists, geochemists, and other experts on a workshop in Fremantle, Western Australia, and then immediately following on a field trip to the Pilbara. The *VFT* team recorded the debates in the field as scientists and other experts examined the evidence for the 3.43 billion year-old ornate structures that are microbially mediated rock known as stromatolites. Some in the area are thought to be older, and were first reported nearly three decades ago (Walter *et al.,* 1980). The extreme age makes organic signatures extremely difficult to detect and to link to putative microbial activity, so not all the pieces of the jigsaw are present. Can the structures be explained by physical or chemical processes as some believe, or does the weight of evidence – partly gathered during the 2005 field trip - now favour the conclusion that these structures are the result of microbial activity as demonstrated for one specific area of the Pilbara by Walter's doctoral student in a Nature paper in 2006 (Allwood *et al.,* 2006)? Allwood describes the evidence for a microbial reef extending nearly 10 kilometres and that shape associations and other evidence extending the length of the reef reveals a typical biological response to the environment. Also see http://pilbara.mq.edu.au/wiki/Reef.

The data collected during the field trip were then brought together in the immersive environment of virtual reality. Users can move over the landscape for up to several kilometres at each location. The scientists are present, with users able to access short video clips in which the experts provide information and interpretations of the evidence *in situ.* The supporting tools allow a fly down from space to each location (*World Wind*), a methodology of seeing a stromatolite from macro to micro (down to microns across) in *Virtual Lab,* and the ability to create a personal database and keep an electronic journal in *What's the difference?*

Fig. 3: *A screen shot of the Pilbara Virtual Field Trip*

Fig. 4: *A Scanning Electron Microscope image of a stromatolite in Virtual Lab*

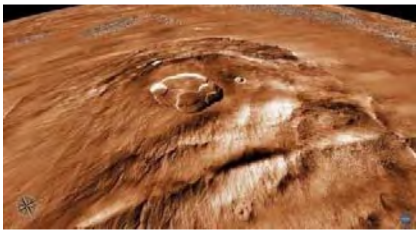


Fig. 5: *Olympus Mons, Mars, in NASA's World Wind*

Fig. 6: *A view of the Pilbara (picture, Abby Allwood)*

4.6 VIRTUAL ENVIRONMENTS IN THE CLASSROOM

Virtual environments, in almost any fashion, allow the user the experience of exploring a remote location or an extreme area in an immersive manner that simple images will not allow. Users can take advantage of perspective, space and the ability to interact with the environment – an important factor in the student ability to learn, as already mentioned.

The environment chosen for the *Pilbara VFT* was 360 degree spherical Quick Time Virtual Reality (QTVR). There are a number of benefits to taking this approach, which include:

- The process of using actual 360 degree location imagery with embedded data at key node points allows users to truly see each of the locations as they currently are
- The robust flexibility for adding links allows expandability and a greater degree of exploration of the site
- The dependability as a cross-platform tool ensures both PC and Mac software users access the same experience on the respective systems
- The rapid development of new locations keeps the tool current
- The ability to develop multiple resolutions rather quickly so researchers are able to access significantly greater resolution for scientific study of each location.
  (Oliver and Fergusson, 2007)

The Pilbara and Shark Bay location sphericals were laced seamlessly via virtual reality 'VR' icons, with the associated multimedia data, gathered during the field trip, embedded in the sphericals and accessed via picture and video icons. The scientific language difficulties encountered during filming were overcome by providing full transcripts with a glossary via the associated Wiki site.

Many comprehensive virtual field trips are found on the Internet, but these guided tours tend to be non-immersive and non-interactive. There are exceptions and at least one is partly aligned in the Earth sciences sense to the *Pilbara VFT*. This was developed by Deakin University in Australia for a first year university course of the Earth's physical systems. Its purpose was to provide an alternative to a real field trip for a number of reasons. Geological field trips can be expensive, there are insurance issues for students, sites can be remote and difficult to reach, and the weather may be far from ideal. Deakin also has a number of students unable to participate in a real field trip, so an immersive Virtual Field Trip was created to provide a substitute. Warne *et al.,* (2004) used teaching strategies based on a constructivist approach with learning outcomes fitting into the world view and prior concepts of the student.

The Deakin project used the same QTVR 360 degree sphericals as employed in the *Pilbara VFT* as well as other interactive features to link the 360 degree environment to detailed views of rock and fossil materials and locational maps also similar to those in the *Pilbara VFT*. In the learner evaluations, 34 of the 148 students responded to a survey on the Deakin virtual field trip. Most were positive comments indicating it added to the learning experience of the students. However, it was noted few students were 'able to, or attempted to generate preliminary answers to excursion questions using the Virtual Reality Geology Excursion CD'. Warne *et al.* put this down to lack of a demonstrator who would normally provide explanations in the field and suggested inserting audio or video clips of demonstrators in the future. The *Pilbara VFT* has taken this step with the clickable multimedia video clips that are embedded. Geologists, microbiologists, and organic chemists provided multiple interpretations of the inconclusive evidence that some of them were seeing for the first time in the field, and the relevance to looking for past and present life on Mars and beyond.

4.7 TESTING AND RESULTS

To begin with, most of the students in both countries had little concept of building a scientific hypothesis or of the actual processes of science. In the Australian study 25 of the 87 students said the experience of the three in-person days had made them decide to take at least some science at university level. They also largely had a positive response to the NASA tools, one being detailed below for *What's the Difference?* In Wales, 39 of the 74 students - after one in-person day with two of the project designers - said they were now more interested in science. Three of the students volunteered information, saying they would now take A-Level science as a result of the day. A-Level is the highest level exam that can be taken at high school level in the UK. Overall, the positive responses to the hi-tech tools, including the *Pilbara VFT*, were fairly similar to those experienced in the Deakin project at university level, suggesting that such technologies may work as well in the high school environment as the university one.

Comments from 2005 cohort students about why they liked the hi-tech tools:

- I learned more because I could take in the information much more easily and I understood the majority of the content.
- You can access the information you wanted a lot faster and more directly rather than having to read a couple of pages of textbook, re-read again.

- Because it gave me a better understanding of the Earth and Mars by allowing us to see 3D images which help to visualise the info.
- Because it is more accurate and up-to-date.
- I haven't learned much at school because we watch documentaries which don't stop and let you choose to manipulate the information.
- I was more involved with the learning due to the interactivity of the program.
- I think I learned more because I was learning at my own pace rather that the pace the teacher wanted to go. The fact that I could actually interact with it was great.

4.8 PROJECT DELIVERY

The Pilbara VFT was released via DVD and the Australian science magazine Cosmos in April, 2007, under the title 'LifeLab'. Cosmos was chosen as the vehicle because 60% of Australian high schools subscribe to the magazine, thus providing a more eye-catching way of delivering to high school science teachers than simply sending a free DVD. The mode gave the project an otherwise hard-to-achieve profile to a key audience as well as addressing other audiences – students and the public. By March, 2008, the associated Wiki technology website *http://pilbara.mq.edu.au* was receiving an average 10,000 page visits per week (about 100,000 hits per week), and the $6.4m Victorian Space Science Education Centre has also adopted the VFT into their high school programs (Oliver *et al*., 2007, 2008).

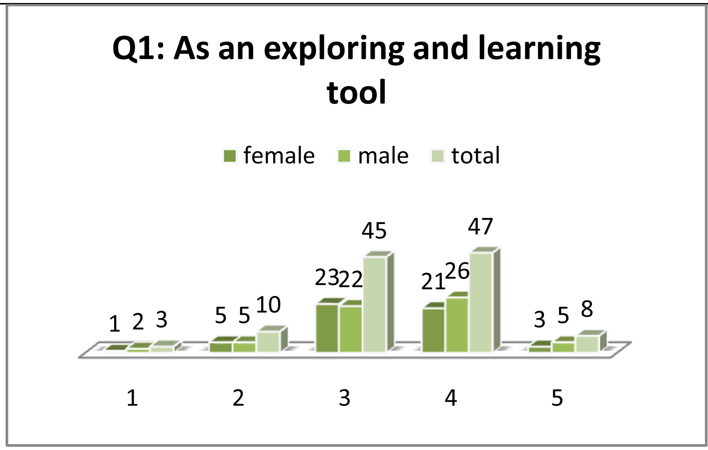
In 2006 five of the seven Sydney schools that were engaged in the 2005 testing brought a new cohort of students to test the finished project. The

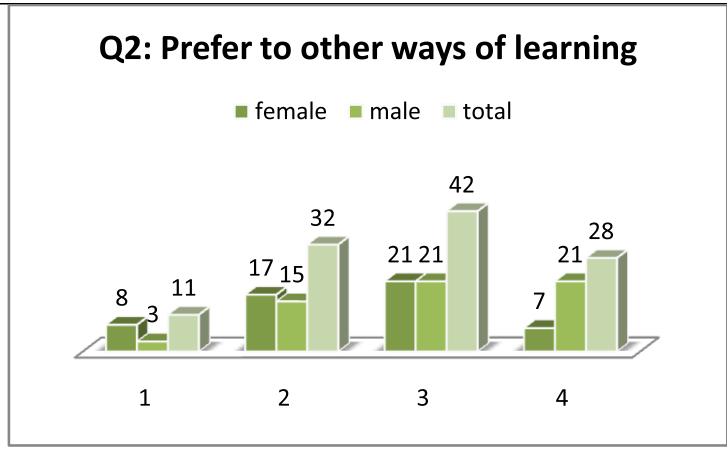
116 students came for one in-person day, making it difficult to test any change in scientific literacy, but it provided an opportunity to test scientific literacy on entry, and to get student evaluation of the tools. For three of the four tools (*Pilbara VFT*, *World Wind,* and *What's the Difference?*) the same three questions were asked (see *Figures 7-10*):

Scaling: Was this tool helpful in exploring and learning about the Pilbara? (Rating: 5 = very helpful; 4 = helpful; 3 = somewhat helpful; 2 = not very helpful; 1 = not helpful at all). Would you rather use this tool than normal ways of learning the same information at school? (Rating: 4 = most definitely; 3 = yes; 2 = perhaps; 1 = no). Overall, what rating would you give to the tool? (Rating: 4 = excellent; 3 = good; 2 = average; 1 = poor). For *Virtual Lab,* questions (1) and (3) are asked, but because of the high level of tool, it was considered more important to replace question (2) with an enquiry as to whether the respondent had seen a Scanning Electron Microscope image before (see *Fig.10*).

As can be seen from the chart below the tools had a high approval rating in different aspects of using the tools. Note in *Virtual Lab* most students had, in fact, had not seen an SEM image before.

Fig. 7: World Wind evaluations 2006 Project *n=113 (see 4.8 for scaling)*





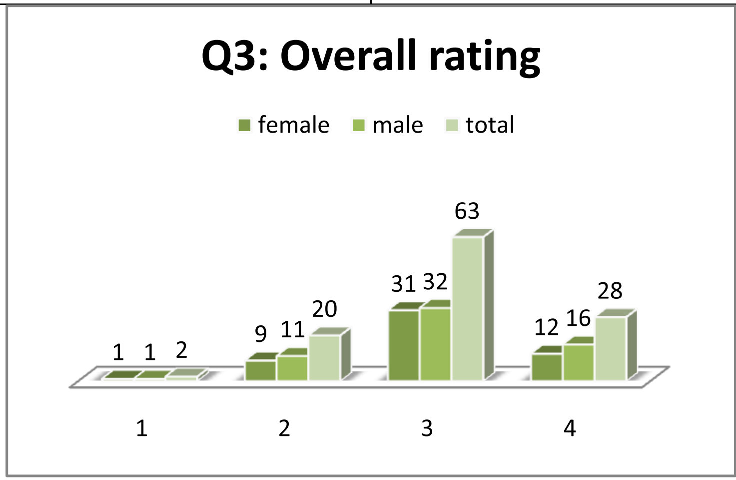
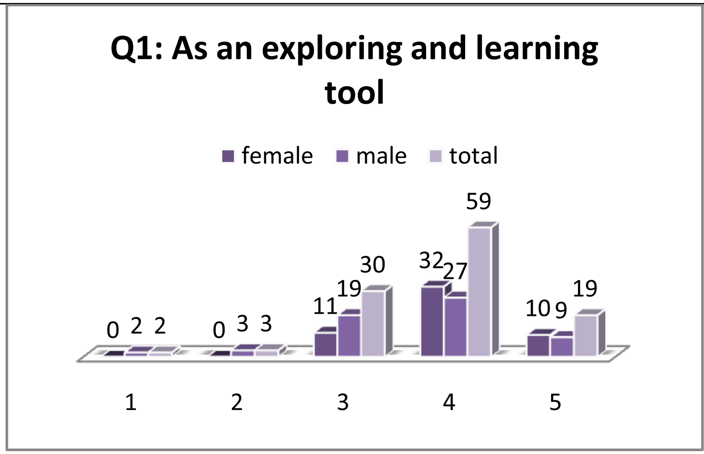
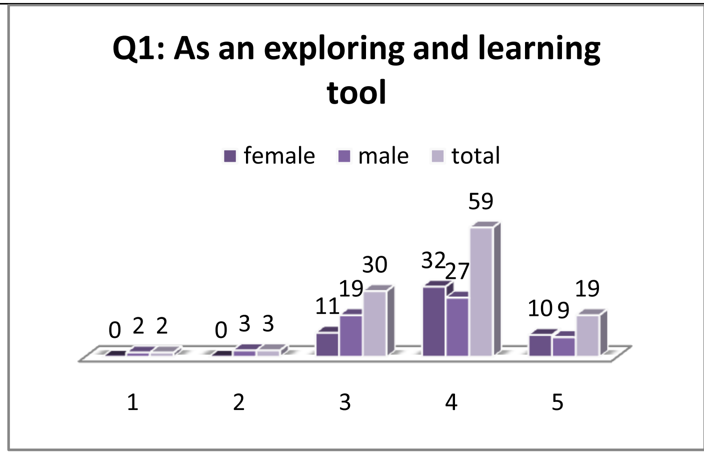


Fig. 8: Virtual Field Trip evaluations 2006 Project *n=113 (see 4.9 for scaling)*





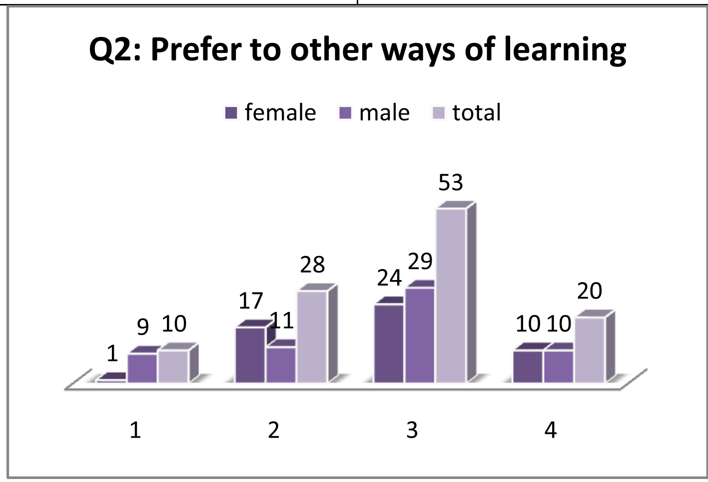
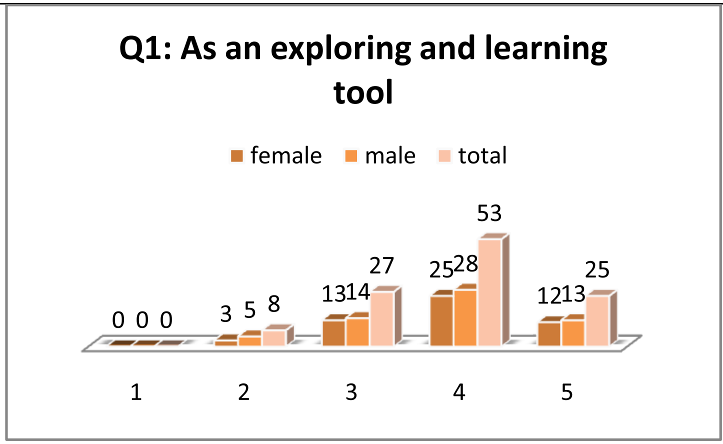
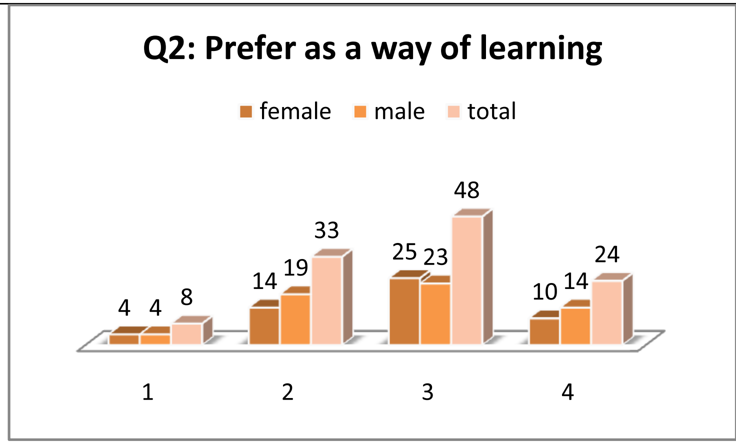


Fig. 9: What's the Difference? evaluations 2006 Project *n=113 (see 4.9 for scaling)*





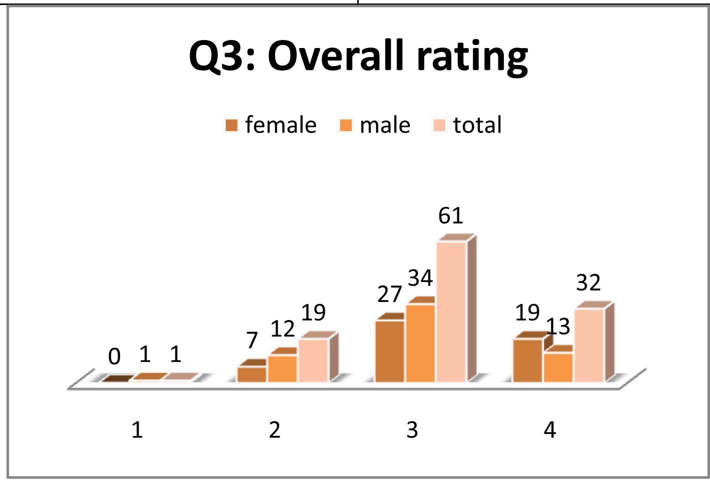
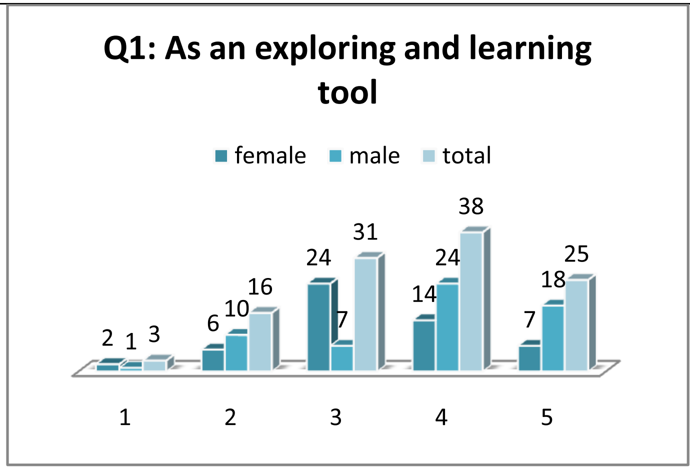
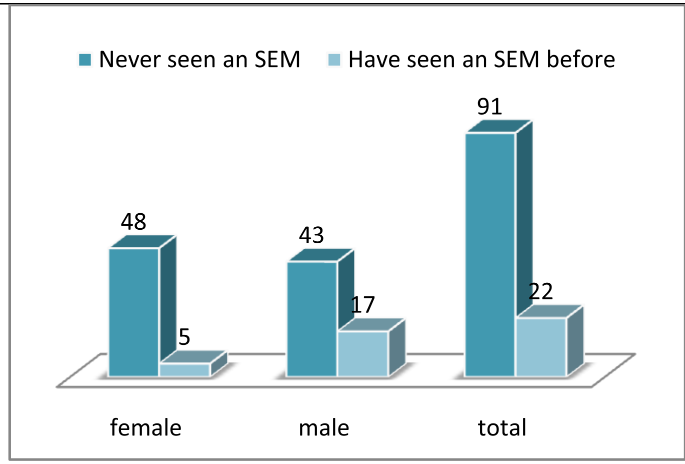
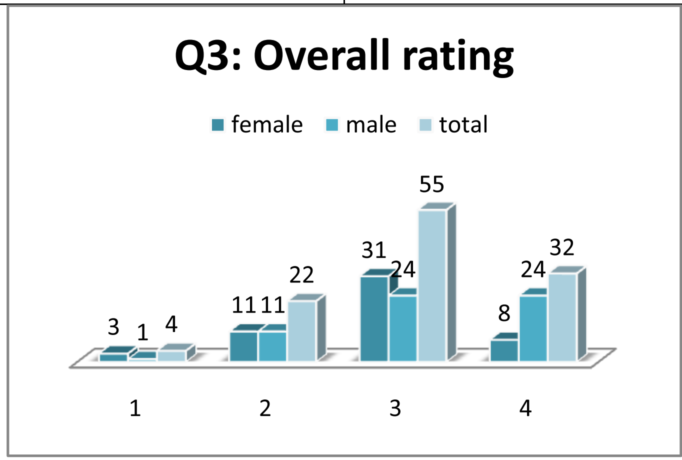


Fig. 10: Virtual Lab evaluations 2006 Project *n=113 (see 4.9 for scaling)*







4.9 SUMMARY

The interactions with the ten schools suggest that technology in schools is still quite limited, and that students tend to be better equipped at home to handle new technologies and that the students use them. Interactions with teachers during the testing of the project indicate that use of multimedia learning tools in schools still has a long way to go.

If one puts a picture of a typical 1906 classroom against a typical 2008 classroom, not much changes except clothes and the blackboard becoming a whiteboard. It is hard to imagine new technologies being introduced in these circumstances. The *Pilbara VFT,* and other projects like it – especially those that tap into the potential of virtual worlds - may be an early step along a road that entirely changes the way students engage with science, whether in the school or at home. Goodrum and Rennie (2007) point out that students spend only 20% of their day at school, and of that, only 20% is spent in studying science. Necessarily, much of the science engagement comes outside of the school gates. Almost two thirds of the students in the 2006 cohort – when the *Pilbara VFT* was complete – said they would use the tools at home whether or not directed by their teachers. *World Wind* alone is approaching 20 million downloads internationally, with 10 million daily requests via the program for imagery. It is a future young people predict, and some are likely to create, for themselves and for their future (NetDay, 2004).

Fig. 11: The April, 2007, cover of Cosmos magazine with the 'LifeLab' (Pilbara VFT) DVD attached

Fig. 1: *Fred Gregory, former astronaut and then Deputy Administrator for NASA (second in command of NASA) engaged with students at the Macquarie ICT Innovations Centre during an official visit in 2005. Note the one-way mirror system in the background.*

Chapter 5:

Methodology

5.1 RESEARCH DESIGN

At the outset in Chapter 1, the research purpose is described: to compare the scientific literacy of students near the end of compulsory science education with the scientific literacy of adult audiences as measured regularly in the US and Europe, but not Australia where such statistics are not collected.

The restated hypothesis is:

The majority of Australian students may be leaving high school as scientifically illiterate are as adults in the US and Europe as measured by standards applied to adults.

The research questions are:

1. What is the scientific literacy level of Australian students near the end of their compulsory science education as measured by standards applied to the adult public?
2. How does that compare to Australian university students?
3. How do Australian students compare with their peer group in UK high schools?
4. How do Australian and UK high school students compare to adult audiences in the US and Europe in terms of scientific literacy?
5. Does interest in science influence the level of scientific literacy?
6. Does study of science in the last two years of non-compulsory science enhance scientific literacy?

Questions 1-4 relate to the core of the hypothesis, while the remaining questions relate to wider questions that might influence the level of scientific literacy, in particular whether there is a difference in scientific literacy between those students engaged in science and those who have no interest in it.

5.2 LOCATION OF RESEARCH

The research for this study was conducted at the Australian Centre for Astrobiology (ACA), the Macquarie ICT Innovations Centre (MICTIC), at Macquarie University, Sydney, Australia, and at three high schools in Wales. As already mentioned the ACA was, at the time of data collection, an astrobiology research centre at Macquarie University. At the time of writing this thesis the ACA had moved to the University of New South Wales, also in Sydney. The MICTIC is a joint project between the New South Wales Education Department and Macquarie University concerned with the teaching, learning and use of Information Communication Technologies (ICT) in the high school classroom.

5.3 PARTICIPANTS

The study involved the participation of 16-year-old students from seven Sydney and Blue Mountains high schools in 2005 and another cohort of the same age group from five of the schools in 2006. To provide some calibration due to lack of Australian scientific literacy data, Australian university students were tested. Three UK schools were also included to compare with Australian high school data. The opportunity arose to collect these data because of the involvement by Centre for Astronomy and Science Education at the University of Glamorgan, South Wales, in the making of the *Pilbara VFT* (see Chapter 4), and was considered a useful international comparison with Australian high school students.

The datasets were drawn from those involved in the *Pilbara VFT* (project), and those not involved (non-project). In 2005 and 2006 the participants were chosen by their teachers. In 2005 the students from the seven Australian high schools attended Macquarie University in Term Three (out of four terms) for three separate in-person days – one largely spent at the ACA, and the remaining two at the MICTIC. In 2006 five of the seven schools were able to participate in both the project and the study. These students attended the MICTIC for one in-person day, also in Term Three. The Welsh students participated in the project in their schools for one in-person day. The 2005 non-project students were selected and asked to participate in this study by their teachers, but did not attend the university. The university students taking part in the study were all in one first-year class *"The History of the World"*, none were science majors and none took part in the project.

The population could be considered all Year 10 students, and then a sample drawn from that for a truly random dataset. Nevertheless the convenience sampling within and outside of the *Pilbara VFT* had the robustness of randomness by virtue of multiple - and to some extent unstructured - methodologies employed to create the sample sets. Though the schools self-selected the teachers were given no guidelines for which students to bring to the project in 2005 and 2006, or whom to choose among the non-project students to participate in the study, except to say the student's science ability should not count. Each of the seven teachers employed different strategies, though for the *Pilbara VFT* project most brought, with some exceptions, only the brightest science students. The schools themselves have demographics from a very low socio-economic level, to the highest level within the New South Wales public school system.

No private or church-run schools were included in sampling due to restrictions on the use of the MICTIC that limits school use to the public school system. That limitation is because of the nature of the collaboration between the NSW Education Department and Macquarie University, as described above. The benefits of using the MICTIC for studies such as this one are its access to the newest ICT, access to multimedia applications, and a one way mirror system with microphones in the classroom to allow access to qualitative study of the learning environment without interfering with it. The latter allowed collection of qualitative data to integrate with the quantitative data, providing another, and deeper, dimension to the datasets.

The nature of the samples restrict use of the central limit theorem to predict a population (i.e. all Year 10 students), but the nature of the study is to provide a direction on what might be tested among all Year 10 students to inform a number of stakeholders – science education curriculum designers, education authorities, governments, and scientists.

5.4 INSTRUMENTATION

This study uses the survey methodology questions relating to demographics, science content and process of science. The quantitative data are supported by two methodologies in collection of complementary qualitative data: observation of the learning environment and interviews with 21students participating in the *Pilbara VFT.*

Surveys provide the most effective instrumentation when large numbers of participants are involved as has been demonstrated by the use of surveys by the US National Science Foundation and the European Union to collect data on the public understanding of science. Survey methodology has been employed in measuring the scientific literacy of the adult public since 1957, particularly in the US where the impact of the launch of Sputnik 1 was most keenly felt. Surveys can consist of multiple choice questions or open ended questions, either verbally or written, in which the participant responds in his or her own words without a prompt, or, more commonly a mix of the two as with this study.

5.5 CONSTRUCTION

Typically, whether in the US or Europe, adults are asked science content questions and process of science questions to judge their level of scientific literacy. Multiple-choice mode is mostly used with the exception of one open-ended question related to the process of science: *What does it mean to study something scientifically?*

Other process questions are multiple-choice and almost always include two questions: one relates to choosing the most correct scientific approach to testing a new drug among 1,000 people, and the other is in the probability of a couple passing on a hereditary illness to their children. From the process of science scores, in the US 28% (estimated 2007) of adults are considered scientifically literate (J.D. Miller, 2007), and in Europe 14% (estimated 2001).

5.6 BENEFITS AND LIMITATIONS IN SURVEY INSTRUMENTS

Survey instruments, among other attributes, allow easy collection of data among often geographically spread respondents. The data can be easily entered onto Excel or other software data packages, and analysed. Surveys also provide a methodology to compare between different datasets, sometimes temporally separated – this case across 50 years of surveys of scientific literacy among public audiences.

The multiple choice mode employed in a survey allows a quick, easy and non-value laden method of measurement, and is less open to human error in analysis. On the other hand, multiple choice limits a participant to a given set of responses, none of which the participant may agree with – or the respondent may guess, or choose according to what he or she thinks the survey creator would like to see. The questions themselves are necessarily subjective in considering what the public should know about science. The open-ended question allows a respondent to choose his or her words, but may be challenged to recall relevant information at that particular moment. It is more time consuming to analyse, may require the training of coders, and is open to human evaluation in deciding whether a particular word or phrase falls into the coding framework.

5.7 DATA COLLECTION

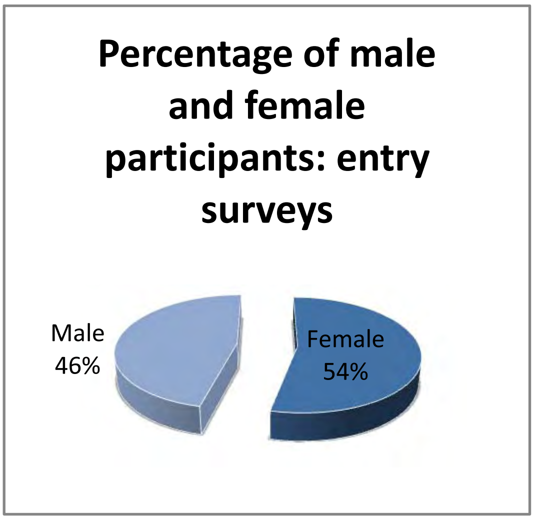
A total of 1,100 entry surveys were distributed over the two year-period 2005-2006. A total of 844 surveys were returned, giving a response rate of 76.7%. Of those 692 surveys were fully complete, giving a completion rate of 82%.

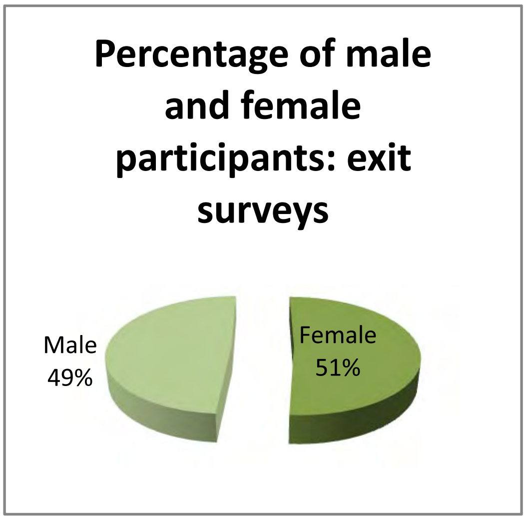
The 692 surveys included 309 students not testing the Pilbara VFT Project but were drawn from the same seven schools by the same teachers selecting those students who would participate in the testing. Among the 309, 79 of the students returned exit surveys – 36 females and 43 males. This subset formed the control group to the project students, although spread over only five of the seven schools. In spite of the missing two schools, the broad socioeconomic spectrum was maintained. The 79 students represent 11.2% of the total sample of 692.

The 2006 project participants came for only one in-person day, the short interaction period making measurement of *changes* in scientific literacy unwise. The 2006 project exit survey therefore differed in some respects from the 2005, and these are detailed later in this chapter.

	Entry male	Entry female	Total	% of data	Exit male	Exit female	Total
2005 project	25	39	64/87	9.25	25	39	64
2005 non project	150	159	309/420	44.65	43	36	79
2005 Welsh schools	25	31	56/66	8.09	25	31	56
2006 Project	60	53	113/116	16.33	60	53	113
2006 university	59	91	150/155	21.68	20	25	45
Totals	319	373	692/844	100	176	184	357

Table 1: *Numbers of participants involved in the study. Red figures indicate the total number of returned surveys before eliminating incomplete surveys. Reasons for rejection are detailed in 5.11.*





Figs. 2 and 3: *Male-female participation in entry and exit surveys by percentage*

5.8 DIFFERENCES IN DATASETS

In this study there is a significant difference in dataset compositions – one soon-to-become adults (students) and the other adults. Adult cohorts have been influenced by the kind of life experiences that shape world views as adults, while soon-to-be adults are yet to have many of those experiences. Each of the dataset types may answer scientific literacy surveys in the context of those experiences. It would seem logical to expect student respondents to be more able to demonstrate an understanding of science that is superior to that of an adult public, some of whom left their formal science education many years ago. The effects of these differences were not measured for several reasons:

1. The focus of the study is on applying adult standards to student testing of scientific literacy.
2. The datasets for this study are non-random, while surveys carried out among public audiences are based on random selection of respondents.
3. Even if the data could be collected it would be difficult to show the differences were causal if students were more or less scientifically literate than adults, or even that it was linked in some way.

5.9 EXPERIMENTAL DESIGN

The design includes:

1. A validation of the survey instrument with the 2005 datasets
2. A second trail the following year with students of the same age drawn from the same schools.
3. Surveying university students for some insight into Australian adult scientific literacy.
4. Surveying of Welsh students for international comparison.
5. Qualitative data collection via observations during the testing of the Pilbara VFT

6. Qualitative data collection via in-depth interviews with 21 high school students drawn from the seven Sydney schools participating in the study.

An entry survey was administered before project students undertook any work in relation to the project and, at the same time, to non-project students in the same time period in 2005. Similarly an exit survey was administered at the end of the project and in the same time period for non-project students. Qualitative data were collected in three ways. One was with interaction with the project group. Another was employing the attributes of the MICTIC – a one-way mirror system surrounding the learning environment that has microphones hanging from the ceiling. This allows observations not possible in the standard classroom environment in hearing and seeing peer interaction within the learning group without being present in that learning group. The third methodology was the selection of three students from each school (selection by the teachers, as mentioned) of students willing to participate in in-depth interviews. All the qualitative data were recorded using a video camera for accurate transcription purposes only. The use of a study group and a control group, consistent results in a standard and new methodology, and consistency with qualitative data suggested no changes were required for use of the survey instrument in 2006. Nevertheless some non-structural changes were made to adapt to each dataset as described below.

5.10 SURVEY CONTENT

The survey instrument consists of two key parts: science content knowledge and science process knowledge. Content is in the form of four (2006 project students) or five (all other datasets) multiple-choice questions, one of which is also a process of science question. This latter question is measured independently of the open-response question: *What does it mean to study something scientifically?* The results of a question asked about interest in science are also reported.

The open-response question was asked again on exit, together with five more content questions.

5.11 DATA REDUCTION

The number of returned surveys – 844 – was reduced to 692 (see Table 1) before data analysis. Reasons for rejection of a returned survey included:

1. No indication of whether male or female
2. Essential missing data
3. Non-response to the open question *"what does it mean to study something scientifically?"* (In this case it could not be determined whether the respondent could not give an answer or chose not to give an answer).
4. A small number of surveys where it was obvious the respondent had deliberately 'spoiled' answers.

The reason for rejection could be more than one of the above, and commonly was with the exception of non-response to the open question of *"what does it mean to study something scientifically?"*

Scientific literacy assessment is commonly based on ability to understand how science works, and this question represents a half to one third of testing for process scientific literacy among high school students. Therefore the decision was made to cull these surveys.

5.12 DATA ANALYSIS

In this section, two types of analysis of scientific literacy are described. The Miller method has been applied broadly since at least 1979, and relies on coding to determine scientific literacy. A new, simpler method of analysis aimed at reducing human error is introduced. Finally, statistical analysis is presented.

5.12.1 *Miller analysis*

For at least several decades American political scientist Jon D. Miller has been engaged in the collection and analysis of data relating to scientific literacy. Notably he produced these data for the National Science Foundation's biennial Science and Engineering Indicators from around 1979 to 2002. Within that period around 10 basic constructs were used in the testing of content (as mentioned in Chapter 2) and included the open response question: *What does it mean to study something scientifically?"* Bauer and Schoon (1993) list the coding employed to elicit whether a respondent would be considered scientifically literate or not. The coding falls into three basic constructs (see below): theory construction and testing, experimentation and controls, and open exploration in an unbiased way.

Note that because of data reduction, only Codes 1-5 are used in analysis of the results in this thesis. There is no Code 6 or Code 7. The higher numbers 8 and 9 were chosen for data analysis purposes.

Table 2: J.D. Miller's coding for analysing responses to the question *"What does it mean to study something scientifically?"* (from M. Bauer and Schoon, 1993, p144)

Coding	Description
1	Theory construction and testing: Response states that something scientifically means that it is studied in the context of a theory about the problem/phenomenon being examined, and/or that the study is an attempt to disprove a hypothesis about the nature of the problem/phenomenon being studied. The words 'hypothesis' and 'theory' would almost certainly have to appear in the response to justify inclusion in this code.
2	To undertake experiments/tests: Responses not falling into Code 1 that refer to the process of the study being to carry out experiments or tests in a strictly controlled way (but this may be implied rather than specifically stated). Words used, in addition to experiment or test, could be 'using strict controls', and 'using control groups'.
3	Open, in-depth exploration of phenomena/problem to be examined: Responses that do not fall into Codes 1 and 2, but which talk about evaluating a problem in an unbiased/open-minded way, taking into account all possible information, and/or studying it on a rigorous basis.
4	To measure or classify/no mention of any rigour in the process: Codes 1-3 do not apply to the response. It may describe a study in terms of concrete actions used by scientists (e.g. use a microscope or telescope) or it may talk about measuring or classifying but without stating the need for an unbiased, rational approach.
5	Other answers (except those falling into Codes 8 or 9 below)
8	Does not know or guessed
9	Not answered

5.12.2 *A new method of analysis*

A new method of analysis is presented. The Miller method, used to analyse the process of science question *"what does it mean to study something scientifically?"* is dependent on rigorous criteria in each code. It normally requires the training of a team of coders to read each answer to place it into one of the Miller codes. The alternative method presented suggests it may be possible to eliminate the time and money involved in intensive coding of thousands of responses for a straightforward counting of scientific terms used to respond to the question.

Data are analysed using both the Miller method and the new method and will demonstrate a mostly moderate to good relationship between the methods in results in all datasets. The terms allowed in the new method are generated by the respondents themselves (see Table 3). In column 4 the terms that are not immediately obvious in the Miller method, but are counted, are listed in the non-Miller column.

The new method has the benefit of reduced exposure to human error – the terms are merely counted. Determination of what counts as a 'term' is subjective, but stated. Some terms were initially considered for inclusion, but were later eliminated as not representing scientific terms. These included 'logical', 'results', 'conclusion', and 'reasoned'. An argument could be made for their inclusion, in some cases because of the context of the response. Nevertheless they were eliminated on the basis that an attempt is being made to measure student scientific literacy with that of the standards (and terms acceptable) applied to adults.

5.12.3 *Comparison of the methods*

All datasets are analysed with both methods (see Chapter 6) and discussed in Chapter 7.

Code 1	**Code 2**	**Code 3**	**Non-Miller terms**
Hypothesis Theory/theories Disprove	Experiment(s), experimenting Testing/ tests Control(s), controlled Systematic Methodical	Evaluate Objectivity Analyse/analytically Critically/critical (least) biased (without) emotion Interpretation/ interpreted Unbiased Without bias Non-biased Without any attachment No bias Conflict or support (your ideas) Non-emotional (not looking at it) subjectively	Proof/prove/proven Evidence Observe/ observations/ observing Discoveries/ discovering/ discovered/ discover Investigate/ Investigations Variables **Predicting/predict** **Probability** Repeat/repetition Explore Empirical

Table 3: *The scientific terms in total generated by respondents over two years. Codes 1-3 represent those terms that fall into the Miller coding only. The non-Miller terms are those that count towards explaining what it means to study something scientifically, but are not represented in the Miller coding. Predicting/predict and probability are in bold to note very low mention, even though both form a key pillar of the nature of science.*

5.12.4 *Statistical analysis*

Microsoft Excel 2003 and 2007 were employed in the analysis of the data. The descriptive statistics are presented - mean, median, mode, standard deviation, standard error, sample variance, kurtosis, skewness, range, minimum and maximum scores, and the confidence level.

Kurtosis and skewness indicate whether the sample represents a normal distribution and the central limit theorem can be applied. The Kurtosis must lie in the -1 to +1 region, indicating the peakedness or flatness of the data, while skewness indicates the degree of asymmetry either to the left or to the right of a normal bell curve and should also fall in the -1 to +1 range.

In addition, relationships between a number of degrees of freedom or dimensions are measured using the correlation coefficient, for example the relationship between interest in science and scientific literacy.

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

Equation 1: *Correlation coefficient, also known as Pearson's Product Moment*

The correlation coefficient describes the strength and direction (positive or negative) of the relationship.

0.0-0.2	Very weak to no relationship
0.2-0.4	Weak to very weak relationship
0.4-0.6	Moderate relationship
0.6-0.8	Good to very good relationship
0.8-1.0	Very good to perfect relationship

Table 4: *Measures of relationship – the correlation co-efficient*

5.13 SURVEY QUESTIONS

All survey respondents were asked on entry whether they:

1. Liked science
2. Which sciences they liked most (could be more than one choice)
3. Whether they intended to go on to university
4. If they did intend to go to university whether they would take at least some science (science education is non compulsory in Australia after Year 10 (16-year-old students).

5. In 2006 students were asked a series of questions about Internet access at home.
6. All surveys asked the open-answer question in thinking about how science is undertaken *"What does it mean to study something scientifically?"*

Students were then asked five questions related to content (2005 students and 2006 university students). The 2006 project survey contained only four of the five questions from the 2005 survey. As mentioned, the question relating to probability in the fall of a coin to either heads or tails was eliminated because the 2005 validation found it was inconsistent with other questions in relation to choices of answer. In the other questions the student could choose from one wrong answer, one partly right answer, and a third answer that was the most correct. The coin question had two wrong answers and a categorical right answer.

All four other questions provided only one incorrect answer, leaving the student to consider between two remaining answers what might be the most correct. For example:

How do we know the Earth goes around the Sun?

If you watch the Sun, it rises in the morning and sets in the evening. It seems the Sun goes around the Earth. But, in fact, we know it is the Earth moving around the Sun, not the Sun moving around the Earth. Which of the following best provides the proof the Earth does move around the Sun?

1. The sun rises and sets at different times every day: Make a measurement of this and the changes will show the Earth moves around the sun.
2. Measure the tiny apparent movement of nearby stars against the starry background at two six-monthly intervals. If the Earth is moving around the sun in a large orbit, a change will be observed.

3. Observe the other planets in the solar system to see if they are orbiting the Earth or the sun because if they are orbiting the sun, so much the Earth.

While number two is the most correct it is worth noting that subsequent to the formulation of the question in consultation with scientists, it came to light that the Earth and Sun are actually revolving around each other at a barycentric point inside the Sun, but not at its centre. H.Bauer (1994) argues strongly that the scientifically literate student will know this (see Chapter 2). No comment was made to this effect in any of the surveys returned.

The remaining questions on the entry surveys (see appendices) are also science content based except for one question that appears to be content based but is, in fact, process based:

How can researchers best test a life-saving drug?

Researchers wish to test what might be a life-saving drug. They have got to the point where the next step is to test with 1,000 human subjects who suffer the disease the drug could cure. Which of the three below approaches would give the most accurate result?

1. Randomly give the drug to 500 among the 1,000 so not only the participants not know whether they are getting the drug or not, but the researchers directly involved with the study do not know which of the 500 received the drug (known as a double-blind study).
2. Split the group into two, giving 500 the drug and 500 a sugar pill.
3. Give the drug to all 1,000 test subjects to see if an improvement takes place.

In this case number one is the most rigorous technique.

All entry and exit surveys contained the open-response question *“what does it mean to study something scientifically?”* , and for most exit surveys five more content questions were asked, one of which was the following process of science question:

How can parents' genes affect their babies?

A husband and wife want to start a family, but their doctor advises their baby has a one in four chance of receiving a defective gene that will lead to serious illness later in life. Which interpretation of that advice is the right one?

1. The first child has the defective gene, so the next three children will be health.
2. If the couple have three healthy children, they should not have a fourth because the child will have the defective gene.
3. All four babies have an equal chance of inheriting the defective gene.

In this case, number three is the correct answer.

In 2006, instead of an exit survey the project students supplied evaluations of the suite of hi-tech tools they were using including the *Pilbara VFT* (results in Chapter 4).

5.14 SUMMARY

This study involves a combination of quantitative and qualitative data collection. The quantitative data collection involves an entry and exit survey applied to both Pilbara VFT project students and non-project students and forms Chapter 6. The quantitative data were collected from both high school and university students. The qualitative data collection involves observations during the testing of the Pilbara VFT in 2005 and 2006, and interviews with 21 students (three from each of the seven Sydney high schools) and is included in Chapter 7. The purpose of the data collection is to test for scientific literacy as measured by standards applied to adults via scientific literacy and public understanding of science surveys in both the US and Europe. Two methods are used to test the process of science understanding: the Miller method and a new methodology that counts the scientific terms used to respond to the question *“what does it mean to study something scientifically?”*

Chapter 6:

Results

6.1 OVERVIEW

Results of the statistical analysis of the survey data are presented in this chapter. There are five datasets. One – the 2005 Non-Project Sub-Group – is a subset of the 2005 Non-Project Group by virtue of having exit as well as entry surveys returned.

6.1.1 *Numbers*

Numbers throughout this chapter are rounded up to one decimal place.

6.1.2 *Sequence of results*

Each of the total of six datasets are analysed sequentially in each of the years the data were collected. Each dataset has two parts: a test for the understanding of science (process), and knowledge of science questions (content). Finally datasets for both years are correlated with interest in science to measure how well this variable acts as a predictor of process and content scientific literacy.

6.1.3 *Process scoring*

Scientific literacy is measured by counting the number of scientific terms used to respond to the question “what does it mean to study something scientifically?” This method is then correlated to one developed by Jon Miller that relies on coding answers into a number of categories. The Miller framework has a number of codes to classify for scientific literacy and scientific illiteracy and, as already stated, normally requires a team of trained coders to analyse responses to the question *"what does it mean to study something scientifically?".* Those responses that fall into codes 1 (theory and construction), 2 (controlled experimentation), and 3 (unbiased, in depth exploration) are classified as scientifically literate. Codes 4 (reference to a specific scientific action) and 5 (all other responses) classify as scientifically illiterate. Two other codes for 'guessed' and 'non response' were not needed for the analysis as they were eliminated from the data. The J.D. Miller codes 1 to 5 are reversed to allow a more direct comparison with the new method, which relies on counting scientific terms only (i.e. no coding required) – for example 'experiment', 'hypothesis' and 'unbiased'. Under the new alternative method, three or more terms is classified as scientifically literate and two or less as scientifically illiterate.

6.1.4 *Content scoring*

The entry and (where obtained) exit surveys each contain five questions except where indicated, making a total of 10 scientific knowledge questions. In all cases the respondent can select from three answers. A score of 3 is assigned as a correct answer, 2 as a partially correct answer, and 1 as a wrong answer.

6.1.5 *Interest in science*

Respondents were asked whether they were interested in science. They had three options: yes, no, and 'don't know'.

6.2 HIGH SCHOOL DATA 2005

In 2005 two Australian datasets were taken – one among students testing the Pilbara VFT project and the other among students from the same schools but not testing the project – the control group. A third dataset in 2005 was collected in three high schools in southern Wales, UK, as an international comparison.

6.3 DESCRIPTIVE STATISTICS 2005 DATASETS

Table 1: 2005 *Pilbara Virtual Field Trip* Project Group (Australia high schools) *n=64*

	Process entry	Process exit	Content entry	Content exit
Mean	1.3	1.9	12.8	12.2
Median	1	2	13	12
Mode	0	0	14	12
Standard error	0.8	0.2	0.2	0.2
Standard Deviation	1.4	1.6	1.4	1.3
Variance	1.9	2.4	1.8	1.7
Kurtosis	0.4	-0.7	-0.3	-0.6
Skewness	1.1	0.4	-0.4	-0.4
Confidence Interval 95%	0.3	0.4	0.3	0.3

Table 2: 2005 Non-Project Group (Australian high schools) *n=309*

	Process entry	Process exit	Content entry	Content exit
Mean	0.7	n/a	11.6	n/a
Median	0	n/a	12	n/a
Mode	0	n/a	12	n/a
Standard error	0.1	n/a	0.1	n/a
Standard Deviation	1.0	n/a	1.7	n/a
Variance	1.0	n/a	3.0	n/a
Kurtosis	3.2	n/a	-0.2	n/a
Skewness	1.8	n/a	-0.3	n/a
Confidence Interval 95%	0.1	n/a	0.2	n/a

Table 3: 2005 Non-Project Sub-Group (Australian high schools) *n=79*

	Process entry	Process exit	Content entry	Content exit
Mean	0.7	0.6	12	11.8
Median	0	0	12	12
Mode	0	0	12	14
Standard error	0.1	0.1	0.2	0.2
Standard Deviation	1.2	1.1	1.8	2.0
Variance	1.3	1.2	3.3	3.8
Kurtosis	2.6	3.4	0.2	-0.3
Skewness	1.8	2.0	-0.3	-0.5
Confidence Interval 95%	0.3	0.2	0.4	0.4

Table 4: 2005 Welsh High School Group *n=56*

	Process entry	Process exit	Content entry	Content exit
Mean	0.5	0.7	12.2	n/a
Median	0	0	12	n/a
Mode	0	0	13	n/a
Standard error	0.1	0.1	0.2	n/a
Standard Deviation	0.8	1.0	1.7	n/a
Variance	0.7	1.0	2.7	n/a
Kurtosis	1.9	0.9	1.0	n/a
Skewness	1.7	1.8	-1.0	n/a
Confidence Interval 95%	0.2	0.3	0.4	n/a

6.4 NATURE OF SCIENCE DATA 2005

The central research question concerns the understanding of the nature of science among Year 10 (16-year-old) students at high school. The following data were collected in 2005 among the best science students from seven Australian high schools (five in North Sydney, one in Western Sydney and one in the Blue Mountains, west of Sydney). The students were participating in the testing of the *Pilbara Virtual Field Trip* Project during Term Three of Year 10. Students in Australia can end their formal science education at this point. The seven schools were divided into three groups, two groups containing students from two schools, and the third from three schools. The students attended three in-person days at the Macquarie ICT Innovations

Centre and the Australian Centre for Astrobiology at Macquarie University, Sydney (making a total of nine days of data collection) over the nine weeks of Term Three. There were no more than 31 students plus their science teachers in any of the three groups. See Chapter 4 for a description of each of the three visits.

At the same time students in the seven schools not participating in the project also filled in entry surveys. The purpose was to measure scientific literacy among a larger group of mixed ability science students. These form the Non Project Group. Of these schools, five returned completed exit surveys from a total of 79 students. This is called the ‘Non-Project Sub-Group’. The data from this group contain many confounds, particularly in non-parity of ability with the Project Group, therefore no paired T-Tests are offered. Nevertheless the data are included. Data collected among science students in three Welsh high schools are also included as a comparison with students where adult scientific literacy data are also available (as stated earlier, no Australian adult scientific literacy data are available).

6.4.1 *Comparison of the understanding of science: 2005 surveys*

Figs. 1 and 2 on the next page present the understanding of the nature of science across four 2005 datasets as described above. The entry survey data reflect the ability to answer the question *“what does it mean to study something scientifically?”* before an attempt in the *Pilbara VFT* Group to increase the level of understanding about the nature of science. The exit surveys included the same question. However, in all cases where the entry and exit surveys were taken in the same day (Wales Group and 2006 Project Group) the exit survey read ‘same as this morning’ thus scoring 0 even where a student had done well in entry survey.

6.4.2 *Entry vs. exit surveys 2005*

There was a 44.1% increase in average scores for scientific literacy among the 2005 Project Group students between the entry and exit surveys. By contrast the Non Project Sub-Group saw a decrease in average scores of 16.3%. This group is confounded by virtue of being a sub-group of a non-random mixed ability group, self-selected by returning an exit survey. More research is required, but it suggests one explanation for the increase in average scores for the Project Group is that responsdents may have been positively influenced by the exposure to the true nature of science during participation in the Pilbara VFT project.

The Wales Group represents change of the period of a single day's exposure to the *Pilbara VFT* project. The participating students were also younger – while in the equivalent of Year 10, it was at the beginning of the northern hemisphere school year in September 2005, rather than the end. Nevertheless, there was a 31.6% increase in average scores for scientific literacy.

Fig. 1: Entry surveys - process of science scores male/female comparison (2005 datasets)

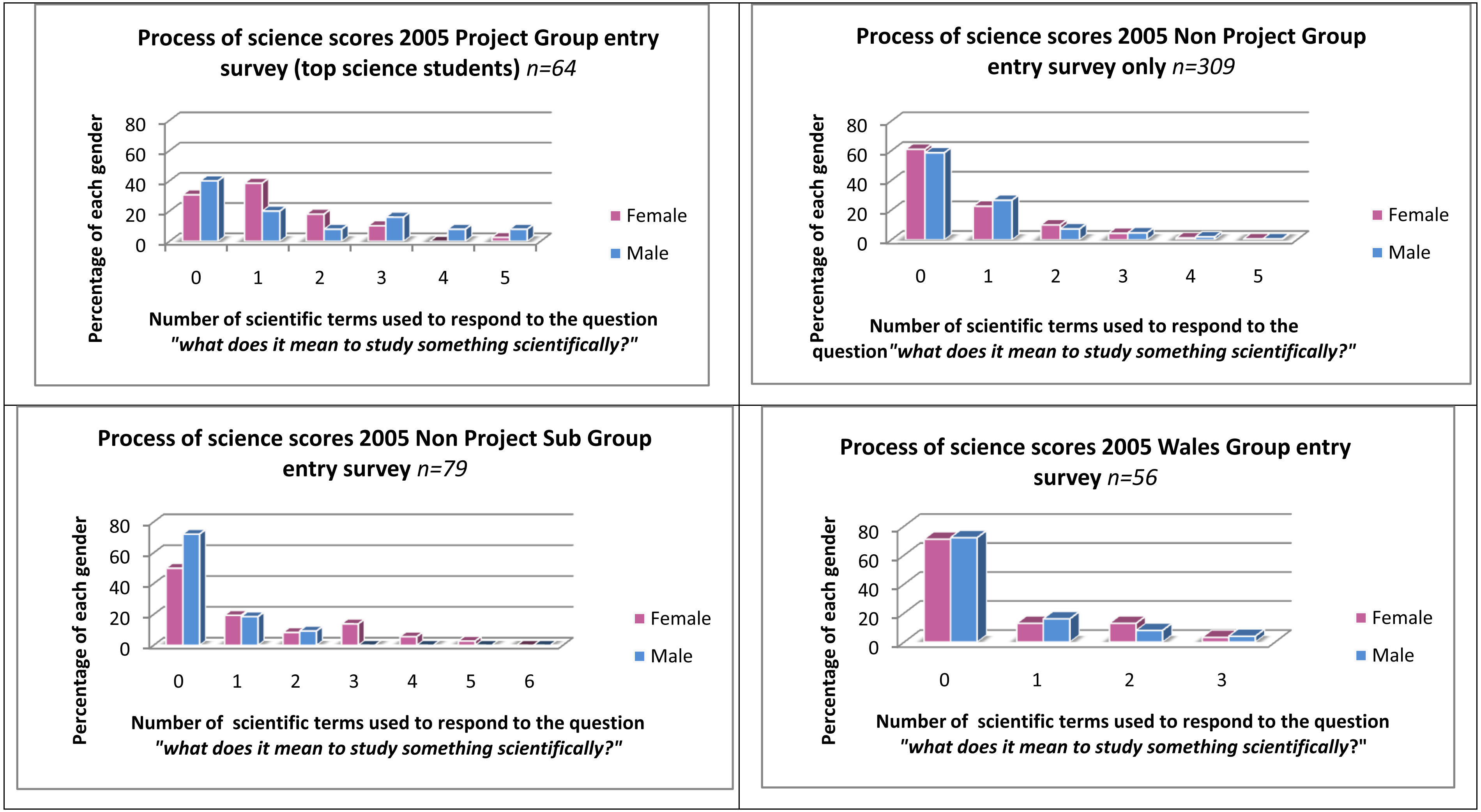
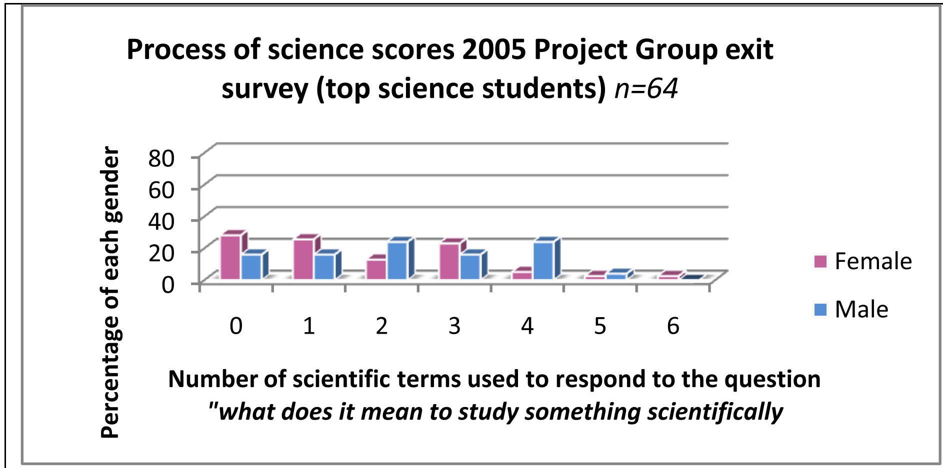
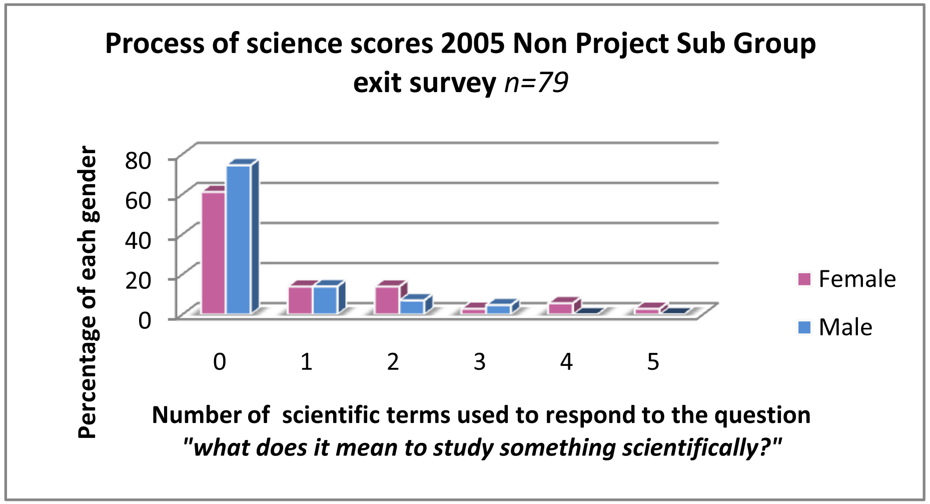


Fig. 2: Exit surveys - process of science scores 2005 datasets male/female comparison



Scores among the Pilbara VFT students (left) increased 44.1% from entry to exit over a full term, as revealed in this somewhat different graph to those of non-project or single-day project students. See Chapter 7 for more discussion.

Note: *No process of science exit survey available for full Non Project Group*



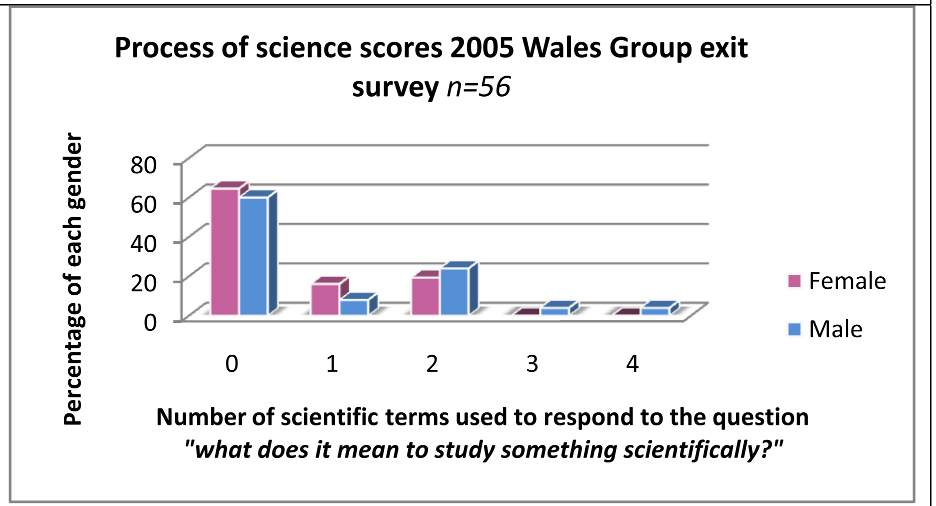


Fig. 3: Entry and exit process of science surveys compared (all students) 2005 datasets

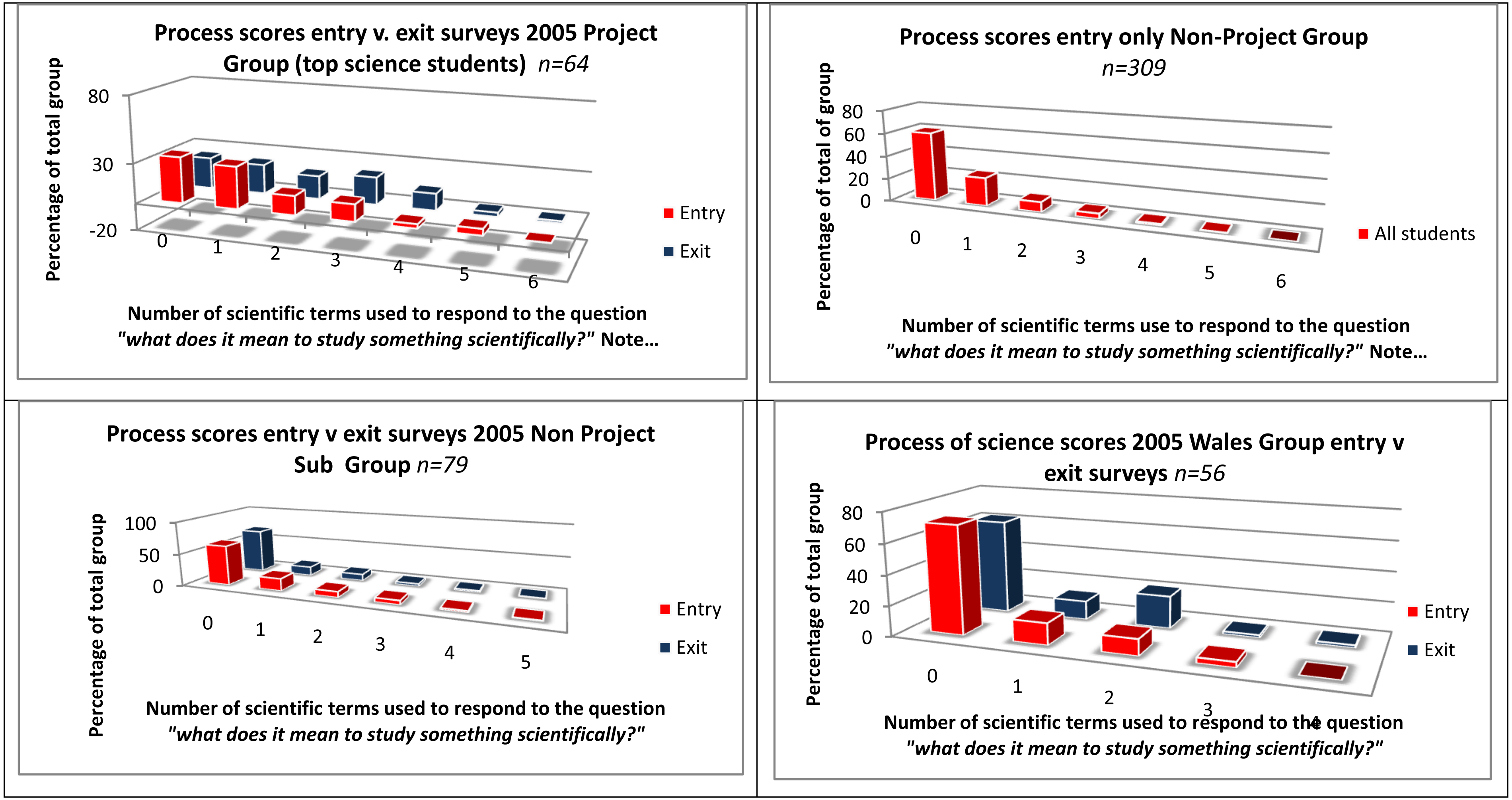


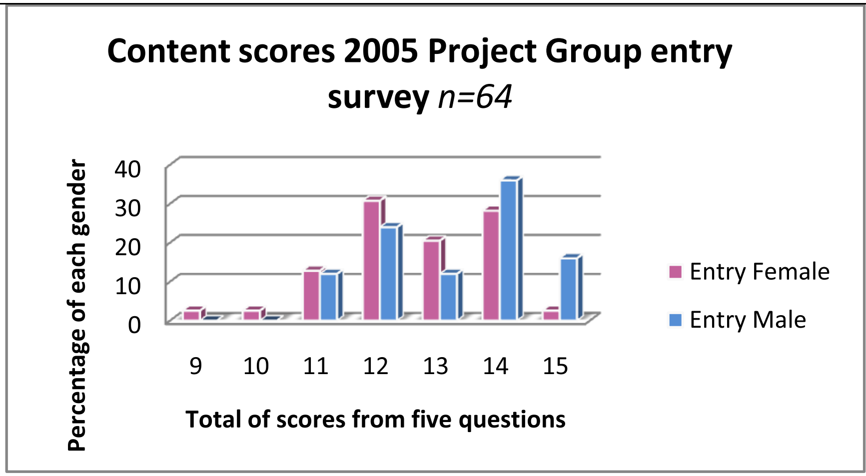
Table 5: Percentage scientific literacy as measured by the number of scientific terms used to respond to the question "*what does it mean to study something scientifically*" (2005 datasets)

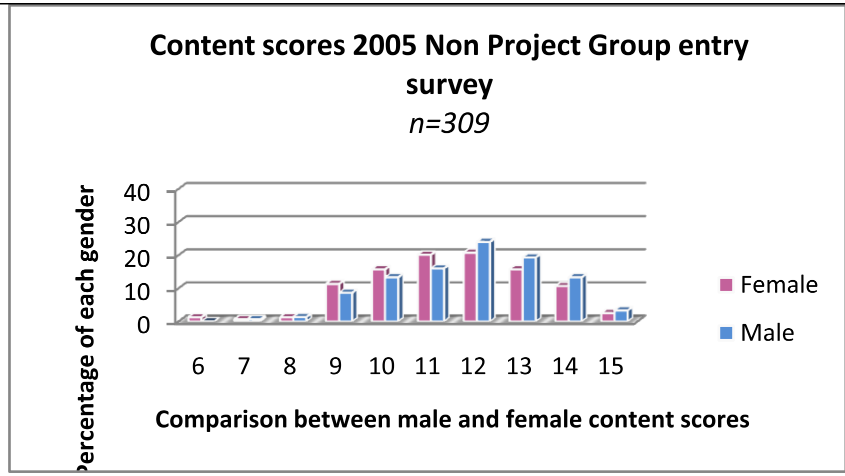
	Male entry	Male exit	Female entry	Female exit	All entry	All exit
Project Group *n=64*	32.0	44.0	12.8	33.3	20.3	37.5
Non Project Group *n=309*	7.3	n/a	6.3	n/a	6.80	n/a
Non-Project Sub-Group *n=79*	0.0	4.7	22.2	11.1	10.1	7.6
Wales Group *n=56*	4.0	8.0	3.2	0.0	3.6	3.6

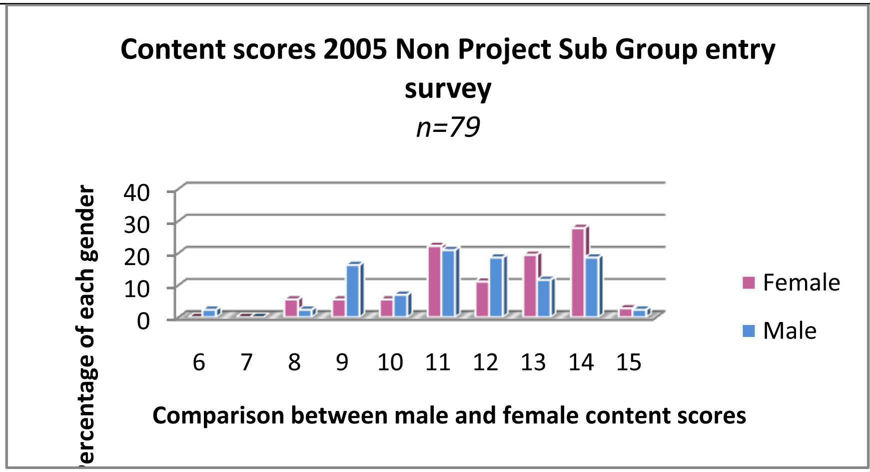
(A student using three or more terms to respond to the above question is considered scientifically literate, which is in line with standard international analysis as shown later in this chapter. It is also is demonstrated as a valid dividing line in review of all answers to the above question as discussed in Chapter 7).

6.5 CONTENT SCORES 2005 SURVEYS

Fig. 4: Entry surveys – content scores male/female comparison (August, 2005 datasets)







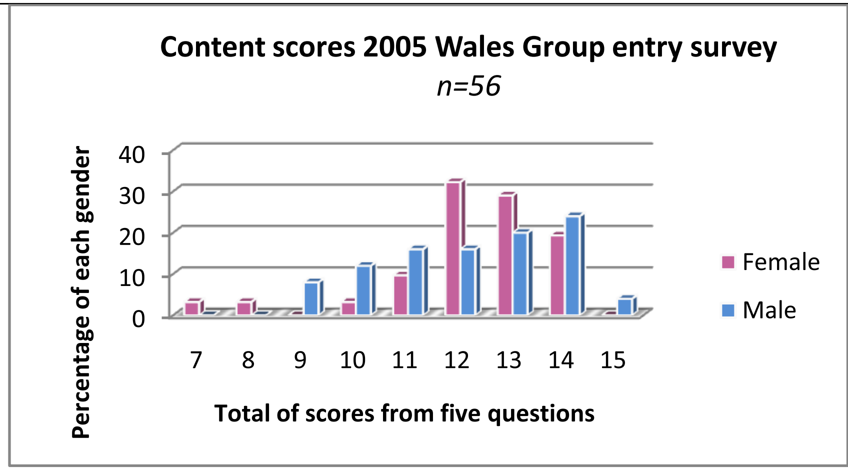
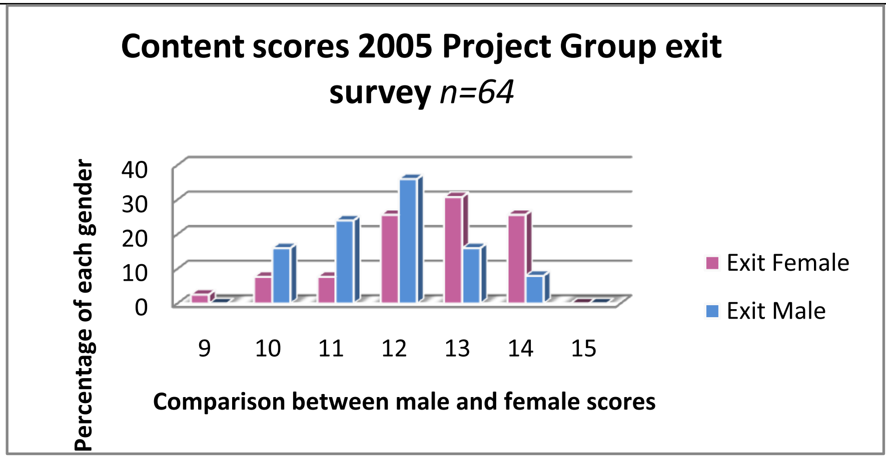
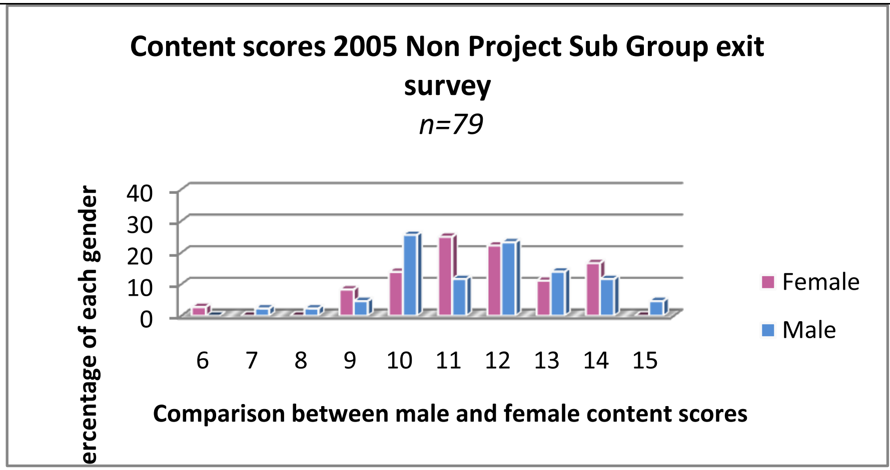


Fig. 5: Exit surveys – content scores male/female comparison (September, 2005 datasets)

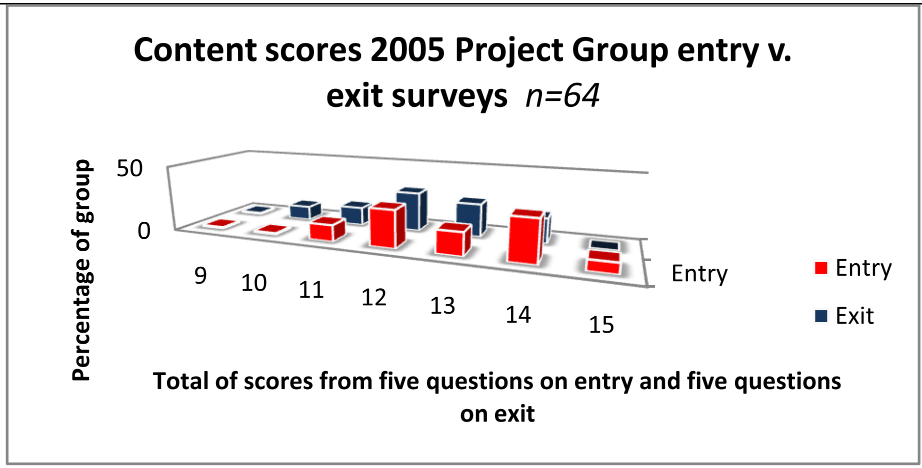


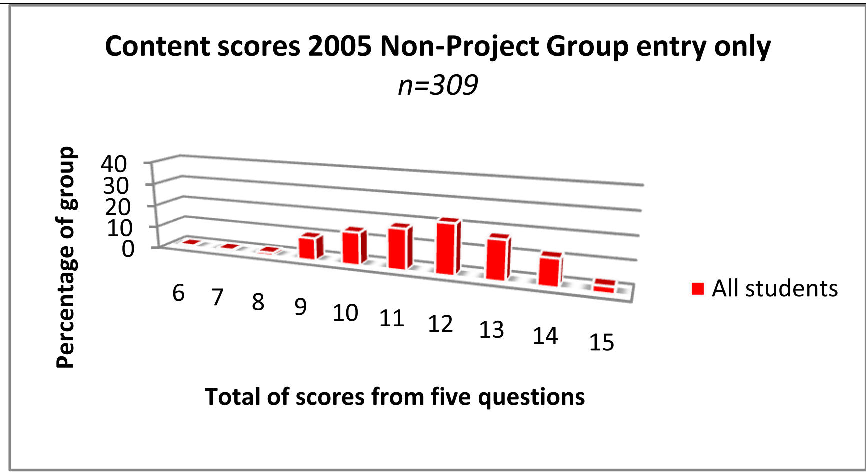
No exit survey available for Non Project Group

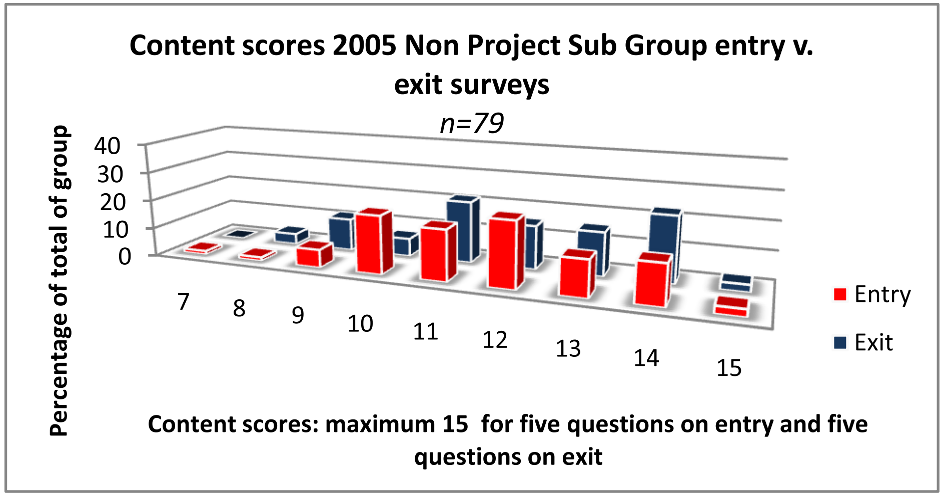


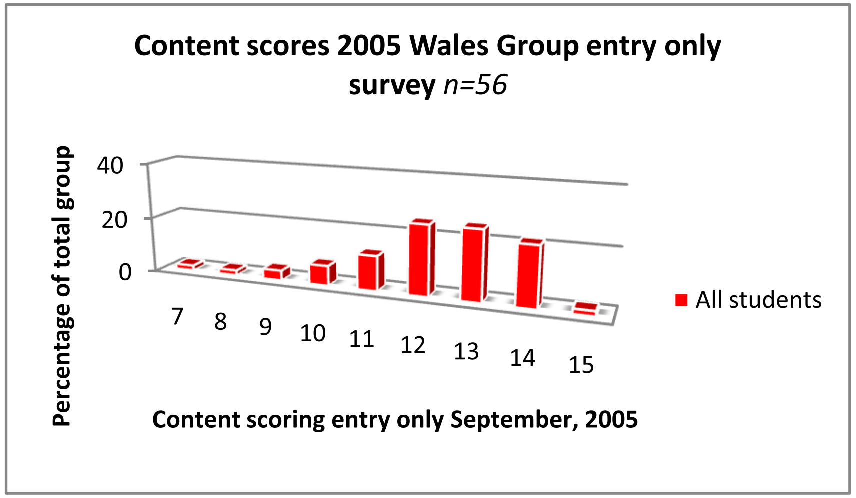
No content questions asked of Wales Group in exit survey

Fig. 6: Entry and exit survey comparison of content scores (All students) September, 2005 datasets









6.6 HIGH SCHOOL AND UNIVERSITY 2006 DATA

The following charts present data collected from two groups in 2006. The first is a group of 113 students from five of the seven 2005 participating schools who attending Macquarie University for a one-day experience with the Pilbara *VFT*. Due to the limited time, students were tested for content knowledge only on the entry survey only. Their understanding of the nature of science was tested at both entry and exit, but the short length of time with the Pilbara Project did not allow meaningful scientific literacy changes to be measured. Nevertheless, the test was carried out on both entry and exit.

The second and final group consists of 150 students undertaking a first year arts-based course with some history of science content. As stated, this group is tested to provide a measure of the scientific literacy of Australian educated adults. Only entry surveys are available for this group.

6.7 DESCRIPTIVE STATISTICS 2006

Table 6: 2006 *Pilbara VFT* Project Group (Australia high schools) *n=113*

	Process entry	Process exit	Content entry	Content exit
Mean	0.9	0.8	9.8	n/a
Median	1	1	10	n/a
Mode	0	0	10	n/a
Standard error	0.1	0.1	0.1	n/a
Standard Deviation	0.9	1.0	1.2	n/a
Variance	0.8	0.9	1.5	n/a
Kurtosis	-0.3	1.3	0.2	n/a
Skewness	0.7	1.3	-0.3	n/a
Confidence Interval 95%	0.2	0.2	0.2	n/a

Note the slight drop in process average scores. On exit 11.5% of respondents noted ‘same answer as before’, and this scored 0.

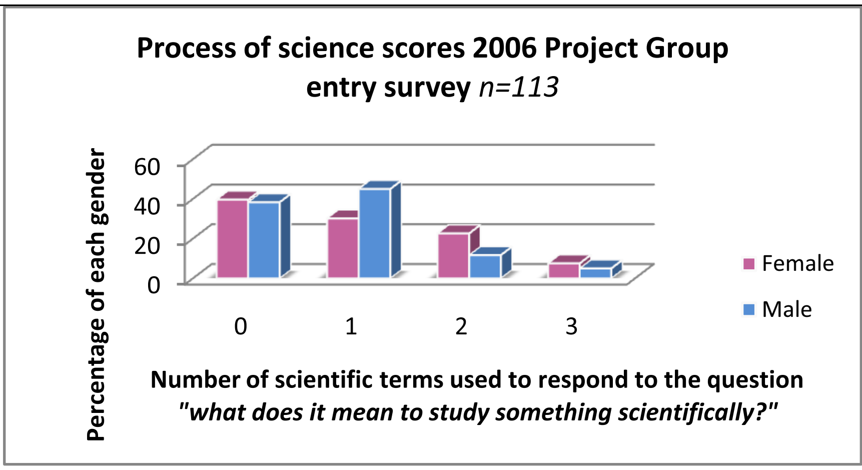
Table 7: 2006 University Group *n=150*

	Process entry	Process exit	Content entry	Content exit
Mean	1.3	n/a	12.1	n/a
Median	1	n/a	12	n/a
Mode	0	n/a	13	n/a
Standard error	0.1	n/a	0.1	n/a
Standard Deviation	1.3	n/a	1.6	n/a
Variance	1.6	n/a	2.5	n/a
Kurtosis	1.1	n/a	0.2	n/a
Skewness	1.1	n/a	-0.4	n/a
Confidence Interval 95%	0.2	n/a	0.3	n/a

6.8 NATURE OF SCIENCE DATA 2006

The high school students participating in 2006 were mixed ability science students from five Australian high schools, including three in North Sydney, one in Western Sydney, and one in the Blue Mountains west of Sydney. Each school brought a full class. The students were participating in the testing of the *Pilbara Virtual Field Trip* Project during Term Three of Year 10 as for the 2005 students, but for only one in-person day at the Macquarie ICT Innovations Centre (making a total of five days of data collection) during Term Three. There were no more than 31 students plus their science teachers in any of the five groups.

Fig. 7: Entry and exit surveys - process of science scores male/female comparison (2006 Project Group)



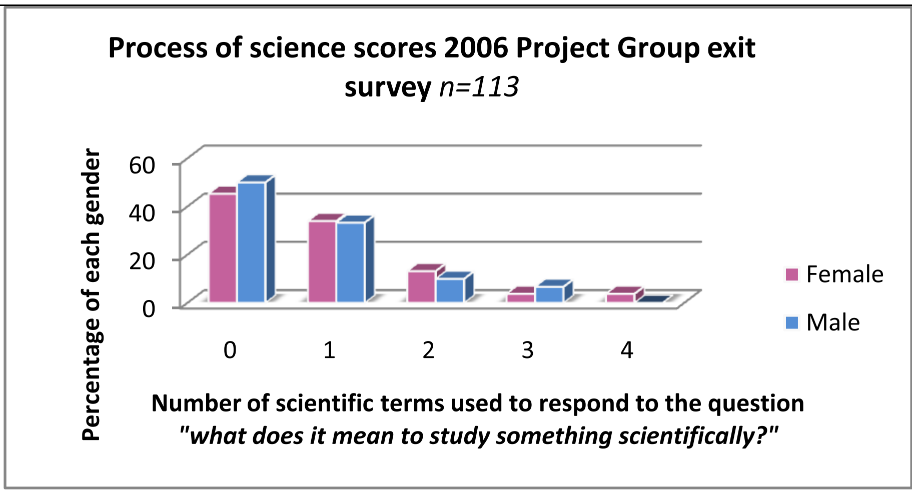


Fig. 8: Entry and exit survey process of science scores (2006 Project Group – all students) *n=113*

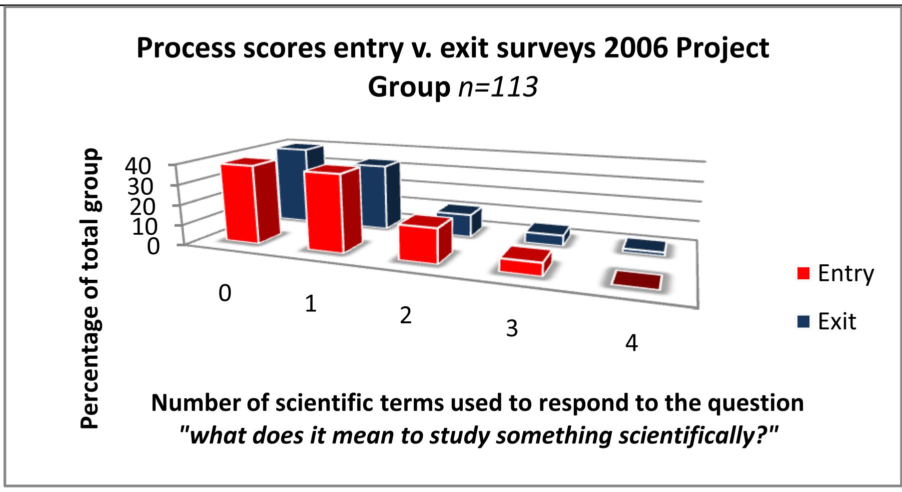


Fig 9: Entry survey - process of science scores male/female comparison (2006 University Group)

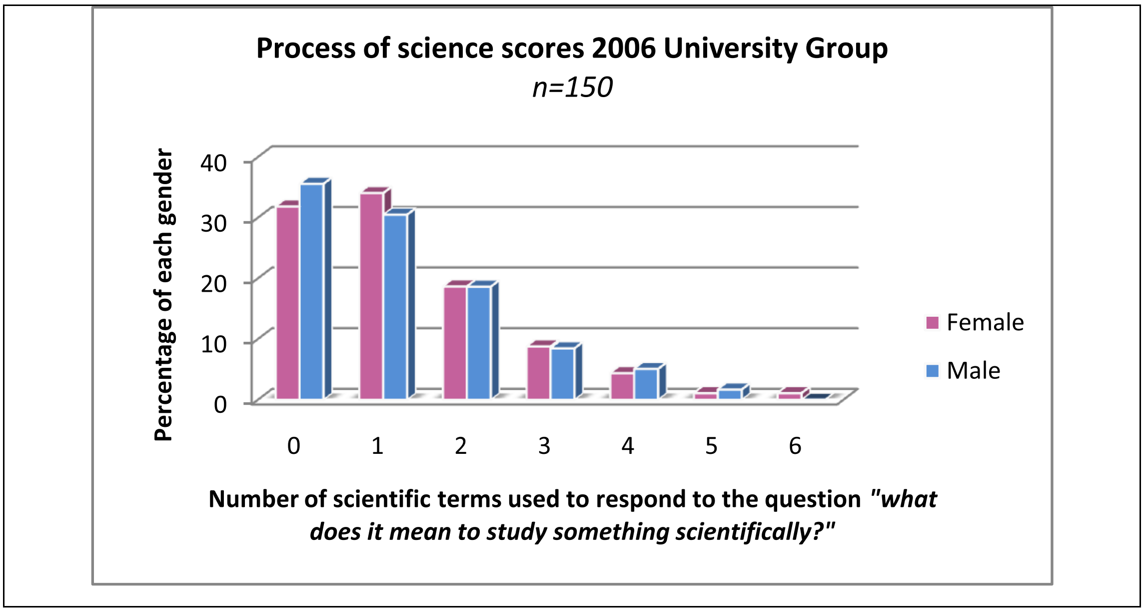


Fig. 10: Entry survey - process of science scores combined (2006 University Group)

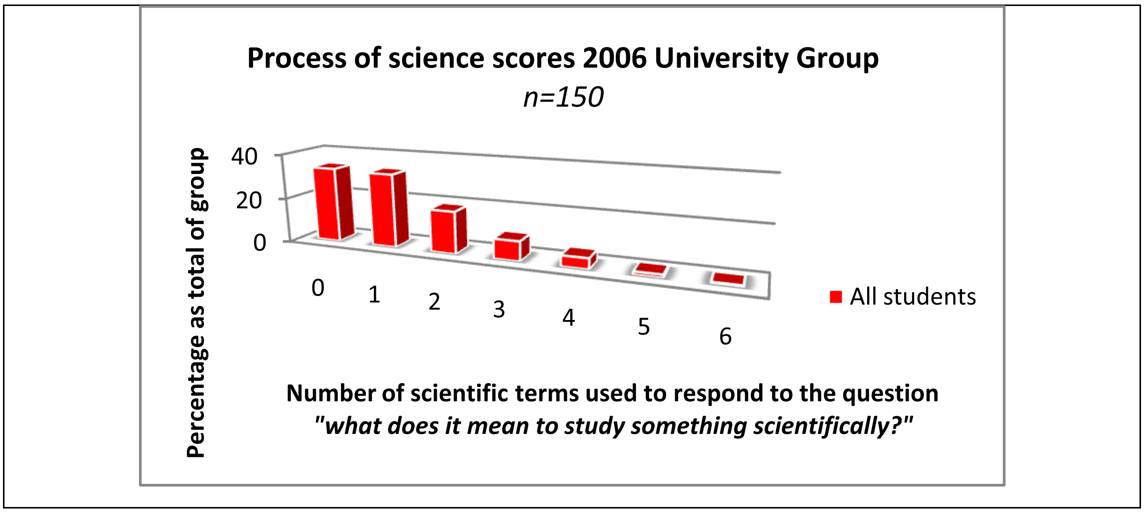


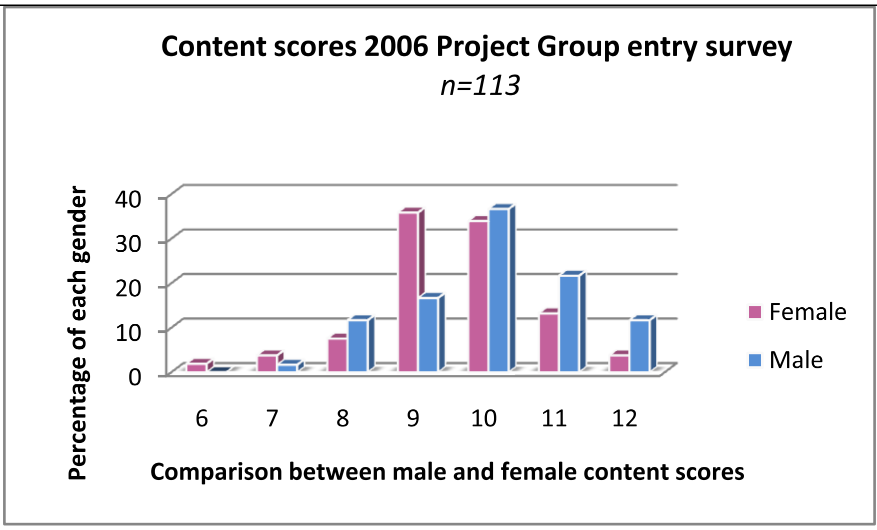
Table 8: Percentage scientific literacy as measured by the number of scientific terms used to respond to the question "*what does it mean to study something scientifically*" (2006 datasets)

	Male entry	Male exit	Female entry	Female exit	All entry	All exit
Project Group *n=113*	5.0	6.7	7.6	7.6	6.2	7.1
University Group *n=150*	15.3	n/a	15.4	n/a	15.3	n/a

(A student using three or more terms to respond to the above question is considered scientifically literate, which is in line with standard international analysis as shown later in this chapter. It is also is demonstrated as a valid dividing line in review of all answers to the above question, as discussed in Chapter 7).

6.9 CONTENT SCORES 2006 SURVEYS

Fig. 11: Entry surveys - content scores male/female comparison (2006 datasets)



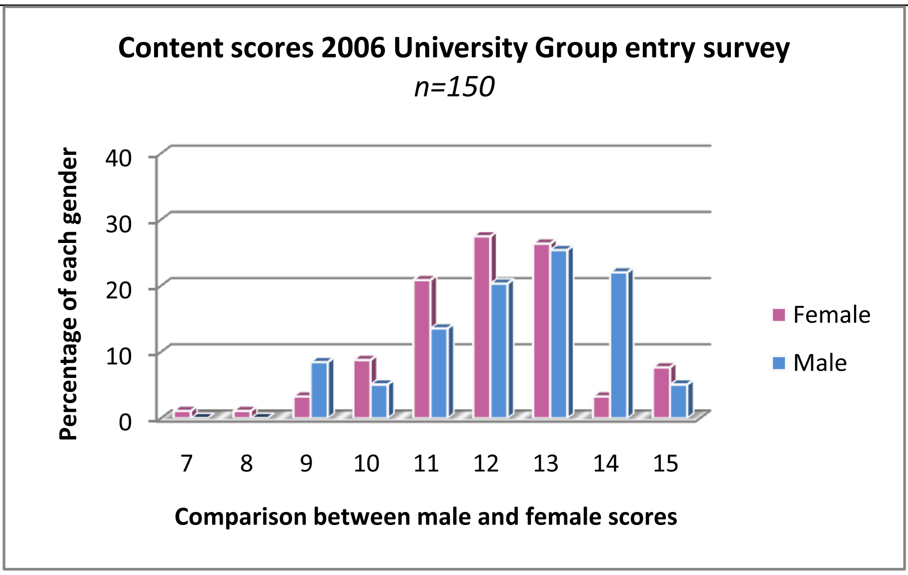


Fig. 12: Entry v exit surveys – comparison of combined content scores (2006 datasets)

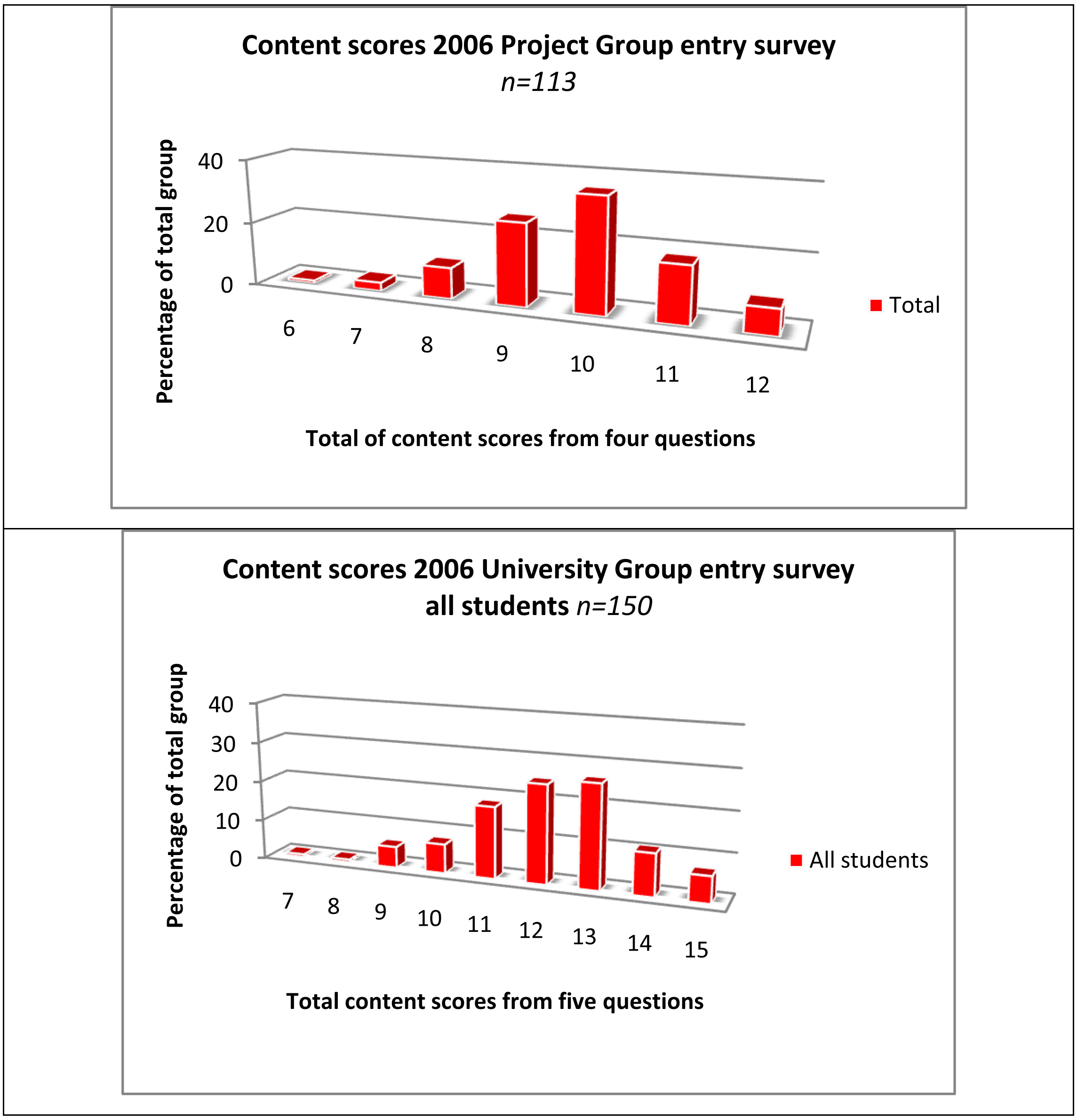


Table 9: Do males do better at science than females? Difference in average content scores between males and females 2005 and 2006 entry surveys expressed as a percentage

	Females	**Males**	**% difference**
2005 Project Group *n=64*	83.9	88.0	Males ahead by 4.1%
2005 Non Project Group *n=309*	76.2	78.6	Males ahead by 2.4%
2006 Project Group *n=113*	63.4	66.7	Males ahead by 3.3%
2006 University Group *n=150*	79.9	82.4	Males ahead by 2.5%
2005 Wales Group *n=56*	81.5	81.1	Females ahead by 0.4%

6.10 COMPARISON OF ANALYSIS METHODOLOGIES

The following charts compare the counting of terms (which can be counted via analysis software such as Excel) in the above charts with the commonly used Jon Miller prescriptive coding (constrained categories) that requires all responses to be hand coded. The results are presented in chart form and the methodologies correlated in the final chart of this section.

6.10.1 *Miller v. terms entry survey charts*

The following charts compare the seven datasets of how students score under the Miller coding method, and under the number of scientific terms used to respond to the question on **entry** surveys *"what does it mean to study something scientifically?"* Terms are generated by the students and are listed in Table 2, Chapter 5.

Fig. 13: Miller and Terms methods of analysis compared entry surveys 2005

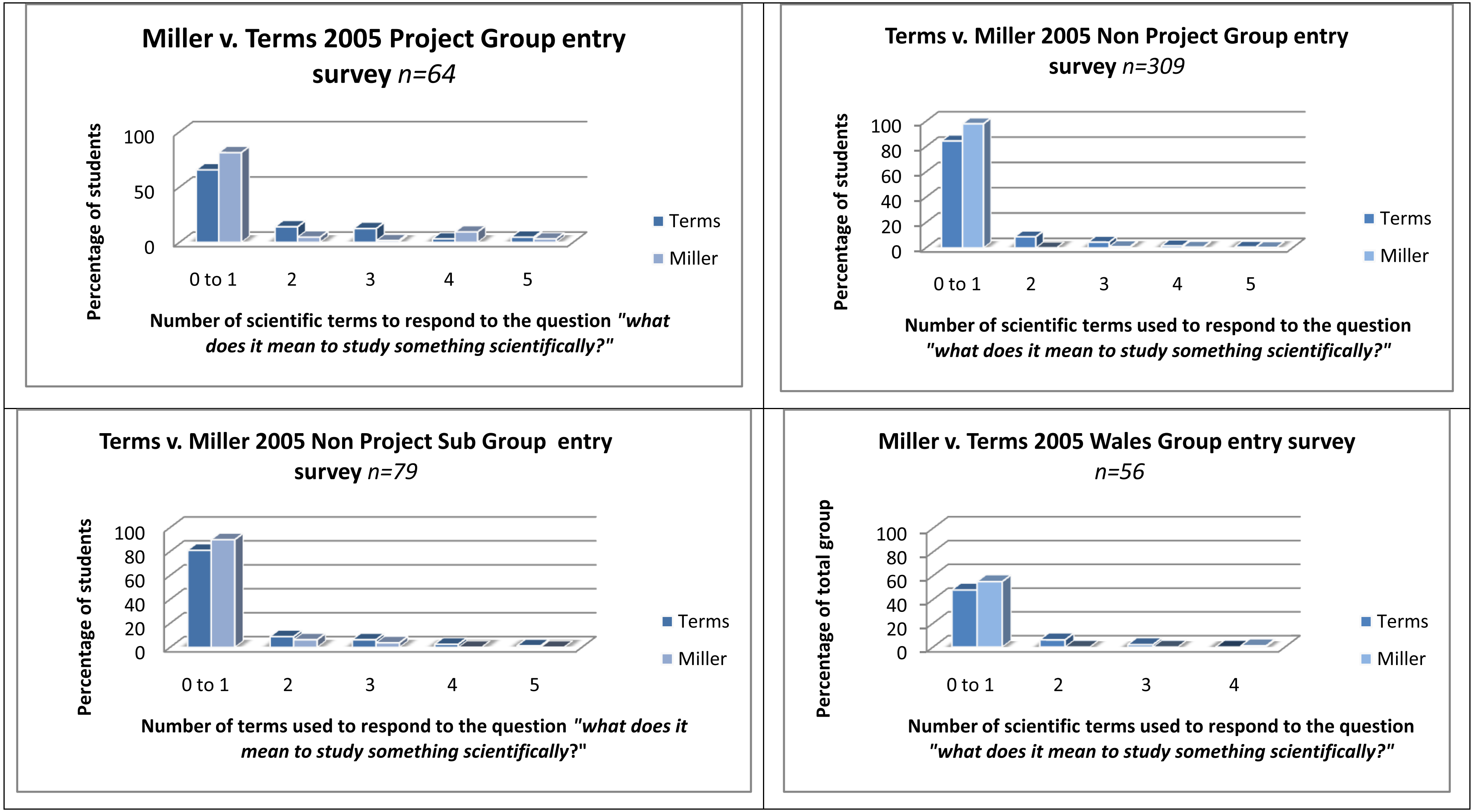
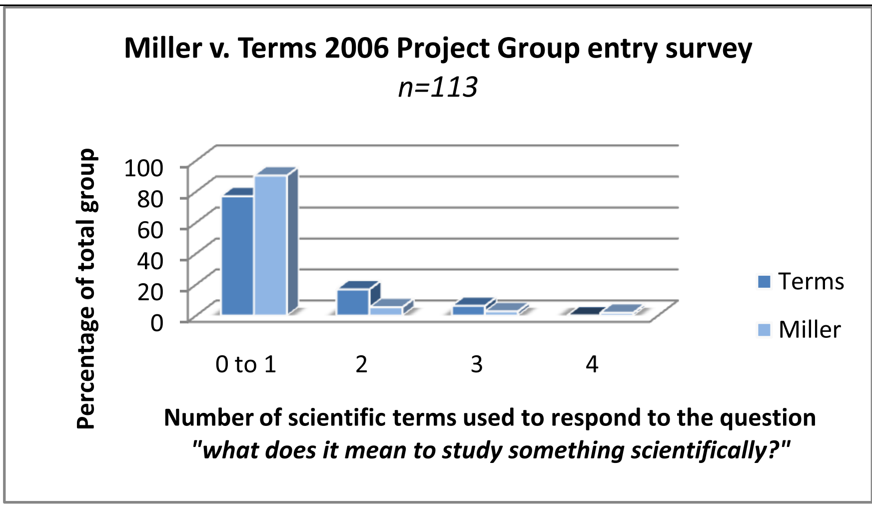
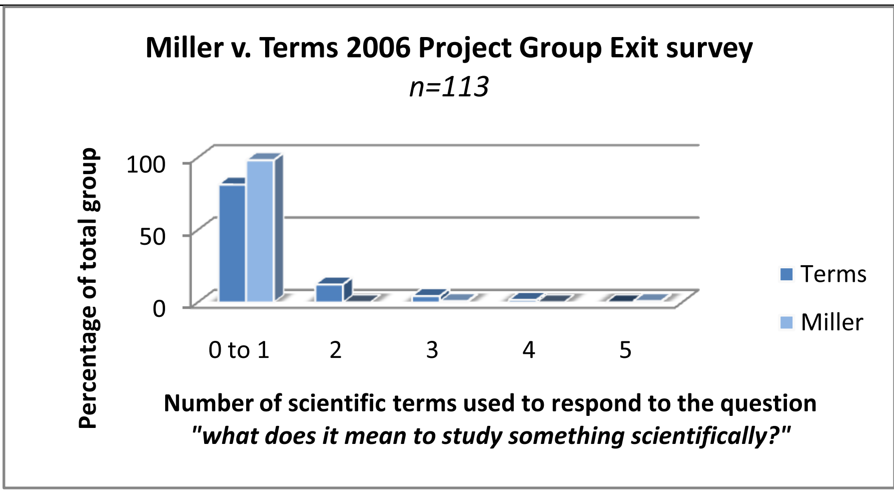
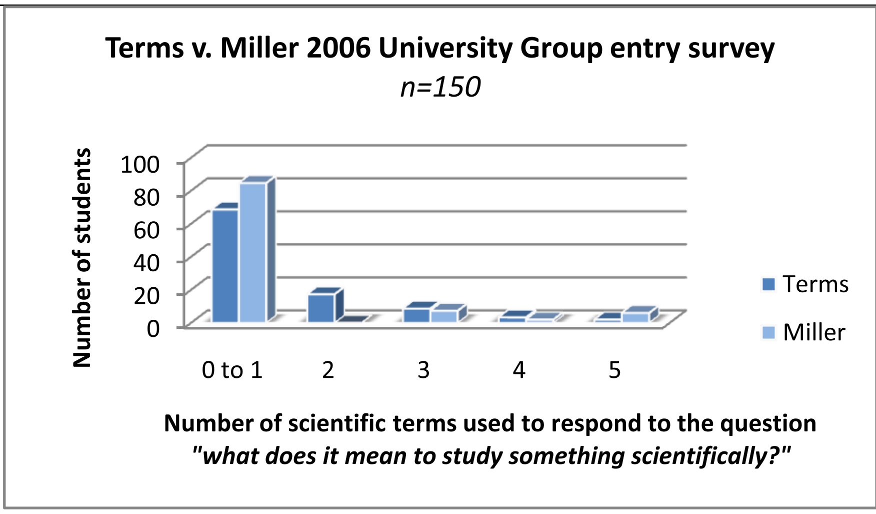


Fig. 14: Miller and Terms methods of analysis compared entry and exit surveys 2006

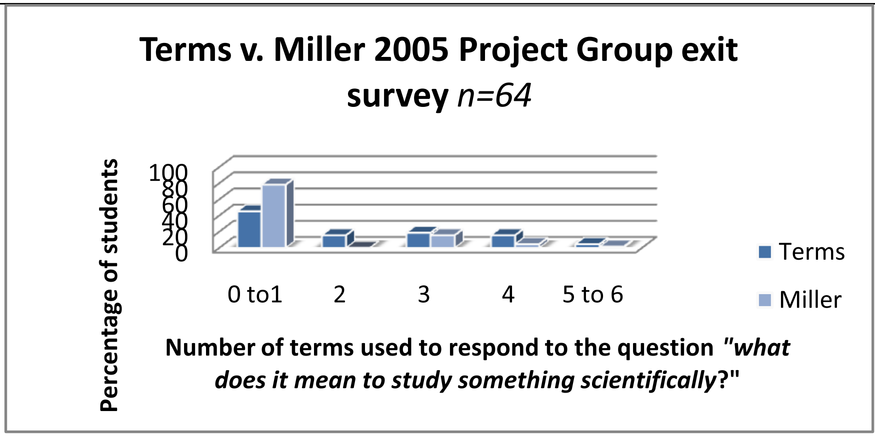




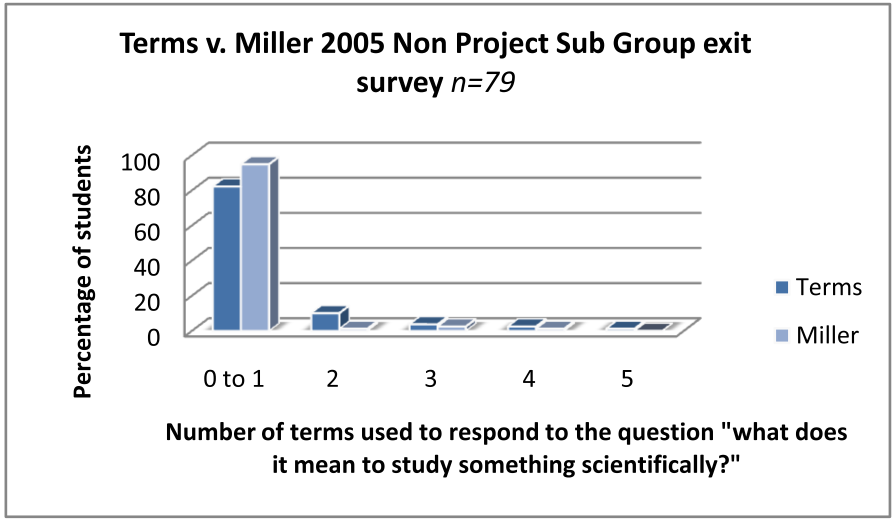


Note: no exit available for University Group

Fig. 15: Miller and Terms methods of analysis compared exit surveys 2005



No exit survey available for Non Project Group



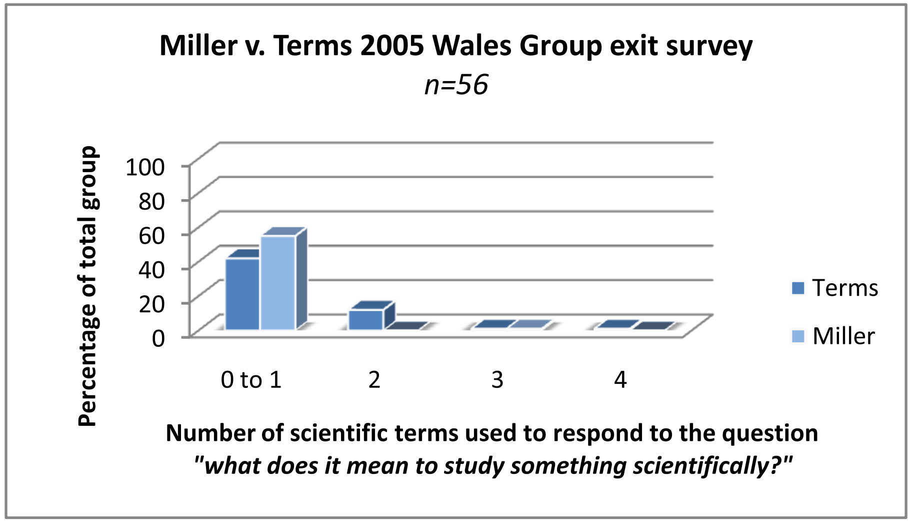


Fig. 16: Entry surveys 2005: Comparison of methods on analysing scientific literacy

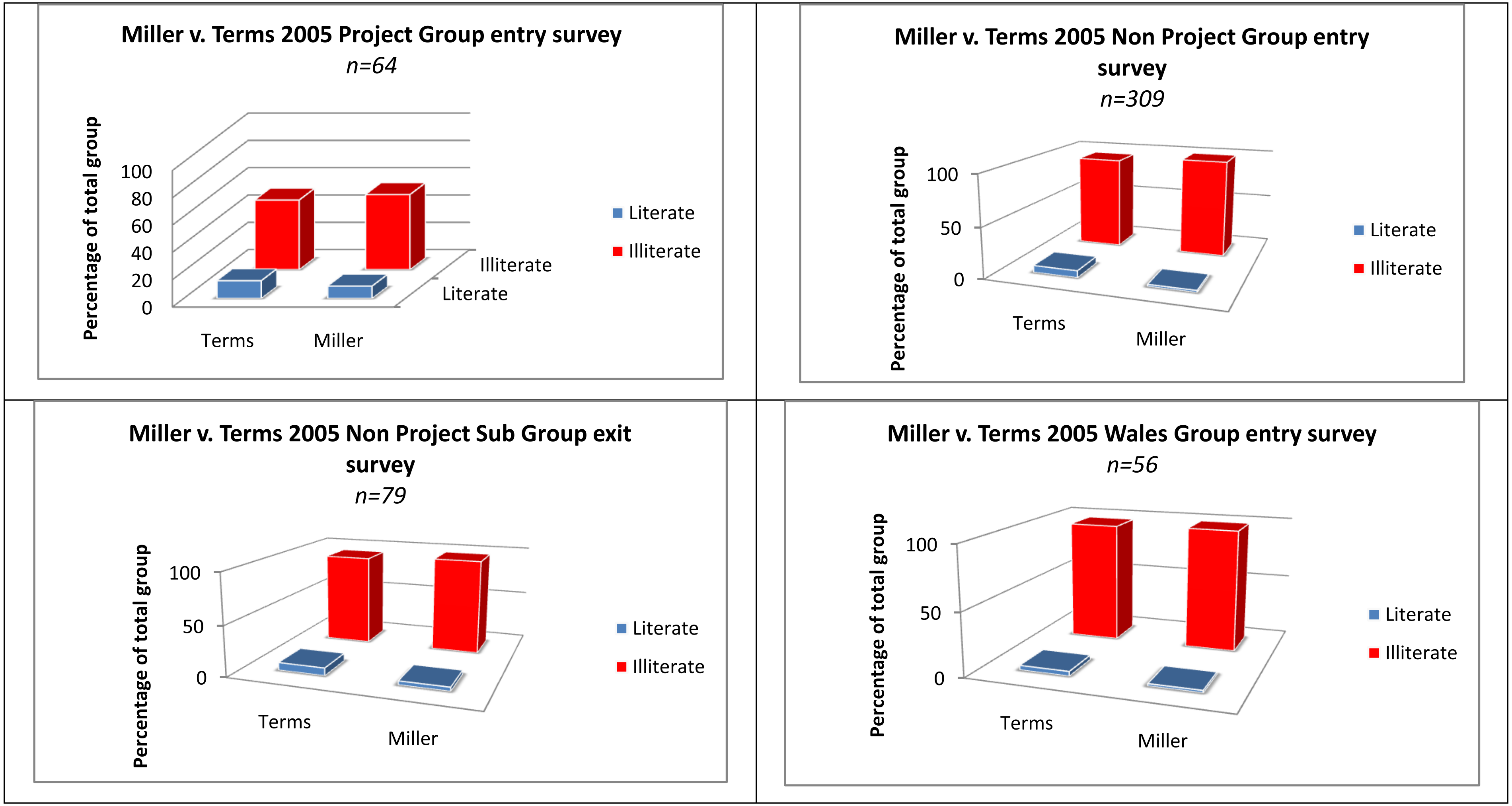
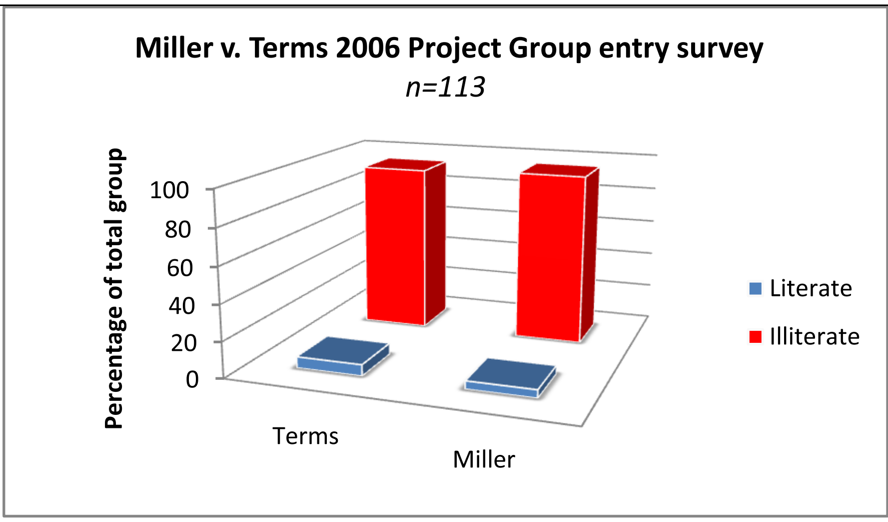


Fig. 17: Entry surveys 2006: Comparison of methods on analysing scientific literacy



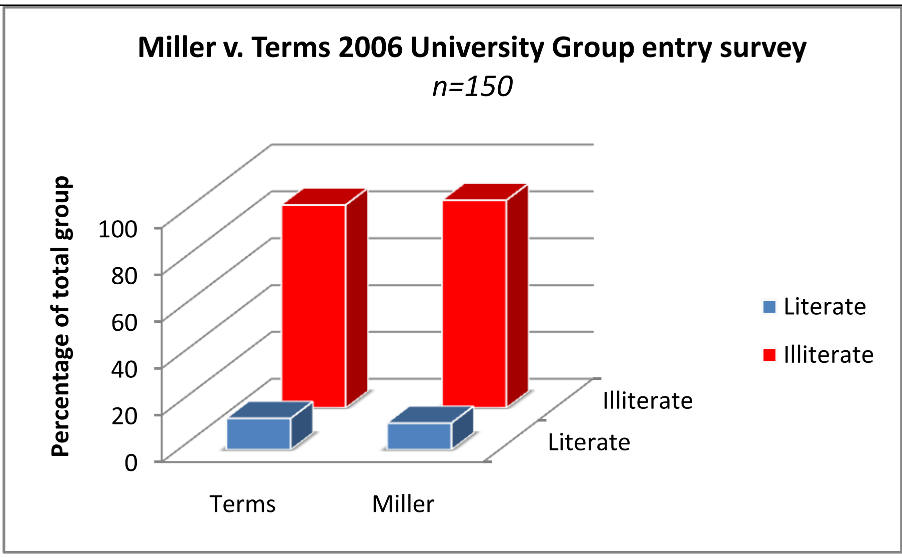
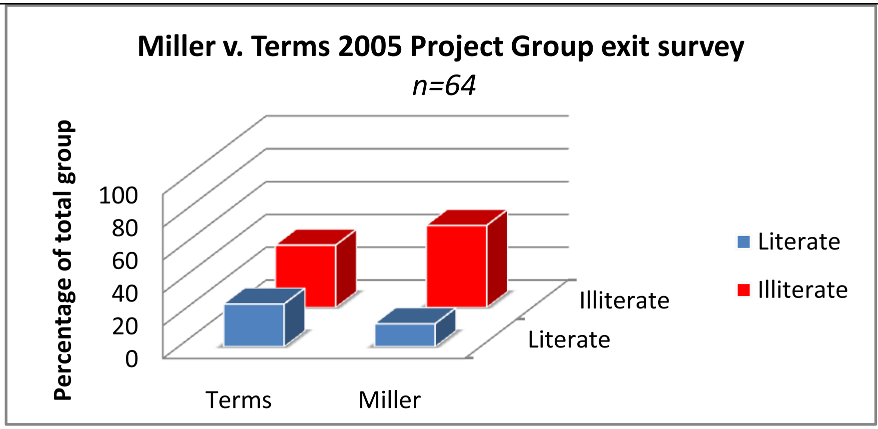
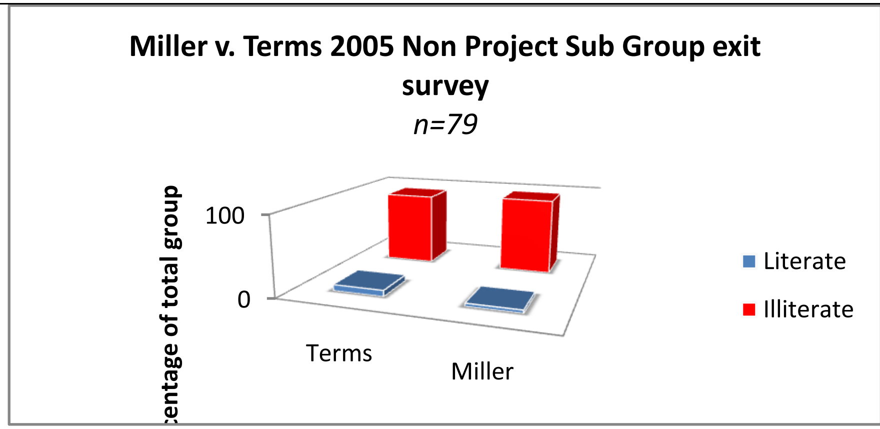
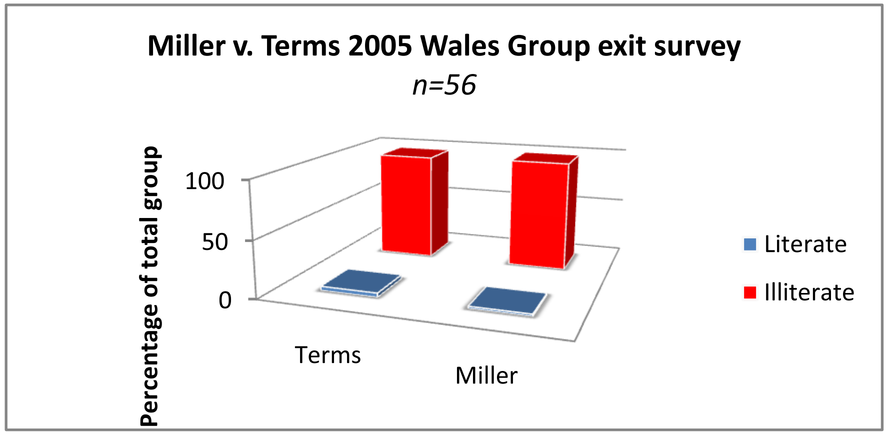
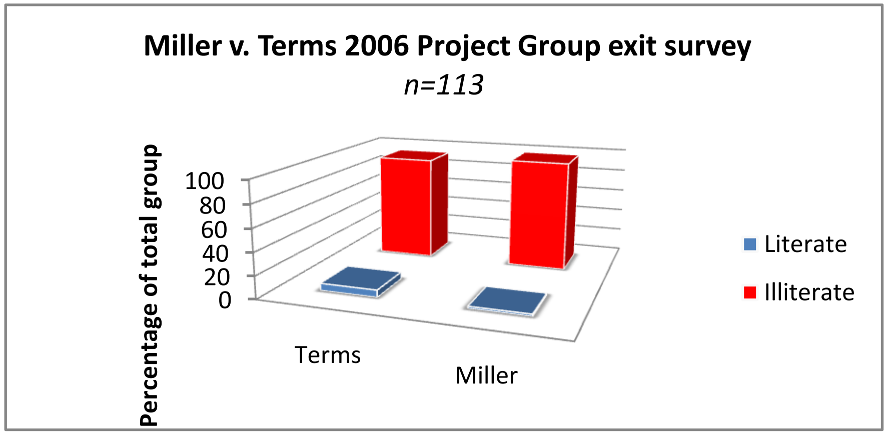


Fig. 18: Exit surveys 2005 and 2006: Comparison of methods on analysing scientific literacy (note no exit survey available for the 2005 Non Project Group)









6.10.2 *Miller v. terms methods correlation coefficients*

The following table collates the statistical comparison that indicates the relatedness of estimated scientific literacy found using either the Miller method of coding or the counting of terms. The Miller method determines scientific literacy if the response falls into one of three categories (coded as 3, 4, 5, for comparison with the terms method). The Terms method determines scientific literacy at three or more scientific terms used to respond to the question *"what does it mean to study something scientifically?"*

A higher correlation coefficient is obtained in all cases if the first category in the J.D. Miller coding relating to theory and construction is changed to proving rather than the Popplarian approach of disproving a hypothesis. This is discussed further in Chapter7.

Table 10: Statistical relationship of J.D. Miller and Terms methodologies

	Entry	Relationship	Exit	Relationship
Project 2005	0.80	Very Good	0.61	Good
Non Project 2005	0.4	Moderate	n/a	n/a
Non-Project Sub-Group 2005	0.4	Moderate	0.49	Moderate
Wales Group 2005	0.7	Very Good	0.56	Moderate
Project Group 2006	0.7	Very Good	0.4	Moderate
University Group 2006	0.6	Good	n/a	n/a

6.11 INTEREST IN SCIENCE

Students were asked whether they were interested in science. They could answer yes, no, or don't know. The following table breaks down the numbers in each of those groups for the four main entry surveys (two in 2005 and two in 2006). In each category the number of students considered to be scientifically literate as determined by the number of scientific terms used to respond to the question *"what does it mean to study something scientifically?"* are given. Note the Welsh group is not included.

Table 11: Is interest in science a predicator of scientific literacy?

	Not interested in science		***Don't know***		***Interested in science***		***Total***
Project Group 2005	4	0	8	1	52	12	64
Non-Project Group 2005	113	3	54	3	142	13	309
Project Group 2006	0	0	27	1	86	5	113
University Group 2006	46	5	15	1	89	17	150
Total	163	8	104	6	369	47	636
Percentage of total 636	25.6%	(1.3%)	16.4%	(1.0%)	58.0%	(7.4%)	100
Percentage of scientific literacy in each group	4.9%		5.8%		12.7%		

6.12 SUMMARY

Process of science scores across all datasets suggests that even among the brightest students, no more than one in five Australian students - on the point of being able to end their formal science education – are scientifically literate if measured by standards applied to the general public in Europe and the United States. The pilot test among young Australian adults entering university supports that indication. Nevertheless, in all cases content knowledge is relatively high with average scores between 12 to 13 out of 15 possible points as demonstrated in Figures 4 to 6 and 11 and 12.

The use of a method that counts the number of scientific terms to measure scientific literacy from responses to the question *"what does it mean to study something scientifically?"* produces similar results to a coding method generally used for this question. Figures 13 to 18 and Table 10 indicate a moderate to very good relationship between the two methods. The Terms method includes more respondents in the 'scientifically literate' category.

Figures 4, 5, 6, and 11 and 12 indicate that, in contrast to process scores, students both at high school and university score well in content knowledge. Table 9 expresses that as a percentage of average scores for males and females, demonstrating very little difference in scoring ability between males and females in spite of a general belief that girls need more encouragement in science than boys.

Interest in science may be a predictor of scientific literacy to some degree as other studies have shown (see Chapter 2). A student stating an interest in science is twice as likely to be scientifically literate as a student who has no interest in science or is not certain whether they are interested.

Chapter 7:

Discussion

7.1 OVERVIEW

In Chapter 6 the adult measure of scientific literacy was applied to Year 10 students in seven socioeconomically diverse Sydney high schools, three UK high schools. The data demonstrate that less than one in ten average science students among those tested near the end of their compulsory science education can give a minimally acceptable answer to the question *"what does it mean to study something scientifically?"* Among the best science students it is still only one in five, while university students from a first year class ranked in the middle at one in seven students. On the other hand, all datasets of students had high average scores in content knowledge at around 12 out of a possible maximum score of 15 – a figure consistent across the average scores of the 692 respondents completing surveys. As expected, interest in science is a factor in the likelihood a student will be scientifically literate.

7.2 ANALYSIS OF PROCESS SCORES 2005 AND 2006 DATASETS

A remarkable consistency runs through all datasets in *Figs*. 1-3 for the 2005 Project, Non-Project and Wales Groups, and for the 2006 Project and University Groups in *Figs*. 7-10. The notable exception is the 2005 Project Group, which stands out with the greater spread of the number of scientific terms used to respond to the question, *"what does it mean to study something scientifically?"* As noted in Chapter 5, teachers from all participating high schools in Sydney chose their best science students to participate in the testing of the *Pilbara Virtual Field Trip* Project and those students formed the 2005 Project Group for data collection and analysis. Students exposed to this authentic science experience in three in-person visits over a whole term increased their average scores in understanding the process of science by 44.1%. They were already good scientific literacy performers as demonstrated in Table 5, Chapter 6, with scientific literacy scores well above the average among the remaining datasets of around 7%. The Wales Group performed on the low side but this might have been due to testing at the beginning of the UK version of Year 10 – the school year begins in September in the UK rather than February in Australia. So the students were younger and yet to study through Year 10.

The 2006 Project Group reflects a rather different cohort – this time of average students. They do not demonstrate an increase in scientific literacy, but this may be largely due to being exposed to only one day of university science as against three days over a whole term for the 2005 Project Group. It may also reveal the difficulty of evaluating change over a single day. The day appeared to be more suited to testing scientific literacy at the beginning of the day and to getting evaluations from the students of the hi-tech learning tools they were presented with. Two thirds of this group said they would download some or all of the hi-tech science learning tools whether or not directed by a teacher because they were interesting and/or fun. The group was also comparable to the 2005 Non Project Group with scientific literacy scores almost identical at around 7%. This means that less than one in ten average science students tested would quality as being scientifically literate as measured by adult standards.

7.3 DISCOVERY, EXPLORATION AND PREDICTION

Science is about exploration and discovery. Perhaps the most striking aspect of the data are that of a total of 692 completed surveys, less than 4% of respondents used the word discover, explore, or in a combination of those explicit words, or implied the concepts without the use of those words (e.g. to find new knowledge) among entry surveys in answering the question, *“what does it mean to study something scientifically?”* Only two students among the 692 mentioned the words predict, predicting or predictions – a method on which all science stands. Science seeks the repeatability and the laws of nature so a prediction *can* be made about the natural world. This identifies another issue not shown in the statistics in Chapter 6. A respondent can be classed as scientifically literate without having any idea about the predictive, probabilistic, and empirical aspects of the nature of science.

While the question, "*what does it mean to study something scientifically?"* is open to challenge, the extremely low numbers of students associating terms such as discover, explore, predict, or anything else that expresses these in another way, suggests they are not readily associated with school science. Instead, the majority of responses attempting to characterise what it means to study something scientifically tend to refer to a formulaic approach to science (not generally employed by scientists): 'make a hypothesis, gather evidence, experiment, analyse and interpret the results, and come to a conclusion'. Very few, if any of the answers, fall into a sufficiently scientifically literate answer that at least hints of the understanding of the nature of real science.

While the data in Chapter 6 demonstrate a problem of disparity in what is expected of students and what is expected of adults in achieving the status of 'scientifically literate', the actual answers given in this pilot study suggest a deeper problem. They suggest most students truly do not fully understand the nature of science at the end of their compulsory science education. This is borne out below with some examples of 'worksheet science' in the words of the students themselves. Later in this chapter, 21 of the students from the 2005 Project Group provide perceptions of science consistent with their answers to the question *"what does it mean to study something scientifically?"* The answers below are from entry surveys, so exposure to the *Pilbara Virtual Field Trip* Project had not influenced answers. A full list of all 692 responses can be found in Appendix D.

From 2005 Project Group:

1. **Female interested in science:** *"To study something scientifically means to analyse and observe something. You conduct experiments and note changes, growth, movement, power and more."*
2. **Male interested in science:** *"To study something scientifically would mean to research into what you are studying, conduct various tests and experiments on the subject to make observations and to draw*

conclusions about the subject so we can find out as much information as possible about the subject."

From 2005 Non Project Group:

1. **Male, not sure of interest in science:** *"To study something scientifically, you observe, have an aim, hypothesis, method and a result. Therefore you take out experiments."*
2. **Female interested in science:** *"I think it means that you investigate or observe a particular topic in a scientific manner. For example you carry out experiments and investigations to prove your hypothesis."*

From Wales Group 2005:

1. **Female interested in science:** *"To study something scientifically is to analyse and breakdown the facts we gain from our results and attempts. There must be variables in the experiment but some must remain constant."*
2. **Female interested in science:** *"To study something scientifically is to run tests and take observations and results."*

From Project Group 2006:

1. **Male interested in science:** *"To research others work, then conducting tests and experiments to further your knowledge making sure to record and compare results and observations."*
2. **Female interested in science:** *"I think to study something scientifically means to look at something from every angle. It means to classify, understand, examine, find what it is made from and find how it works."*

From 2006 University Group:

1. **Male interested in science:** *"Basing observations or empirical evidence to ascertain a result based on changing variables. And comparing this to a hypothesis."*
2. **Female not interested in science:** *"To look at it carefully finding proof in the study through experiments."*

7.4 ANALYSIS OF CONTENT SCORES 2005 AND 2006 DATASETS

As with the process scores, there is a strong similarity in scoring across all datasets (including the bright students in the 2005 Project Group, who show little difference). Note in Table 1 below that the 2006 Project had only 12 questions on entry and none on exit. The reduction in questions was due to the need to ask students to participate in three other surveys during their one-day visit to the university to determine how to complete the *Pilbara Virtual Field Trip* Project.

	2005 Project Group entry	**2005 Project Group exit**	**2005 Non Project Group**	**2005 Wales Group**	**2006 Project Group**	**2006 University Group**
Mean	12.8	12.2	11.6	12.2	9.8	12.1
Median	13	12	12	12	10	12
Mode	14	12	12	13	10	13
Out of	15	15	15	15	12	15

7.5 WHAT THE 2005 STUDENTS SAID ABOUT SCIENCE: A CASE STUDY

The 2005 *Pilbara Virtual Field Trip* Project testing in Sydney was the only dataset to be taken over a longer period than a day. In most cases, data collection took place over eight to nine weeks. This provided a case study to measure any change in the level of scientific literacy in that period that might be due to exposure to the project. It also allowed the opportunity to acquire interviews with 21 students from the seven schools – three per school, and to interview that group of three. Of the 21 students, 81% said they had a better understanding of science as a result of participating in the *Pilbara VFT* Project.

Among the total of 87 Year 10 students attending the Pilbara Virtual Field Trip testing during the third term of 2005, 25 of them reported that they would now take at least some science at tertiary level. In the US, university students are required to undertake at least one year of science as part of their general education. J. Miller (2007) attributes an increase in scientific literacy rates in the US to this policy. Several other studies indicate a relationship between level of science education and scientific literacy (for example, Ishii, 2002).

7.5.1 *Views of science before starting the Pilbara VFT project*

Students who expressed a view said science lessons varied from boring to interesting, whether in terms of theory or practical work. One student summarised the responses in his comment that it depended on, *"If you have a lot of practicals in it and whether they were the sort of things a primary school kid could do."* Theoretical work appeared to be unanimously regarded as 'boring', and there were specific views about 'good' and 'bad' teachers. For example one student said it was like *"...I'm going to tell you this and you're going to learn it."* Another student said you *"...can generally tell whether a teacher is a good teacher of not by how thick the book is. If it's really thick like it's got a lot of sheets they've just photocopied and stuck in then the teacher just walks in and goes 'do this' rather than explaining (anything)."*

7.5.2 *Understanding of science as a result of the project*

Several students indicated an increase in understanding the nature of science by talking about the difference between school science and actual science. For example, *"When you're learning science at school it's just like the textbook and you, but when you've got programs like the one we're testing out (the Pilbara Virtual Field Trip) it's got a lot of different views and you can compare different things and that science is really undetermined."* Another commented*, "Part of the fun is actually finding it, not having it handed to you on a silver platter."*

7.5.3 *Perceived differences between school science and real science*

Another theme came from several students on the difference between school science and actual science: *"I had a basic idea (of science) that was not very accurate."* Another student said she thought the Pilbara VFT Project was *"just for our learning, like test that and then you'll understand, but when it's a concept that's not for sure, then that has to be done."* Another student reported *"...I thought I had an understanding of how science is done. (In science) you observe first but in high school that's not how we actually start off. We start off with doing background information then our science teaching going 'okay this is what we want to find, this is your experiment you do, go do this experiment, write up the results and find a conclusion and what you would do differently'."* One student described the method of doing science at high school: *"You have the guidelines, you just have to fill in the blanks."* There was a comment about school practicals, *"It's like more test tubes. I just kind of thought that's all science really is – just mixing stuff. But there's a lot more to it."* Finally a student sums up the difference: *"Most people (at school) see science as a lot of facts – they don't think about how it works, what does it all mean? It's a factor out here. They don't dispute it (the information) – and if they do they are going to lose points."*

7.5.4 *The future of science education through user eyes*

Students were asked to imagine what new technologies might evolve to make the nature of science easier to access from the classroom. Most believed computers would be involved in some way. One student said school would be a virtual world accessed via virtual helmets, *"Like instead of going to the Pilbara you can have a virtual world. You can pick up things in your mind and try to find things."* Another foresaw a time when *"rather than opening up a textbook and reading along you can actually click on different links and stuff like that and pop ups and you can see videos and stuff like that and listen to audio rather than* *listening to a teacher. It's like having a personal teacher, having a computer in front of you."* Another student wanted to see a virtual science dictionary that *"...explains every term to you, not just the teacher's own opinion. All the facts – get straight to it."*

7.6 ANALYSIS OF MILLER AND TERMS METHODOLOGIES

Figs. 13-15 in Chapter 6 measure the differences and similarities between the J. Miller method of coding responses to the question *"what does it mean to study something scientifically?"* and counting scientific terms (the terms generated by the respondents themselves – see Table 2, Chapter 5). Although the two methods correlate well (see Table 10, Chapter 6, and *Figs*.16-18) there are some relatively moderate differences particularly in the 2005 Project Group exit survey (see *Fig.* 18). The J.D. Miller method is more constrained by prescribed parameters in the coding – in particular the requirement a student says science is about *disproving* a hypothesis rather than *proving * it. In almost all cases where the two methods differed it was due to the Popperlarian view of science that the coding takes, yet this view of science is challenged by some scientists.

7.7 SUMMARY

Chapter 6 reported figures that suggest the majority of Australian high school students nearing the end of their compulsory science education are apparently scientifically illiterate as measured by the test for adult audiences. Behind the figures students have views of science beyond the constraints of the question "*what does it mean to study something scientifically?"* In answering the question, most demonstrate a 'worksheet science' response. However, when asked about the difference between school science and actual science after exposure to actual science, most describe a world where rote learning is still in force and the realisation that is not how science is actually done. These comments need to be tempered by the fact that all student interviewees came from the top science students. Norris and Phillips (2002) noted that literacy is a prerequisite to scientific literacy. Indeed around

10% of responses display illiteracy in both, with no students who displayed inability to construct a sentence being able to provide an acceptable answer to the question *“what does it mean to study something scientifically?”*

Chapter 8:

Conclusions

8.1 WHAT IS SCIENTIFIC LITERACY?

The most basic finding of this thesis is that the scientific literacy enterprise - in all its forms - is built on a foundation of sand. This is because it fails on the most basic of premises, and that is in the lack of an agreed definition of scientific literacy.

As mentioned in Chapter 7, in testing a total of 692 students over two years– at a point where they are able to finish their high school science education – less than one in ten would be considered scientifically literate using the same measures that are applied to adult testing. Among the brightest science students, it is one in five. Among young educated adults (first year university) it is one in seven. Bear in mind that Australia – where all but 56 of the respondents were located – rates among the top nations in high school scientific literacy in both the PISA and TIMSS international surveys (see Chapter 3). That leaves a choice: either we believe that even the best science students are leaving school largely scientifically illiterate, or there is a fundamental problem with the perception that most adults are scientifically illiterate.

As stated at the outset of this thesis, no criticism is aimed at the quality of science education, of the international testing of school students, or of testing among the adult public. The focus is solely on the major inconsistency between what we expect of students and the public in terms of scientific literacy and what we find through testing. The inconsistency probably explains what we see: little change in public scientific literacy over more than half a century in spite of innovative efforts in science education and the media. As a result, a paradigm shift is required in our thinking about what scientific literacy is, and what we expect from a high school science education and among the adult public.

Whether the measures used for adult testing are good or not is largely irrelevant: it is the method currently used to declare that most of the adult public – at least where it is measured in the US and Europe – are scientifically illiterate judged by responses to the question *'what does it mean to study something scientifically?'* and some key concept content knowledge questions. It is on this basis that assumptions are made about public audiences. Often considerable resources (e.g. science education aimed at creating scientifically literate citizens) are applied to either remedy a perceived situation, or to create a scientifically literate public. No approach through science education, media, and public outreach apparently has produced a largely scientifically literate public since statistics were first collected in 1957.

Australia is in a precarious position in any assumptions made that high school science education produces scientifically literate citizens. This is because of the lack of public testing to understand outcomes of a high school education among the public – outcomes that are desired or otherwise. In addition, assumptions must be made about public scientific literacy in order to carry out public education, media and public outreach activities, including the Australian Government's annual national Science Week. The key to any successful communication is to know the audience. 'Feel good' on-the-day evaluations and 'bums on seats' counts are largely meaningless except as a measure of public interest.

8.2 IS PUBLIC SCIENTIFIC LITERACY ESSENTIAL?

Is scientific literacy among the public as essential as is proposed by governments, institutions, scientists and science communicators? Why is it any more important than most of H. Bauer's list of at least 41 literacies from cultural and social to literate and numerate? (See Chapter 2). None of the list of standard reasons given by science communication pundits and researchers – as to why scientific literacy is essential – truly stands up to scrutiny. For example, a commonly given reason is that democracy is at risk if adult citizens are not scientifically literate (e.g. Sagan, 1996). There is no evidence to demonstrate either failure of democracy due to high levels of scientific illiteracy among the public, or that it is put at less risk when that public appears to be becoming more scientifically literate (as in the US in recent years). That is not to say it is not a good thing to be scientifically literate – only that the claimed essential reasoning does not hold up. Another claim is that scientific literacy among the public increases the economic wealth of a nation. There is evidence that not enough good students are being attracted into studying science at university to take up careers in science, and this has the potential to impact on Australia's future economy. Scientific literacy judged by adult measures does not appear to be regarded as essential, as evidenced by the general lack of surveys (although Victoria is beginning to think about the issues). One small study among first year science students suggests there may be cause for concern with many failing the test on the question *"what does it mean to study something scientifically?"* (Keen, 2007).

So why is it important for all citizens to at least understand how science goes about its business pushing back the limits of human knowledge? Perhaps the answer is that science stands apart from all other disciplines, by its evidence-based, empirical, probabilistic and predictive critical thinking. A painting of a cliff-face can be the subject of critical thinking, but ultimately that thinking is a critique that can range from that of a casual onlooker to the opinions of experts with a wealth of knowledge about art, and there is no rigorous basis for testing those opinions. Can there be right and wrong opinions about the quality of the painting? A geologist goes into the field, studies the same cliff face, gathers specimens relevant to the ideas he or she is testing, analyses the specimens, and then interprets the information using what he or she knows about the cliff face together with existing knowledge. Peer review, and perhaps debate too, will take place. The difference between the critical thinking associated with the picture and that concerning the geological interpretation is that the latter will be empirically based.

The empirical and predictive nature of science is the difference between science and any other kind of literacy. These tools at the heart of scientific thinking are tools that may well be as important as being able to read and write and undertake simple numerical calculations. The application of scientific thinking takes place in everyday circumstances such as understanding risk of acquiring cancer to buying a used car. In this kind of application of scientific thinking it would seem logical that it enables citizens to fully exercise their democratic rights, whether it is in voting in elections or in participating in debate surrounding science-based issues such as global warming or the need for a desalination plant. In contrast, scientific knowledge – the content part – is more a part of general education. With this perception, it becomes clear why it as important to know that the Earth orbits the Sun as it is to know where China is located. But that is general knowledge, not scientific literacy.

8.3 THE NATURE OF SCIENCE

The question used to test scientific literacy *“what does it mean to study something scientifically”* begs the question of what we expect as an answer. Do we really mean what is science?

J.D. Miller’s coding for analysis of replies to the question (see Chapter 5) suggests what H. Bauer (1994) criticises as the myth of the scientific method – that science consists of making a hypothesis, creating a method, collecting data, experimenting, analysing and interpreting the results, and drawing a conclusion. J.D. Miller’s approach is reasonable because that is how the work of science is published among peer audiences in appropriate scientific journals. This approach is taught in schools, but as the students themselves reveal in their answers to the question, H. Bauer’s criticism holds up. The students have a ‘worksheet science’ perspective – follow the scientific method formula to get a result (or the result the teacher wants to see). This is demonstrated in the fact, as mentioned in the previous chapter, that less than 4% of 692 students studied over two years used the words discover, or explore, or derivatives of those words, or phrases that could mean the same.

Only three students in the total dataset mention the word predict, or derivatives of that word such as prediction, or a phrase that could mean the same. Almost all the answers to the question *“what does it mean to study something scientifically?”* that qualify as ‘scientifically literate’ repeat the rote-learned formula (see Appendix B for a sample of such answers). Yet science is about exploration and discoveries in the natural world that enable predictions to be made based on observed patterns or effects in nature. It frequently involves accidental discoveries, unpredicted observations, insights resulting from chats over a beer, and the like. The true nature of science may be eluding most high school students.

While science does indeed have the logical formula of a scientific method running through its backbone, it is far from what frequently happens in science. While there are differences in approach and even within a single discipline, for example the modellers and experimentalists in chemistry (George, 2007), science itself is a broadly creative, often highly personal, almost ‘fuzzy logic’ style enterprise. Science often takes twists and turns, not the straight line approach of the scientific method. Discovery arises from experiences, knowledge, serendipity, the putting together of small pieces of information, the quest for new knowledge, the Eureka moment. It is set in a swamp of our humanness and all the emotions that come from that irreducible effect. Within this is the demand for objectivity, the demand for evidence, and the ability to reproduce results. An example of this less than straight path through the scientific method was demonstrated by Abigail Allwood, a former doctoral student at the Australian Centre for Astrobiology. She produced a paper in Nature (Allwood *et al*., 2006) describing a 3.4 billion year old microbial reef in the Pilbara region of Western Australia – a reef that extends partly into the area covered by the Pilbara Virtual Field Trip. What the paper does not describe is anything outside of reporting and interpretation of the observations. It does not report, for example, the Eureka moment: the night she came back to camp one evening and drew pictures in the sand of the data she had collected over several years. The picture of the reef emerged under her stick in the sand. She spent a sleepless night planning the next day to walk the ten kilometres across the hilltops to test her picture (pers. com., Abigail Allwood).

So scientific thinking allows scientists to extrapolate from evidence already garnered to create and test ideas to push back the limits of human knowledge about the natural world. In astrobiology this is often done through the exploration of space and other worlds, such as the ongoing exploration by NASA's two Mars Exploration Rovers, Project Phoenix, and the orbital Mars Reconnaissance Orbiter mission and the European Space Agency's orbital Mars Express. Evidence gained from ideas about how to collect evidence and to interpret it is slowly painting a picture of a planet that hints at the presence of subsurface water and the geological circumstances for biology now or in the past. Whether life exists on Mars today, or has in the past, is still in the realm of opinion because there is no convincing evidence either way. Nevertheless, scientists continue to search for life on Mars because scientific thinking is applied in a clear, logical and (eventually) testable basis.

In the everyday world one might argue scientific thinking is an essential tool – like literacy and numeracy – to be able to determine fact from fiction, evidence from belief, and to understand the foundation for continued research. Perhaps this reason alone is why it may be at the top of the list of 41 literacies.

8.4 THINKING SCIENTIFICALLY

Is scientific thinking synonymous with scientific literacy?

Another striking aspect of this study is that of 1,049 answers (total of entry and exit surveys) to the question "*what does it mean to study something scientifically*?" none makes the connection directly of the daily application of thinking scientifically. Yet this may be the single most important, defendable, reason as to why scientific literacy is important. An evidence-based approach to everyday decision-making could be said to be essential.

Can we correct the worksheet view of science among high school students as described above? The *Pilbara VFT* Project, demonstrated that an understanding *does* increase when students are exposed to the true nature of science – in this case a 44.1% increase, as measured by adult standards, in average scores on surveys between entry and exit over a full school term. Student interviews (previous chapter) indicate qualitatively that the understanding goes beyond 'worksheet science'. For example the comment, *"Most people (at school) see science as a lot of facts – they don't think about how it works, what does it all mean?....They don't dispute [the information] – and if they do they are going to lose points."* School science textbooks are also unhelpful sometimes in promulgating the idea of science being a static body of knowledge. For example, some school textbooks describe ancient stromatolites as being formed by oxygen-releasing cyanobacteria. Scientists now strongly doubt that was true on early Earth, though it is true now. Another example is the demotion of Pluto to a minor planet – older astronomy textbooks would count it as a planet.

8.5 SCIENCE, ENGINEERING, AND TECHNOLOGY CAREERS

There is no apparent direct relationship between scientific literacy issues and recruitment issues, at least none that demonstrate an increase in scientific literacy will result in more students in Science, Engineering, and Technology (SET) careers. As noted, Australia is among the top-performing countries in scientific literacy among 15-year-old students (Organisation of Economic Cooperation and Development, 2006a). Nevertheless, universities continue to experience declining numbers of students wanting to study science, and consequently take up a career in science. The Australian Department of Education, Science and Training, estimates that Australia will face a shortfall of 20,000 skilled Science, Engineering, and Technical workers by 2012. Increasing *interest* in science is commonly cited as a way to solve these issues, but there is no evidence that efforts to increase interest are having any effect.

There is an irony that stands out starkly against good performance in international surveys. Those Australian students taking up science may be less, or at least no more, scientifically literate than their peer group that chooses not to go into science (Keen, 2007). Keen speculates that there may be several reasons for this, including needing lower scores to get into science at tertiary level, and that those students interested in science but with higher scores may not want to waste those higher scores, or be actively turned off science by parental and/or school advisors given the higher score and potential for a well-paid career elsewhere. Universities may be therefore largely attracting the less able students into science.

8.6 FUTURE RESEARCH DIRECTIONS

The data provided in this thesis constitute a pilot study. The results reveal an inconsistency between expectation at high school and reality among the public. A larger nationwide study among Year Ten students, with rigorous sampling, is beyond the economic and logistical constraints of a single PhD thesis, probably requiring a team of researchers. Nevertheless, it would provide the kind of evidence and further questions needed to understand the scientific literacy issues both in definition and in expectations of young citizens emerging from an Australian science education.

The Australian public should be tested for scientific literacy, using current standards for the measurement of adult scientific literacy. Whatever the deficiencies of definition and measurement, such tests provide a benchmark – at least until there is an alternative – for understanding how Australia measures against adults in the US and Europe. This in turn informs a multitude of stakeholders on the effectiveness of an Australian science education.

There is another concern in relation to the expectations a scientist has when communicating his or her work. It is reasonable that if valuable research time is given up for the public communication of science, then the effectiveness of that communication needs to be measured so that improvements can be made. At the moment all communication by scientists into the public community can be little more than a hand-waving duty to report on Australian research. Therefore any Government that views science communication as essential, and/or demands its scientists give up research time to engage with the public, should also consider longitudinal data gathering on the effectiveness of that communication. This takes real resources.

Unquestionably the next steps on from this thesis concern taking a new approach to scientific literacy in the public community, and the development of a new instrument with which to measure it. If functioning as scientifically literate citizen is essential then understanding of the nature of real science should be gained in the high school environment. Also it is essential to understand how teachers and students learn about the nature of science. From such studies we may learn how to bridge the gap between high school science and the kind of authentic science experiences that are becoming possible by using new and emerging communications technologies to develop those experiences for broad use, such as those employed in the *Pilbara VFT.*

8.7 CONCLUDING COMMENT

We are on the threshold of a new discipline: data-driven public understanding of science. The field is hopelessly short on evidence. As Sless and Shrensky (2001) pointed out, the evidence we have on the effectiveness of science communication is about as good as the level of the expectation that rain is the consequence of rainmaking ceremonies. Hopefully this thesis will be one of many that will help us grasp the role and application of scientific thinking in the wider public community, and contribute to informing the many stakeholders involved in scientific literacy - to national and international benefit.

REFERENCES

REFERENCES

Abd-El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N.G., Mamlock-Naaman, R., Hofstein, A., Niaz, M., Treagust, D. and Tuan, H.L. (2004) Inquiry in science education perspectives, *Science Education,* **88(3):**397-419.

Allwood, A.C., Walter, M.R., Kamber, B.S., Marshall, C.P., & Burch, I.W. (2006) Stromatolite reef from the Early Archaean era of Australia, *Nature*, **441(7099):** 714-718.

Almond, G.A. (1960) Public opinion and the development of space technology, *Public Opinion Quarterly,* **24(4):**553-572

American Association for the Advancement of Science (1951), Executive Committee Statement http://archives.aaas.org/docs/documents.php?doc_id=241

American Association for the Advancement of Science (1989) Science for all Americans, Project 2061,*Oxford University Press,* New York and Oxford.

Australian Council for Educational Research (2007) Australian students perform well in science, but many below OECD baseline, media release, http://www.acer.edu.au/documents/MR_071204-PISA2006.pdf

Baggott La Velle, L.M., McFarlane, A.E. and Brawn, R.J (2003) Knowledge transformation through ICT in science education: a case study in teacher-drive curriculum development - case study 1, *British Journal of Educational Technology*, **34(2):**183-199.

Bailey, J. (2007) Australian Centre for Astrobiology astronomer, personal communication, December.

Barab, S.A. and Hay, K.E. (2001) Doing science at the elbows of experts: Issues related to the science apprenticeship camp, *Journal of Research in Science Teaching,* **38(1):**70-102.

Bauer, H.H. (1994) Scientific Literacy and the Myth of the Scientific Method, *University of Illinois Press.*

Bauer, M. And Schoon, I. (1993) Mapping variety in public understanding of science, *Public Understanding of Science,* **2:**141-155

Bauer, M., Allum, N. and Miller, S. (2006) What can we learn from 25-years of PUS research? Liberating and widening the agenda, *Public Understanding of Science special issue.*

Bishop, J. (data unknown) CASW History: The 5 W's of CASW, *Council for the Advancement of Science Writing,* http://www.casw.org/history.htm

Bodmer, W. (1985)The public understanding of science, *Royal Society,* London.

Borchelt, R. (2001) Communicating the Future: Report of the research roadmap panel for the public communication of science and technology in the twenty-first century, *Science Communication* **23(2):**194-211.

British Association (2002) Advice to the Office of Science and Technology from the BA, http://www.the-ba.net/NR/rdonlyres/D2123DB7-8EC6-493C-9944-30A8700662A0/0/SCIENCEINSOCIETYadvice.pdf

Bybee, R. (1998) The Sputnik era: Why is this educational reform different from all other reforms? *Forum on education,* Washington DC

http://www.americanphysicalsociety.com/units/fed/newsletters/apr98/sput.cfm
Burns, T.W., O'Connor, D.J. and Stocklmayer, S.M. (2003) Science communication: a contemporary definition, *Public Understanding of Science* **12:**183-203.
Carleton, D. (2001) Landmark congressional laws on education, *Greenwood Press.*
China Association for Science and Technology, (date unknown) http://218.241.72.36:7001/jsp/contentpub/browser/contentpro.jsp?contentid=b8b1d1e0b777&name=Science%20Popularization (accessed November, 2006).
Chinn, C.A. and Malhotra, B.A. (2002) Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks, *Science Education,* **85(2):**175-218.
Christian, C.A. and Kinney, A. (1999) The public impact of the Hubble Space Telescope, *Office of Public Outreach, Space Telescope Science Institute,* Monograph Series Number 102 http://www.stsci.edu/publinfor/PR.html
Clark, F. And Illman, D.H. (2001) Dimensions of civic science: Introductory essay, Science Communication **23(1):** 5-27.
Clarke, B.R. (2001) Strategies for improving communication between scientists and the public, *Journal of Commercial Biotechnology*, **1(8):** 51-58.
Cohen, P. (2008) Dumb and dumber: Are Americans hostile to knowledge? Article in the *New York Times*, February 14 edition http://www.nytimes.com/2008/02/14/books/14dumb.html
Collins, H. And Pinch, T. (1998) The golem: what you should know about science, *Cambridge University Press.*
Cribb, J. (2001) Former science journalist The Australian, personal communication.
Davidson, K. (1999) Carl Sagan: A life, *John Wiley & Sons, New York*
DeBoer, G.E. (1998) What we have learned and where we are headed, *Forum on Education Conference,* Washington DC http://www.americanphysicalsociety.com/units/fed/newsletters/apr98/sput.cfm
DeBoer, G.E. (2000) Scientific literacy: another look at its historical and contemporary meanings and its relationship to science education reform, *Journal of Research in Science Teaching,* **37(6):**582-601.
Department of Education, Science and Training (2006) Audit of science, engineering, and technical skills, *Australian Government summary report* http://www.dest.gov.au/NR/rdonlyres/AFD7055F-ED87-47CB-82DD-3BED108CBB7C/13065/SETSAsummaryreport.pdf
DeVore, E. (2006) Deputy Chief Executive Officer, SETI Institute, personal communication.
Dover decision (2005) Tammy Kitzmiller *et al*., V Dover Area School District, http://www.pepperlaw.com/pepper/pdfs/DoverOpinion.pdf
Dulles, J. (1957) Communication between Dulles and James C. Haggerty, http://www.hq.nasa.gov/office/pao/History/sputnik/15.html
Durant, J.R., Evans, G.A. and Thomas, G.P. (1989) The Public Understanding of Science, *Nature* **340:**11-14.

Durant, J.R. (1993) What is scientific literacy?, in *Science and Culture in Europe,* edited by John Durant and Jane Gregory, London, Science Museum pp 129-138.
Einsiedel, E.F. (1994) Mental maps of science: knowledge and attitudes among Canadian adults, *International Journal of Public Opinion Research,* **6(1):** 35-44.
Eurobarometer 55.2 (2001) Europeans, Science and Technology, http://ec.europa.eu/research/press/2001/pr0612en-report.pdf
Accessed January, 2007.
European research headlines (2006) British scientists struggling to communicate? http://ec.europa.eu/research/headlines/news/article_06_08_02_en.html
Accessed December, 2007.
Evans, G. and Durant, J. (1995) The relationship between knowledge and attitudes in the public understanding of science in Britain, *Public Understanding of Science* **4(1):**57-74.
Fata, R. (2008) quality assurance manager, Montabelo Homes, Phoenix, Arizona, private communication.
Friedman, S.M., Dunwoody, S. abd Rogers, C.L. (1986)) Scientists and journalists: Reporting science as news, *Free Press,* New York.
Gatowski, S.I., Dobbin, S.A., Richardson, J.T., Ginsburg, G.P., Merlino, M.L. and Dahir, V. (2001) Asking the gatekeepers: A national survey of judges on judging expert evidence in a post-Daubert world, *Law and Human Behavior*, **25(5):**433-458.
George, S. (2007) Macquarie University organic geochemist, private communication.
Gingrich, N. (2001) The role of federal research in the nation's prosperity and security, *National Science Board Symposium,* National Science Foundation.
Goodrum, D. and Rennie, L.J. (2007), Australian School Science Education National Action Plan 2008-2012, *Department of Education, Science and Training,* Vol 1.
Greenfield, S. (2004) Tomorrow's People: How 21st Century technology is changing the way we think and feel, *Penguin Books,* London.
Gregory, J. and Miller, S. (1998) Science in public: Communication, culture and credibility, *Plenum Trade*, New York.
Guillemette, R. (1997) Sputnik and the crisis that followed, US Centennial of Flight Commission, http://www.centennialofflight.gov/essay/SPACEFLIGHT/Sputnik/SP16.htm
(accessed November, 2006)
Harford, J.J. (date unknown) Korolev's Triple Play: Sputniks 1, 2 and 3, http://www.hq.nasa.gov/office/pao/History/sputnik/harford.html Accessed November, 2006.
Hargreaves, I. (2000) Who is misunderstanding whom? *Economic and Social Research Council,* UK.
http://www.esrc.ac.uk/ESRCInfoCentre/about/CI/CP/research_publications/index27.aspx?ComponentId=6545&SourcePageId=20656
Hargreaves, I. (2004) Towards a better map: Science, the public and the media, *Economic and Social Research Council,* UK.

http://www.esrc.ac.uk/ESRCInfoCentre/about/CI/CP/research_publications/index27.aspx?ComponentId=6545&SourcePageId=20656
Hartz, J. and Chappell, R. (1997) Worlds Apart: How the distance between science and journalism threatens America's future, *First Amendment Centre,* http://www.freedomforum.org
Hassan, G. and Treagust, D. (2003) What is the future of science education in Australia?, *Australian Science Teacher's Journal,* **49(3):**6-15.
Hazen, R.M. (2002) Why should you be scientifically literate?, http://www.actionbioscience.org/newfrontiers/hazen.html
Highfield, R. (2000) Selling science to the public, *Science,* July 7, **289(5476):** 59.
Hipkins, R., Stockwell, W., Bolstad, R. and Baker, R. (2003) Commonsense, Trust and Science, *Ministry of Research, Science and Technology,* http://www.morst.govt.nz/current-work/science-in-society/new-zealanders-attitudes/
Hodson, D. (2005) What is scientific literacy and why do we need it? http://www.mun.ca/educ/faculty/mwatch/fall05/hodson.htm Accessed August, 2007.
House of Lords Select Committee Science and Technology (2000) Science and Society: Third report of the session 1999-2000, *HM Stationery Office,* London.
Huppert, J., Lomask, S. M., and Lazarowitz, R. (2002) Computer simulations in the high school: Students' cognitive stages, science process skills and academic achievement in microbiology, *International Journal of Science Education* **24(8):**803-821.
Institute of Education Sciences (2003) Trends in International Mathematics and Science Study, *US Department of Education,* http://nces.ed.gov/timss/
Internet World Stats: Usage and Population statistics (2007) Internet Coaching Library http://www.internetworldstats.com/stats.htm
Irwin, A. and Michael, M. (2003) Science, Social Theory and Public Knowledge, *Open University Press, Maidenhead and Philadelphia.*
Ishii, M. (2002) The influence of people's liking of science at school age on their understanding of science as grown-ups, *National Institute of Science and Technology Policy,* Japan.
Jacobs, B. (2004) NASA portal makes a little bit of Mars available to everyone on Earth, *NASA press release 04-064.* http://www.nasa.gov/home/hqnews/2004/feb/HQ_04064_portal.html
Jacoby, S. (2008) The Age of American Unreason, *Pantheon Books,* New York.
Jenkins, E. (2007) School science: a questionable construct? *Journal of Curriculum Studies,* **39(3):**265-282.
Jennings, A. (2007) Fewer journalists seeking fellowships, *New York Times,* June 11, http://www.nytimes.com/2007/06/11/business/media/11fellowships.html Accessed December, 2007.
Keen, M.J. (2007) Scientific literacy of students entering university, Honours thesis, Macquarie University, Sydney.
Keighbaum, H. (1968) The diffusion of science news, in *Science and the Mass Media,* New York University Press.
Kaufman, J. (2001) A successful failure: NASA's crisis communications regarding Apollo 13, *Public Relations Review,* **27:**437-448.

Kubicek, J.P. (2005) Inquiry-based learning, the nature of science, and computer technology: New possibilities in science education, *Canadian Journal of Learning and Technology,* **31(1).**

Labinger, J.A. and Collins, H. (Eds) (2001) The one culture? A conversation about science, *University of Chicago Press.*

Laugksch, R.C. (1999) *Scientific literacy: A conceptual overview,* Science Education **84(1):** 71-94.

Launius, R. (1997) Sputnik and the Origins of the Space Age, http://www.hq.nasa.gov/office/pao/History/sputnik/sputorig.html (accessed November, 2006)

Liem, A. (2005) Promoting science literacy by engaging the public, *PLoS Biology,* **3(12):**2075-2076.

Lewenstein, B.V. (1992) The meaning of the public understanding of science in the United States after World War II, *Public Understanding of Science,* Sage Publications, **1:**45-68.

Lewenstein, B.V. (1997) Life on mars and in science, *Mercury magazine, Astronomical Society of the Pacific,* **1** Jan/Feb**,** pp 24-26.

Longino, H. (1990) Science a Social Knowledge, *Princetown University Press*, Princetown New Jersey.

Mahone, G. and Mirelson, D. (2004) NASA builds success based on the vision for space exploration, *NASA press release 04-408,* http://www.nasa.gov/home/hqnews/2004/dec/HQ_04408_year_end_review.html

Marris, E. And Powell, K. (2006) *Nature* **439** 23 Feb p 902

McIlwaine, S. (2001) Science and journalism: A Mexican stand-off?, *Australian Journalism Review,* **23:**167-188.

Miller, J.D. (1986) Reaching the attentive and interested publics for science, in *Scientists and Journalists: Reporting science as news,* eds Friedman, S.M., Dunwoody, S. and Rogers, C.L., American Association for the Advancement of Science.

Miller, J.D. (1993) Theory and measurement in the public understanding of science: a rejoinder to Bauer and Schoon, *Public Understanding of Science,* **2:**235-243.

Miller, J.D. (1998) The measurement of civic science literacy, *Public Understanding of Science,* **7:**203-223.

Miller, J.D. (2004) Public understanding of, and attitudes toward, scientific research: what we know and what we need to know, *Public Understanding of Science,* **13:**273-294.

Miller, J.D. (2006) Civic scientific literacy in Europe and the United States, *A paper presented to the annual meeting of the World Association for Public Opinion Research*, Montreal, Canada, May 17.

Miller, J.D., Augenbraun, E., Schulhof, J. and Kimmel, L.G. (2006) Adult science learning from local television newscasts, *Science Communication*

Miller, J.D. (2007) Civic scientific literacy across the life cycle, *American Association for the Advancement of Science conference,* San Francisco, Feb 17.

Miller, S. (2003) Science communication's burnt bridges, *Public Understanding of Science,* **12:**105-108.

MORI poll (2002) Public expects the impossible from science, http://www.mori.co.uk/polls/2002/science.shtml (accessed November, 2006).
NASA Astrobiology Institute (1998) Astrobiology Roadmap, http://astrobiology.arc.nasa.gov/roadmap/1998/
National Geographic Education Foundation(2006) Geographic Literacy Survey, GK Roper Public Affairs http://www.nationalgeographic.com/roper2006/pdf/FINALReport2006GeogLitsurvey.pdf (accessed December, 2007).
National Science Education Standards (1992) Scientific Literacy, http://www.literacynet.org/science/scientificliteracy.html
National Science Foundation (2002) Science and Technology: Public attitudes and understanding, *Chapter 7, Science and Engineering Indicators,* http://www.nsf.gov/statistics/seind02/pdf/c07.pdf
National Science Foundation (2004) Science and Technology: Public Attitudes and Understanding, *Science and Engineering Indicators* http://www.nsf.gov/statistics/seind04/c7/c7h.htm
National Science Foundation (2006) Science and Technology: Public attitudes and understanding, *Chapter 7, Science and Engineering Indicators,* http://www.nsf.gov/statistics/seind06/c7/c7h.htm
National Science Foundation (2008) Science and Technology: Public attitudes and understanding, *Chapter 7, Science and Engineering Indicators,* http://www.nsf.gov/statistics/seind08/pdf/c07.pdf
Nelkin, D. (1995) Selling science: How the press covers science and technology, *W.H. Freeman and Company,* revised edition from 1987.
Nemiroff, R. and Bonnell, J. (1995) Astronomy picture of the day, *NASA,* http://antwrp.gsfc.nasa.gov/apod/ap951003.html (accessed November 2006).
NetDay in partnership with the US Departments of Education and of Commerce. (2004) Visions 2020.2: Student views on transforming education and training through advancing technologies. http://www.netday.org/speakup_forstudents_2004.htm#Visions
Nielsen NetRatings (2003) http://www.nielsen-netratings.com/pr/pr_030220.pdf
Nisbet, M.C., Scheufele, A.D., Shanahan, J., Moy, P., Brossard, D. and Lewenstein, B. (2002) Knowledge, reservations, or promise? A media effects model for public perceptions of science and technology, *Communications Research,* **29(5):**584-608.
Norris, S.P. and Phillips, L.M. (2002) How literacy in its fundamental sense is essential to science literacy, *Science Education,* **87:**224-240.
Office of Science and Technology (2001) Science and the Public: A review of science communication and public attitudes towards science and technology, *Public Understanding of Science* **10** 315-330.
Oliver, C.A., Fergusson, J., Ryde, S., Anitori, R., Walter, M., and DeVore, E. (2004) Education project provides interesting results, *International Bioastronomy Conference,* Reykjavik, Iceland, July 12-16.
Oliver, C.A., Fergusson, J., Scalice, D., Evans, R.H., Gaskins, T., Walter, M.R.W. and Hogan, P. (2005) Evolving a new approach for science education using astrobiology, NASA Astrobiology Institute General Meeting, Boulder, Colorado. April 10-14, *Astrobiology* **5(2):**236.

Oliver, C.A., Fergusson, J., Bruce, G., Gaskins, T., and Evans, R. (2006a) NASA Macquarie University Pilbara Education Project: A hi-tech approach to astrobiology education, AbSciCon 2006, Washington DC March 27-30, *Astrobiology* **6(1):**241.

Oliver, C.A., Fergusson, J., Bruce, G., Gaskins, T., Evans, R. (2006b) The NASA-Macquarie University Pilbara Education Project: Connecting the public to 'science in the making' via virtual reality and the Internet, invited paper, *American Geophysical Union Fall Meeting,* San Francisco, California, December 11-16.

Oliver, C.A. and Fergusson, J. (2007) Astrobiology: Pathway to adult science literacy? Acta Astronautica, Elsevier, **61(7-8):**716-723.

Oliver, C.A., Walter, M.R. and Davies, P.C.W. (2008) How a novel international astrobiology project changed the understanding of science for almost half of the students, *AbSciCon*, Santa Clara, California, April 15-17.

Oliveira, C. (2008) Lecturer at the University of Texas, personal communication.

Organisation for Economic Cooperation and Development (2007a) Programme for International Student Assessment (PISA) http://www.pisa.oecd.org/pages/0,2987,en_32252351_32235731_1_1_1_1_1,00.html

Organisation for Economic Cooperation and Development (2007b) OECD's PISA survey shows some countries making significant gains in learning outcomes, (press release), http://www.oecd.org/document/22/0,3343,es_2649_34487_39713238_1_1_1_1,00.html

Osborne, J. (2002) Science without literacy a ship without a sail?, *Cambridge Journal of Education,* Carfax Publishing, **32:2.**

Paisley, W.J. (1998) Scientific literacy and the competition for public attention and understanding, *Science Communication,* **20:** 70-80.

Popli, R. (1999) Scientific Literacy for all citizens, *Public Understanding of Science* **8:**123-137.

Poundstone, W. (1999) A Life in the cosmos: Carl Sagan, *Henry Holt Books.*

Prime Minister's Science, Engineering and Innovation Council (2003) Science engagement and education: Equipping young Australians to lead us to the future, *PMSEIC Working Group on science engagement and education.* http://www.dest.gov.au/sectors/science_innovation/publications_resources/profiles/science_engagement_and_education.htm

Pringle, S. (1997) Sharing science, in *Science today: Problem or crisis?* Eds Levinson, R. and Thomas, J., Routledge, London.

Rahm, I., Miller, H.C., Hartley, L. and Moore, J.C. (2003) The value of an emergent notion of authenticity: Examples from two student/teacher-scientist partnership programs, *Journal of Research in Science Teaching,* **40(8):**737-756.

Raison, M. (2006) Macquarie University Science, Engineering and Technology Study, *Macquarie University.*

Rees, M. (2002) Science, communication, and the media, *Interdisciplinary Science Reviews,* **27(1):**10-12.

Rennie, L.J. and Williams, G.F. (2002) Science centers and scientific literacy: Promoting a relationship with science, *Science Education,* **86(5):**706-726.

Rensberger, B. (2000) The nature of science, *Science,* **289(5476):**61.

Rensberger, B. (2002) Reporting science means looking for cautionary signals, *Nieman Reports,* **56(3):**11-13.
Rensberger, B. (2003) Science journalist. Personal communication.
Roper Center for Public Opinion Research Data Archive (accessed 2008) US studies of the Public Understanding of Science and Technology, articulation chart of variables, *Principle investigators J.D. Miller and L. Kimmel, International Center for the Advancement of Scientific Literacy.*
Roth, W-M. And Lee, S. (2002) Scientific literacy as collective praxis, *Public Understanding of Science,* **11:**33-56.
Royal Society (2006) Factors affecting science communication: a survey of scientists and engineers, http://royalsociety.org/page.asp?id=3180
Accessed November 2007.
Rutherford, F.J. and Down, A.G. (1995) *The new quest for science literacy,* http://www.cosmos-club.org/web/journals/1995/rutherfd.html Accessed October 2007.
Sagan, C. (1994) Pale Blue Dot, *first published by Random House, 1994, First Ballantine Books Edition: September, 1997.*
Sagan, C. (1996) The demon-haunted world: Science as a candle in the dark, *Ballantine Books,* New York.
Siddiqi, A.A. (1997) Korolev, Sputnik, and the International Geophysical Year, http://www.hq.nasa.gov/office/pao/History/sputnik/siddiqi.html (accessed November, 2006).
Schwartz, R.S., Lederman, N.G. and Crawford, B.S. (2004) Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry, *Science Education,* **88(4):**610-645.
Science magazine press release (2004) Discovery of Mars' watery past hailed by Science as breakthrough of the year, *AAAS,* December 16. http://www.aaas.org/news/releases/2004/1216bt.shtml
Selby, J. (2004) *Quiet your mind*, Inner Ocean Publishing Co p20.
Shamos, M.H. (1995) The myth of scientific literacy, *Rutgers University Press,* New Brunswick, New Jersey.
Shapin, S. (1992) Why the public ought to understand science-in-the-making, *Public Understanding of Science,* **1:**27-30.
Shapiro, W. *(1997)* Running Scared, *in World's Apart, eds Hartz. J. and* Chappell, R. pp 61-63 *First Amendment Centre,* http://www.freedomforum.org
Sky & Telescope (1989) Scientific illiteracy – the movie – a private universe, **77:**586
Sless, D. and Shrensky, R. (2001) *Science Communication in Theory and Practice,* eds Stocklmayer, S., Gore, M.M. and Bryant, C.R., Kluwer Academic Publishers.
Smith, K. (2006) Literacy and numeracy foundations of education, http://education.qld.gov.au/marketing/publication/edviews/html/art-2006-16-03.html
Accessed December 2007.
Snow, C.P. (1998) The Two Cultures, *Cambridge University Press,* first published 1959, 31st reprinting.
Snyder, L. (2006) William Whewell, *Stanford Encyclopedia for Philosophy,* http://plato.stanford.edu/entries/whewell/ (accessed November, 2006).

Special Eurobarometer (2005) *Europeans, Science and Technology*, http://ec.europa.eu/public_opinion/archives/ebs/ebs_224_report_en.pdf
Stocklmayer, S. (2001) *Reaching the public – communicating the vision*, in Science Communication in Theory and Practice, eds Stocklmayer, S., Gore, M.M., and Bryant, C.R., pp 143-150, Kluwer Academic Publishers.
Stootman, F. (2008) Physicist, University of Western Sydney, personal communication.
Sturgis, P. and Allum, N. (2004) Science in society: re-evaluating the deficit model of public attitudes, *Public Understanding of Science,* **13** pp 55-74.
Swinehart, J.W. and McLeod, J.M. (1960) News about science: Channels, audiences, and effects, *The Public Opinion Quarterly,* **24(4):**583-589.
Thagard, P. (1994) Mind, society and the growth of knowledge, *Philosophy of Science,* **61:**629-645.
Thomas, G. and Durant, J. (1987) Why should we promote the public understanding of science? *In M. Shortland (Ed), Scientific Literacy Paper: A Journal of research in science, education, and research,* (pp. 1-14). Oxford: Oxford University Department for External Studies.
Thomson, S. and De Bortoli, L. (2008) Exploring Science Literacy: How Australia measures up, *Australian Council for Education Research Press.*
Triese, D. and Weigold, M.F. (2002) Advancing Science Communication, *Science Communication,* March **23(3):**310-322.
Triese, D., Walsh-Childers, K., Weigold, M.F. and Friedman, M. (2003) Cultivating the science Internet audience: Impact of brand and domain on source credibility for science information, *Science Communication,* **24(3):**309-332.
Trindade, J., Fiolhais, C. and Almeida, L. (2002) Science learning in virtual environments: a descriptive study, *British Journal of Educational Technology*, **33(4):**471-488.
Tytler, R. (2001) Dimensions of evidence, the public understanding of science and science education, *International Journal of Science Education,* **23(8):**815-832.
United States Information Agency (1959) Impact of US and Society space programs on world opinion, http://www.hq.nasa.gov/office/pao/History/sputnik/july59.html
United States Department of Education (2004) Trends in International Mathematics and Science Study, http://nces.ed.gov/pubs2005/2005005.pdf
Valenti, J.M. (1999) How well do scientists communicate to the media? *Science Communication* December **21(2):**172-178.
Van der Sanden, M.C.A. and Meijman, F. J. (2004) Evidence based science communication: an essay, *Science Communication* **25(3):**272-87.
Van der Sanden, M.C.A. and Meijman, F.J. (2008) Dialogue guides awareness and understanding: an essay on different goals of dialogue leading to different science communication approaches, *Public Understanding of Science,* **17:** 89-103.
Van Dijck, J. (2003) After the “Two Cultures”, *Science Communication,* **25(2):**177-190.
Webster, G. (2004) NASA rovers’ adventures on Mars continue, *NASA press release 2005-001,* http://marsrovers.nasa.gov/newsroom/pressreleases/20050103a.html

Wagner, W. (2007) Vernacular science knowledge: its role in everyday life communication, *Public Understanding of Science,* **16:**7-22.
Walter, M.R., Buick, R. And Dunlop, S.R. (1980) Stromatolites 3400 – 3500 Mya old from the North Pole area, Western Australia, *Nature,* **284:**443-445.
Warne, M., Owies, D., and McNolty, G. (2004) Exploration of a first year university multimedia module on field geology. In R. Atkinson, C.McBeath, D.Jonas-Dwyer & R. Phillips (Eds), Beyond the comfort zone: *Proceedings of the 21st ASCILITE Conference* (pp-924-933). Perth, 5-8 December. http://ascilite.org.au/conferences/perth04/procs/warne.html
Weigold, M. (2001) Communicating Science: A review of the literature, *Science Communication,* December **23(2):**164-193.
Wertheim, M. (1995) Pythagoras' Trousers, *Fourth Estate,* London.
Withey, SB. (1959) Public opinion about science and scientists, *The Public Opinion Quarterly,* **23(3):**382-388.
Wolfendale, Sir A. (1995) Report to the committee to review the contribution of scientists and engineers to public understanding of science, engineering and technology, *HM Stationery Office,* London.
Wynne, B. (1992) Public understanding of science research: new horizons or hall of mirrors, *Public Understanding of Science,* **1:**37-43.
Ziman, J. (1991) Public understanding of science, *Science, Technology, & Human Values,* **16(1):**99-105.

APPENDICES

APPENDIX A: Survey instruments

2005 Project high school students (entry survey)

NAME____

Female/Male (circle one)

Here are some general questions about how you feel about science. In questions 1-4 please tick one answer. Thank you!

1. Do you like science?

   - Yes
   - No
   - Don’t know

2. If yes, which science do you like best? If no which science do you like least?

   - Physics
   - Chemistry
   - Biology
   - Earth sciences
   - Astronomy

3. Are you thinking of studying science at university?

   - Yes
   - No
   - Don’t know
   - May take some science subjects
   - Not intending to go to university

4. Are you staying on to Year 12?

   - Yes.
   - No
   - Don’t know yet

5. Tick all of the following you think is science related:

   - Cooking

- Gardening
- Flying in a jet aircraft
- Robots on Mars
- Exercising

(question 5 continued)

- Using a computer
- Astronomy
- Astrobiology
- Astrology

6. Please write one or more sentences on this question: What do you think it means to study something scientifically?

____
____
____
____
____

Here are some questions about science. In each case please tick which answer you think would be the *best choice* or the *most probable.*

How do we know the Earth goes around the sun?

If you watch the sun, it rises in the morning and sets in the evening. It seems the sun goes around the Earth. But, in fact, we know it is the Earth moving around the sun, not the sun moving around the Earth. Which of the following best provides the proof the Earth does move around the sun?

1. The sun rises and sets at different times every day: Make a measurement of this and the changes will show the Earth moves around the sun.

2. Measure the tiny apparent movement of nearby stars against the starry background at two six-monthly intervals. If the Earth is moving around the sun in a large orbit, a change will be observed.

3. Observe the other planets in the solar system to see if they are orbiting the Earth or the sun, because if they are orbiting the sun, so must the Earth.

How does probability help in a game of chance?

A game is played with two coins being flipped. Sometimes the coins both land heads up, sometimes both tails up, and sometimes one coin is heads up and the other tails up. The two coins are flipped together. Which of the results is most likely?

1. Both heads up

2. Both tails up

3. One heads up, one tails up

How can researchers best test a life-saving drug?

Researchers wish to test what might be a life-saving drug. They have got to the point where the next step is to test with 1,000 human subjects who suffer the disease the drug could cure. Which of the three below approaches would give the most accurate result?

1. Randomly give the drug to 500 among the 1,000 so not only do the participants not know whether they are getting the drug or not, but the researchers directly involved with the study do not know which of the 500 received the drug.

2. Split the group into two, giving 500 the drug and 500 a sugar pill.

3. Give the drug to all 1,000 test subjects to see if an improvement takes place.

Why do balloons with gas in behave differently to those just inflated with air?

What would be the best explanation for why balloons filled with gas will zoom away if you don’t hold onto them, which air-filled balloons just float gently to the ground if there is no breeze?

1. The gas inside is lighter than the air outside.

2. A little bit of the gas inside is constantly leaking from the gas-filled balloon, providing an upward thrust, a little like a rocket.

3. The pressure inside the gas-filled balloon is different to the outside air pressure.

Why does New Zealand have so many earthquakes?

Records show that New Zealand has many more earthquakes than Australia. What is the best explanation?

1. New Zealand is positioned upon a tectonic plate boundary

2. New Zealand has active volcanoes where as Australia has none.

3. New Zealand has more fault zones than Australia

NAME___________________________________

Female/Male (circle one)

SCHOOL_________________________________

Here are some general questions about how you feel about science.

1. Will you study science in Year 11?

    - Yes
    - No
    - Don't know

2. If yes, which science(s) will you study?

    - Physics
    - Chemistry
    - Biology
    - Earth sciences
    - Astronomy

3. Since the first survey, have you changed your mind about studying science at university, and will now undertake at least some science subjects or a degree in science?

    - Yes
    - No
    - Not intending to go to university

4. Please write one or more sentences on this question: What do you think it means to study something scientifically?

____

____

____

____

____

____

____

Here are some questions about science. In each case please tick which answer you think would be the *best choice* or the *most probable.*

How can parents' genes affect their babies?

A husband and wife want to start a family, but their doctor advises their baby has a one in four chance of receiving a defective gene that will lead to serious illness later in life. Which interpretation of that advice is the right one?

1. The first child has the defective gene, to the next three children will be healthy

2. If the couple have three healthy children, they should not have a fourth because the child will have the defective gene.

3. All four babies have an equal chance of inheriting the defective gene.

When will an asteroid next hit the Earth?

Asteroids – pieces of space rock from the size of a large house upwards – hit the Earth one every million years, on average. The last asteroid impact was a million years ago. Which of the following is the most accurate interpretation of that?

1. We should expect an asteroid impact within the next 100,000 years.

2. We should expect an asteroid impact within the next 1,000 years.

3. We should expect an asteroid impact within the next 100 years.

Ice floating in water

Ice is water in its solid form, so why does it float in liquid water?

1. The air bubbles trapped within the ice give it buoyancy.

2. Ice is less dense than liquid water.

3. Ice is colder than liquid water.

Cold germs and a science experiment

A researcher cultures microbes at the same time as she has contracted a cold. How can she be sure the culture is not contaminated by the cold?

1. She makes sure she doesn't sneeze near the culture cannot contain any cold-related bacteria

2. She is certain the culture cannot contain any cold-related bacteria.

3. She tests the culture for cold-related bacteria.

Why are fish fossils found on Everest?

Recently fish fossils were discovered near the summit of Mt Everest. How did they get there?

1. Tectonic plate activity has lifted Everest from under the sea.
2. They came from a time when the sea level was higher.
3. They were the remnants from meals of the first successful climbers of Everest.

These are questions about the Pilbara virtual field trip project, which you have seen only in part as we explore these new concepts in science education learning experiences:

1. What were your overall impressions of your experience with us on this project?

2. What should we include/exclude from the eventual whole virtual field trip?

3. What were your overall impressions of the NASA tools?

2006 Project high school students (entry survey)

Name:

Please circle one. **Male** **Female**

1. Do you like science?

 - ☐ Yes
 - ☐ No
 - ☐ Don't know

2. If yes, please tick which sciences you like. If no please go onto question 3.

 - ☐ Physics
 - ☐ Chemistry
 - ☐ Biology
 - ☐ Earth sciences
 - ☐ Astronomy

3. Are you intending going onto university?

 - ☐ Yes
 - ☐ No
 - ☐ Don't know yet

4. IF you answered 'yes' to question 3 will you take at least some science at university?

 - ☐ Yes
 - ☐ No
 - ☐ Don't know yet

5. Do you have access to the Internet at home?

 - ☐ Yes
 - ☐ No

6. IF yes what kind of connection do you have?

 - ☐ Dial-up
 - ☐ Broadband

These next two questions are for those who have home Internet access. If you do not, please go question 9

7. Do you use the Internet at home for your homework?

 Yes
 No

8. What other uses do you make of the Internet?

 IM
 E-mail
 Chat room
 Finding information NOT related to school work
 Playing online games

The next questions are for all students:

9. Thinking about how science is undertaken, what do you think it means to study something scientifically? Please write one or two sentences.

____

____

____

____

____

10. Here are some questions about science. In each case please tick which answer you think would be the *best choice* or the *most probable*.

How do we know the Earth goes around the sun?

If you watch the sun, it rises in the morning and sets in the evening. It seems the sun goes around the Earth. But, in fact, we know it is the Earth moving around the sun, not the sun moving around the Earth. Which of the following best provides the proof the Earth does move around the sun?

1. The sun rises and sets at different times every day: Make a measurement of this and the changes will show the Earth moves around the sun.

2. Measure the tiny apparent movement of nearby stars against the starry background at two six-monthly intervals. If the Earth is moving around the sun in a large orbit, a change will be observed.

3. Observe the other planets in the solar system to see if they are orbiting the Earth or the sun, because if they are orbiting the sun, so must the Earth.

How can researchers best test a life-saving drug?

Researchers wish to test what might be a life-saving drug. They have got to the point where the next step is to test with 1,000 human subjects who suffer the disease the drug could cure. Which of the three below approaches would give the most accurate result?

1. Randomly give the drug to 500 among the 1,000 so not only do the participants not know whether they are getting the drug or not, but the researchers directly involved with the study do not know which of the 500 received the drug.

2. Split the group into two, giving 500 the drug and 500 a sugar pill.

3. Give the drug to all 1,000 test subjects to see if an improvement takes place

Why do balloons with helium gas in behave differently to those just inflated with air?

What would be the best explanation for why balloons filled with gas will zoom away if you don't hold onto them, while air-filled balloons just float gently to the ground if there is no breeze?

1. The gas inside is lighter than the air outside.

2. A little bit of the gas inside is constantly leaking from the gas-filled balloon, providing an upward thrust, a little like a rocket.

3. The pressure inside the gas-filled balloon is different to the outside air pressure.

Why does New Zealand have so many earthquakes?

Records show that New Zealand has many more earthquakes than Australia. What is the best explanation?

1. New Zealand is positioned upon a tectonic plate boundary.

2. New Zealand has active volcanoes where as Australia has none.

3. New Zealand has more fault zones than Australia

2006 Project high school students (exit survey)

Name:

1. Overall, what rating would you give the technologies you used today as learning tools?

    - ☐ Excellent
    - ☐ Good
    - ☐ Average
    - ☐ Poor

2. Thinking about the Pilbara and looking for life on Mars and using these technologies to learn about that, how would that compare to the way you normally learn science at school?

    - ☐ Very much better
    - ☐ Better
    - ☐ About the same
    - ☐ Less well

3. Would you use these technologies at home if this was not set as homework?

    ☐ Yes – all of them

    ☐ Yes – one or more (please underscore those you'd use: Virtual Field Trip and wiki, Virtual Lab, What's the Difference, World Wind)

    ☐ No

    ☐ Don't know

4. What did you think of the tools? Please write one or two sentences:

____

____

____

____

____

5. What kinds of technologies would you like to see developed to help you learn about science and how it is undertaken?

6. IF you intend to go to university, will you now take at least some science at university as a result of today's experience?

 Yes

 No

 Don't know

 I was already intending taking some science at university

This last question repeats one from this morning. It is asked again now you have had the chance to experience the tools in the project and listened to some of the scientists involved.

7. Thinking about how science is undertaken, what does it mean to study something scientifically?

APPENDIX B: Survey answers

Entry survey answers to the question: *"What does it mean to study something scientifically?"* (Note all are reported verbatim, including grammar and spelling errors)

Project Group 2005: *n=64*

I think to study something scientifically is to INVESTIGATE, research and to find a logical explanation and resolution to answer a problem.

I think it means to learn more about something or to find a solution using science.

I think that it means to study something in detail and using scientific equipment and ideas

I think that studying something scientifically is to study something that is logical and is backed up by PROOF.

It means using facts and EVIDENCE to ANALYSE something. A THEORY may be though up if and then scientists try to PROVE or DISPROVE of further study the topic or issue.

To study in more detail using facts and PROOF to figure something out. To ANALYSE these facts and EVIDENCE so scientists and prove the issue.

To look more in depth into the chemical or object and to see what or who put it there and why it is there.

To study something scientifically would be to look at it in details and understand and OBSERVE its properties.

To study something scientifically I think it means you study something in depth, knowing every key detail about it in scientific areas. Eg to study life on Mars you go through processes to make DISCOVERIES and OBSERVATIONS.

To study something with OBJECTIVITY, accuracy in the hope of increasing understanding of an area

Using logical formulas to explain something using EXPERIMENTS to explain something.

To study something scientifically means to ANALYSE and OBSERVE something. You conduct EXPERIMENTS and note changes, growth, movement, power and more.

Research, ANALYSE, TEST, write a report.

I think it means finding its origins and how it works.

It means to find a thing's origin and how it works.

It means to find a thing's origin and how it works.

OBSERVING something and then recording your observations and making a conclusion from your results.

To study all the aspects of a subject from a scientific point of view.

To find facts that provide EVIDENCE.

To study something with the intent to gather scientific results.

To look at it from a scientific point of view and try to learn or connect things together.

OBSERVING what you are studying and also recording results and observations so that comparisons can be made at a later date.

Conducting EXPERIMENTS, TESTING, THEORIES, researching facts, applying knowledge, ANAYLSING matter.

To do research using EXPERIMENTS etc to find some RESULTS.

To DISCOVER and learn how our body functions, origin of life, manipulating chemicals. In other words gaining a more accurate understanding of how things work.

To study scientifically means to study something in particular with the aid of EXPERIMENTS, VARIABLES etc

To study something scientifically is to ANALYSE it, EXPERIMENT with it, describe its functions and results.

To study something scientifically you must make accurate OBSERVATIONS, take into account the VARIABLES and record the results so they are easy to read.

It refers to you examining topics or objects in a logical perspective and find answers to how, why, what happens etc.

Studying something scientifically is finding out the facts and using creative and effective methods to PROVE a HYPOTHESIS.

To study something in great detail possibly TESTING THEORIES and methods to find a scientific conclusion.

It means to ANALYSE it logically against PROVEN models or THEORIES to try and prove or DISPROVE a certain HYPOTHESIS.

It means to OBSERVE and carry out your studies from a scientists' point of view. It should include most scientific terms and a use of logic and understanding of the subject.

To study something in detail. Eg to study how a plant grows is scientific.

To have a CONTROL group as well as you VARIABLES. To also OBSERVE and collect data.

To study something is to INVESTIGATE and TEST a THEORY or an object to find out as much information as possible. This improves our understanding.

To extensively research something and repeat the method several times to have a more exact result.

To form an exact result or conclusion in answer to a need or requirement and to obtain these results in an ethical manner.

To look into something from a factual point of view in how it works, why it works etc. Is much more factual than personal INTERPRETATION but HYPOTHESIS thought up and TESTED.

To study something scientifically is to properly ANALYZE something based on OBSERVATIONS, EXPERIMENTS etc.

To study something scientifically, there will have to be CONTROLLED EXPERIMENTS or collected PROOF with a lot of data collecting, and a lot of PREDICTIONS made based on the information gathered.

Scientifically studying something means you OBSERVE and TEST one or more subjects to PROVE, DISPROVE or support a certain HYPOTHESIS. Take notes, test, observe over a period of time, collect data to prove something.

To study something scientifically would mean to research into what you are studying, conduct various TESTS and EXPERIMENTS on the subject to make.

OBSERVATIONS and to draw conclusions about the subject so we can find out as much information as possible about the subject.

To learn how something works, why it works and how we can use it.

To make an educated guess of what will happen then set out to PROVE if you are wrong or right. If you are wrong then find out why.

It means to research and do EXPERIMENTS on a subject for the purpose of gathering information or knowledge about the subject.

Research it and come up with explanations. I don't really know.

To study something scientifically is to look at it and examine it in every way from every angle possible. And then to make statements about it.

Look at in detail at every aspect to understand what it's about.

To study something scientifically means to OBSERVE a particular object or place with great detail and find information on why things act the way they do.

To me this means to study a certain area of science by doing EXPERIMENTS and just generally all things like that.

To study something scientifically is to look and OBSERVE characteristics, take notes on particular actions and occurrences to the object being studied. Once studied the object can be correctly identified and PREDICTIONS can be made.

To study something scientifically is to OBSERVE and research that topic.

To study why or how something does anything. Look at how it happens or why.

When you are studying something scientifically it means you are using information around you and your own to develop with THEORIES and solutions.

To study something scientifically is to thoroughly examine something using scientific means, for example, EXPERIMENTING.

To OBSERVE different properties of something, how something was formed, history of objects.

To study something using scientific research and facts.

To study scientifically means to find out how and why it works.

To INVESTIGATE and find out how and who something is as it is.

To study something scientifically is to use a SCIENTIFIC METHOD eg the method/ the HYPOTHESIS.

To study something scientifically means to study a scientific subject.

To study something scientifically a series of processes must be undertaken in order to better understand how something works, or to improve it.

Studying something scientifically is to ANALYSE it. So we can learn why is works, how it works, its purpose and to expand our understanding.

Non Project Group 2005: *n=309*

I don't know..

To study something scientifically you might carry out EXPERIMENTS e.g. OBSERVING and the results

To study really hard, and find as much information as you can.

To study it very closely with a lot of care.

Use the formula to do everything

To learn some of usefully things and real things (sic)

To study something scientifically is to solve it using science.

It means to study it with great detail and to find out all the bits and pieces to it.

To study it into fine detail.

Don't know coz I'm not that smart - sorry

To study something in depth.

Well good question. Frankly I think I should be in the fire brigade when I am older.

It means that you're interested in science, so you want to study it

Don't care

To look at it and take it down to the smallest thing and find where they come from

It means to get a better idea of how thinks work and how to make things better. And find out exact answers

Nothing at all

Study something scientifically means that you use technology.

I think it really boring and you shouldn't do science if you really want to do (sic)

To get a better understanding of it. To get a different perspective.

I do not know

Check things out INVESTIGATE as deep as possible

I think it means studying something beneficial to most career choices in life

to find out all the facts about the thing where it came from why it's here etc

Deep research done, understanding of all aspects of subject, able to define and describe any occurrences with reason

To add your knowledge you can know more things in science on the earth

I don't really care I hate science shouldn't be compulsory should only be if you want to be a gay scienticians but good-luck to the one who want to become scienticians

Study something extensively and create formulas to explain how things work.

Take a dump then look at it for a while

It means to study something scientifically is to do a research project on a specific topic and found out who, what, how and why and the reasoning behind it

To look at it in detail from scientific perspective.

It means to study something using scientific resources

Studying something in detail, finding how it works and why it works

To find out everything about an object or organism.

Studying something scientifically means to look at things from all angles and other possible solutions.

It means to study what the affects are and how they affect

To research the effectiveness of the earth and its environment.

I don't know

To have an interest in it.

I don't know.

Thinking about the question, go in depth of the topic

To study the science of something

To research something and find out how it works and why it works/doesn't work

To make an informed decision on facts

It means doing funky things with chemicals and computers and stuff. I chose the last 3 words because they look like fancy scientified words.

To do science on it

To look at it in detail from a scientific perspective

Find out how and why things work

I think it means to study something scientifically is good.

To study it carefully.

Really boring and something I don't think should be compulsory unless the student intends on pursuing a career in science. To be studying scientifically is to be studying about chemicals and all that boring stuff.

I think that it is to get all scientific facts on

I am not really know. Sorry. (sic)

I don't know.

I think it means to study something in great detail and go a lot further into something rather than just looking at the surface and what everyone normally sees

This is a trick question isn't it? I have no idea but I hate the science topic

Go in to a lot of detail, study a lot of it

So boring and shouldn't be compulsory to study it's pointless to what I want to do as a career

Study something extensively and create formulas to explain how things work and happen

Research its structure. Anything hard and complex

To study something and look at all the things that make it into that one thing

Wouldn't have a clue

To study something scientifically is to perform experiments to test your HYPOTHESIS.

Its boring and you shouldn't do science unless you really want to do it.

A lot of concentration, time, and a passion for what you are studying.

Being heaps smart. Being a nerd

No

I don't know.

It means a lot but its so boring. Too much writing.

Sciences cover all aspects of life on earth therefore studying science will help to understand the world in its past present and future.

Read books and study the world

It means to study something and try and get a better idea on the way many things in the world work

I think it means to do into depth with something that involves the creation of something or what it's turned into

To look at things logically. Pull things apart and study them. Work things out using the science in whatever is.

Check things out INVESTIGATE as deep as possible

To use scientific machines and learn about stuff that involves something like astrology or biology.

If you want to be a scientist and DISCOVER things

To INVESTIGATE it in a thorough manner

To conduct EXPERIMENTS and write down and results - also studying science text books.

To ANALYSE something

It means to draw a HYPOTHESIS, conclusion

To ANALYSE and find out a lot about it, by studying the way in which it works

It means to study something to get a better idea of how things work, move. It involves TESTING and researching information

To ANALYSE and record the conclusion.

Studying and OBSERVING the matter closely

Being very smart and have the right standards and also OBSERVE the matter closely

I think it means to find out all the facts on it and to do EXPERIMENTS.

Using all the methods scientists use (like HYPOTHESIS, aim, method, results and conclusion).

You want to know how thing work and like DISCOVERING new (sic)

To ANALYSE it

It means you study in detail with scientific EVIDENCE using data

OBSERVE things and write stuff

To gather information by either research or by EXPERIMENTATION until you get the result ANALYSE something and take data E=MC2.

Process something

To study something in depth using many methods

To do a scientific EXPERIMENT

I think it means you INVESTIGATE the workings of it. How it works, is designed etc. You work it out logically

To study something scientifically I think is to study and run EXPERIMENTS on a subject

Study something with scientific knowledge PROOF and understanding

When you study scientifically it means you go into detail or try and find the answers to questions or THEORY.

To look at something and study all the facts and reaction to collect data, process and EVALUATE.

To look at write OBSERVATIONS and conclusions about the nature and organisms that surround us.

You have to research, do EXPERIMENTS and to look at everything thats got to do with science

To do TESTS or EXPERIMENTS

To study it using scientific methods science or to PROVE a HYPOTHESIS.

To study something scientifically is to collect data, process and EVALUATE it.

To OBSERVE and record data from a specific EXPERIMENT

It means to HYPOTHESISE, OBSERVE, and reach a conclusion by using a series of scientific questions and methods.

To study science means INVESTIGATING, EXPLORING and finding answers to questions of nature and the elements. Study something scientifically needs patience, keen OBSERVATION and perseverance

To study something scientifically means to think something through thoroughly and have an aim, HYPOTHESIS, method and result

OBSERVE, ANALYSE and EXPERIMENT to find things or PROVE things

THEORIES and EXPERIMENTING different thing. Scientists us a HYPOTHESIS to INVESTIGATE or study something

Science can help you on many things but some people don't like it because they are not good at it.

Study scientifically usually always good and specially for people who want to be nurse or doctor. (sic)

Studying something about science

To find out more about something and about its environment

It means study something about science

Science is in everything. So to study anything would be to study something scientifically

Study something scientifically is finding out information about everything that is related or concern that study.

To study something using science

Anything to do with science

Study hard. Don't know.

Being at school and sit there learning stuff that I'm not going to use again.

I think it means to look at something using scientific resources to study it

That means to find out how things and our life borned and how we can live better in today's life! (sic)

To study something scientifically is to study a certain topic of science and get a better understanding of it

Environment, life, everything in details

It means studying something that has to do with living, how things work and life.

To research something or an issue related to science

You study some facts

Research, study molecular construction, have interests in a research background

It means you study something using informed decisions on facts

I think it means hope in finding new things that have not been done or found before.

It mean to find more about something in different ways (sic)

Find more information about something in different ways.

I think it is to find out the different outcomes.

To look into it really hard and it's a science thing.

To study something deeply

To study scientifically is to use a know method or an unknown one to find out more about that scientifically.

It means to study something from a view of science. Also using science to explain it. Research, study all parts in detail.

To ANALYSE science stuff.

To study a project ANALYTICALLY and in the perspective of science.

To study something scientifically means to ANALYSE data.

Find out what or how a thing works properly and do EXPERIMENTS to help that.

They do EXPERIMENTS to find out what they want to know

To EVALUATE something in all its areas

It could mean all different things you look and ANYLISE (sic) things and how they work or function.

To answer a question with giving EVIDENCE.

It means to study everything from a strategic and scientific point of view, utilising scientific procedures.

To look at it very closely and deeply and INTERPRET it.

Look at all the aspects of that certain thing (sic). OBSERVING.

To ANALYSE and EXPERIMENT with it.

EXPERIMENT and ANALYSE the subject create an aim to achieve, etc

To scientifically study something would be to DISCOVER how something works, and to EXPERIMENT with it to get results.

To study in detail and to try and PROVE or DISPROVE something.

To OBSERVE, ANALYSE, results.

To OBSERVE, ANALYSE the results.

THEORIES and EXPERIMENTING different things.

To find VARIABLES and CONTROL the science is this world. To get rid of all the terrorists and find the dangers in their head.

To look at it in many different ways. Study how it affects is surroundings etc devising a HYPOTHESIS, carrying out TESTS, using a CONTROL, coming to a conclusion.

To study something scientifically, OBSERVE, EXPERIMENT, ANALYSE.

To choose something to TEST for in a CONTROLLED manner to achieve results. Then using these results to improve or INVESTIGATE something is to study something scientifically.

OBSERVING, EXPERIMENTATION, recording, TESTING

To study something scientifically, you OBSERVE, have an aim, HYPOTHESIS, method and a result. Therefore you take out EXPERIMENTS.

To study something scientifically, is to look at all the components of an object. To break it down and see what is what and to understand or get a better view of what the object is/how it works etc

It means study on things like animals to biology studying stuff from like stars etc

Take results and stuff

It means to study something means to do something that relates to something

To study something scientifically is to study about things that is happening around. (sic)

Study something scientifically is to study about science that we don't know about anything in science and try to study to learn (sic)

Is to study something that involves depth and experiences to find the answer.

To study something scientifically means to study the more technical sides of how things work etc.

To study something scientifically means you study something really well and in high level of studying.

I don't know

It means to do a lot of research and practical to gain an outstanding result.

To study something that has to come from somewhere

To look at something in depth and search for things that alter its existence such as how it eats, how it grows and how it's evolved over time

I think it means that you look into everything and you see how it works and what it's made out of, things like that

It means to study something that relates to science.

To study something in detail using scientific formulas to figure out things.

I don't understand this question because I am not good at English.

I think it means that it would help the way we live and to know what is going around us.

I think it means to study something scientifically, you have to love what your studying because if you want to succeed in life you should do what you love to do. To study something scientifically you have to use your senses to answer questions of nature.

I think it is good. It helps to understand certain things more easier and better through more accurate views.

I don't know

Deep research alone, understanding of all aspects of subject, able to define, describe any occurrences with reason.

To study something with an eye that seeks to learn how it works, what it I, how it came to be and what it will be.

Find out different ways to cure people; different planets; the body

For me it means to study something that involves science. Like the orbits of the planets, how chemicals are put together and other stuff that historical study can't answer.

Looking beyond what you see

It means that science is a very educated thing to study to learn more about whats around us of whats been going on all over the universe. (sic)

To learn some real things and know the truth.

It is everything in our day to day lives.

To learn further into it and the scientific reasons of this case

To work out every last detail, any really studying what happened in a chain on how changes happen what happens and when it is changing

To have a bit of interest in life.

To delve into the object of study to farther information.
.
To understand how something works in a scientific way.

It means to get a better understanding of things on or off this planet.

To explain something in a deeper way, not only explaining what something is but how it works and why.

You want a carrier (sic) in it or something to do with science!!!

To study something scientifically means to study its behaviour, body parts and its environments.

All over the subject and relationship between the science (sic)

To learn about science, think scientifically and research about science.

To study its origin, function, habitat and effects and also if it could be used for other things, basically its whole existence.

I think it means to study something more in depth rather than just look at it

To study something scientifically gives you answer which is backed with ideas relevant to the question.

To study something scientifically means to study that thing in the real way and to know the fact about that thing. Because only the science know the right facts

I think it means that the hypothetical constitions (unreadable) itself to conquer once or more in the motivational skills of the environment.

This dilapitates the emotional beings of one another and therefore cannot be installationized (sic)

To me it means studying a subject that reads and interconnects with science

To collect data on it and then organise it *

It means some type of science being studies. I really don't know

To INVESTIGATE the fact and information delving into depth and researching the facts and sources thoroughly

It mean to learn about how things work and why they work.

No answer given.

It means to understand something at a deeper and more intense level. To look at all possibilities.

To study all characteristics of what you studying and to understand and develop THEORIES ?????

Research on it, how it works, why it works and everything that effects it.

Studying something closely and use formulas. (sic)

Studying scientifically means that you use your knowledge in the science field eg physics, chemistry, biology to make something or learn how things are made.

When something can happen every time and we can explain about that. That is scientifically. (sic)

To study something like how it does some things like how a human makes a scar that’s scientifically studying something.

Yes

Studying something according to science and not by myth and doesn't have any science explanation

To break something down and see how it works and find the science in it

why do you need to know (unreadable)

To look at the facts, look at the reasoning behind.

To study something scientifically means to learn about something to a large extent using formulas, methods, etc

It's great to study scientific stuff. Science is everywhere in our life so it must be very helpful.

Go into more detail

To study something using loads of science and scientific methods.

To go into detail in something studying science

I think it means to study scientifical things, statements

You learn more about the world you live in and how things work. It is also extremely interesting and fun at the same time.

To research into scientific studies and to break something down into its research components

To study something scientifically I think means to research or reason why stuff is the way it is and what happens in great detail.

To take an open-minded approach to something.

Study something like chemistry or physics etc

To study something scientifically you do a lot of research on it

I don't know

Something to do with science

To study something scientifical means to find out how it works and what makes it so

Studying science related topics like the earth and planets; humans; plants & animals; rocks and solving problems and finding solutions to scientific related topics

You OBSERVE everything about that object. How it works, what it's purpose is what effects it makes on the environment surrounding object

Using formula and facts to make THEORIES.

Study it in detail with scientific EVIDENCE

To study something in a professional and accurately. To OBSERVE all the components that make things work.

To OBSERVE it in an accurate way. To take in all aspects of the particular object.

I think it means to research something. It also means to DISCOVER answers and consequences. It can give you a more detailed answer

So that you can do the EXPERIMENT to check your thinking.

To ANALYSE it from different points of view

I think it is conducting difficult EXPERIMENTS and taking lots of notes at every step.

You look at how it works. You OBSERVE it

By deeply understanding how it works, in relation to laws and THEORIES about the universe

To study something scientifically I believe is to INVESTIGATE why, when and what happens to something, or to try and find out more information about it

It means to research and INVESTIGATE everything in the world and beyond.

I think studying something scientifically means to ANALYSE, inspect and find out how something works by using science and relating it to the subject. Recording progress and any other information.

To carry out EXPERIMENTS.

To find out information on something based on PROVEN facts or to make a THEORY based on facts you know.

To OBJECTIVELY attempt to understand why, how and when

To study something scientifically to me means that you study the subject down to every fine detail using high tech computers and ANALYSING machines

To ANALIZE it

Something that's got to do with some EXPERIMENTS, using chemical liquids or substances. Learning new things, such as the things we can't see in with our own eyes or learning things around us.

To use scientific meaning and THEORIES

To use scientific THEORIES and equipment

To study the ways in which something may work and the reasons behind something and its happenings. Often using EXPERIMENTS to find answers.

To INVESTIGATE something in depth.

When you study or OBSERVE how something works, why it is there, how it got there and things like that.

Studying something with physical EVIDENCE to back up your idea.

To study something using a method and by using the same equipment for every EXPERIMENT.

To study something to find out how, why, when and where, and it's PROBABILITY of re-occurance

To ANALYSE it in a scientific way.

To INVESTIGATE a subject and (unreadable) a result to a practice

To gather information by either research or by EXPERIMENTATION

Carry out an EXPERIMENT or series of experiments to find out more about what you are studying research, survey and ask questions about it

To ANALYSE it in a certain scientific way.

Study based on scientific. PROVE and measure

I think it mean study something base on fact and EVIDENCE (sic)

To study something scientifically is to ANALYSE and study thorough, record data and create results

To study something scientifically you are developing a THEORY and may undertake EXPERIMENTS to obtain the correct results

I think this means to study in detail a particular element, what makes up this element and how it works. OBSERVE it and draw conclusions from it.

Studying something scientifically means to OBSERVE, ANALYSE and research the "thing being studied" to great depths to find its significance and why it exists.

To ANALYSE something with a scientists perspective and knowledge. This will be carried out with a series of EXPERIMENTS and solutions.

When you do a series of EXPERIMENTS to DISCOVER a possible solution to one of life's functions or the world.

To try and find out a question or THEORY and to PROVE or disprove it.

To make OBSERVATIONS on the thing being studied, record these. Making TESTS on the thing, recording results. Gather and summarise information.

Studying scientifically is study a particular thing my EXPERIMENT and write a scientific report.

To study scientifically is to research something, create an EXPERIMENT and make a HYPOTHESIS at the end. Then we study if the hypothesis and our result match

To look at a subject and study it in an UNBIASED way. Taking is every possible aspect and possibility involved and coming up with a THEORY or conclusion

There are always aim, HYPOTHESIS, result and conclusion, CONTROLS and so on.

Well I believe it means to research something and find out facts about it and to do surveys on and OBSERVE it. Also to do a scientific method and do EXPERIMENTS.

To study something scientifically means to research, gain EVIDENCE for, create THEORIES and create a better understanding of proposed subjects (ie the human body, plants etc) by using scientific methods.

To DISCOVER/PROVE something, record data. Learn more about it

To study something in great depth and carry out OBSERVATIONS and EXPERIMENTS to find something out or to PROVE a point

To research and do EXPERIMENTS, find results and write conclusion to DISCOVER or perhaps PROVE something scientific

Studying something scientifically means we need to do EXPERIMENTS and need EVIDENCE to PROVE stuff.

It means to have a method, distinguish faults and problems encountered and continually REPEAT as necessary to get STATISTICAL EVIDENCE to draw up a conclusion. HYPOTHESIS are you a good idea.

Studying facts and creating THEORYS. Making OBSERVATIONS and coming to a conclusion on something whilst backing it up with reliable EVIDENCE

To study something scientifically is to come up with a THEORY for something and either PROVE it or DISPROVE it

It may involve EXPERIMENTS and your own THEORIES. Also rely on EVIDENCE to back you. Looking at other statistics too.

You have to research, ANALYSIS, come to a suitable conclusion, conducted a CONTROLLED EXPERIMENTS (in many cases)

To research something using different EXPERIMENTS, formulas using VARIABLES, asking why something happens making HYPOTHESIS and TESTING.

To INVESTIGATE it and carry out EXPERIMENTS to PROVE your THEORIES on it

Researching, ANALYSING and looking at something conducting EXPERIMENTS to TEST THEORIES or ideas, and finding out how something works.

I think it means that you INVESTIGATE or OBSERVE a particular topic in a scientific manner. For example you carry out EXPERIMENTS and investigations to PROVE your HYPOTHESIS.

To take note about it study it break down all details about the thing and explain it scientifically

Make the HYPOTHESIS, make the EXPERIMENTS, ANALYSE results, check HYPOTHESIS, create THEORY.

Wales Group 2005: *n=56*

Look at something very closely, TEST it, see how it was made, why it was made, what does it do etc

To explore the way it works and the uses of it.

You understand the knowledge behind activities. You gain a better understanding of the world and how it works.

To look at something closely and work out.

To study it using scientific knowledge - explaining it using knowledge such as particles etc.

To find out in detail how something works or happens and to find out why it happens and if it can be useful to us or not.

It means that we are investing into a certain subject and trying to get an answer for by explaining it with science.

If you study something scientifically you would make a PREDICTION of what you think will happen and study your results.

To study life, elements, energy, astronomy etc

To study something in any way.

To work out how every little bit of something works and why it works.

I think it means to look at how something works eg the lungs and the effect it has on the rest of the body or whatever else you are looking at.

To study something scientifically means to study it thoroughly using scientific knowledge.

I think it means to study the science behind a certain subject/field. To study gardening scientifically you would study the soil and work out when plants will grow getting the minerals needed.

To look at the way things work in detail and using scientific explanations.

I believe to scientifically study something you are INVESTIGATING it's purpose or even its uses.

Looking at the way things grow, work, develop and why.

To look at their biological activity and to give reasons why it is like that.

To do an EXPERIMENT of any type or something with a THEORY related to it.

To study something scientifically you take a slow and METHODIC approach ruling out irrelevancies, ANALYSING anomalies.

I think it is an important qualification.

To study something in more detail. To find out why or how it happens.

To study something fairly and accurately and safely.

To look very closely how it functions, how it was created and to develop your understanding of it.

To study something scientifically is to study it in a lot of complicated detail.

I think that to study something scientifically means to study it in depth, what it is made up of or why different things happen.

To look at things more closely and learning more about it.

To look at something scientifically and to see what makes up that thing, how it works etc

To study something scientifically is to run TESTS and take OBSERVATIONS and results.

To study something in a lot more detail.

I think that it means INVESTIGATING the thing to find out what you need to know. The way is reacts, it's properties.
Studying something to do with science.

To study the way something reacts, behaves, grows. To increase your knowledge by studying to EXPERIMENT and research.

I think it means to take a THEORY and study the facts of the theory and DISCOVER whether that theory is true.

To look at it in detail. To DISCOVER more about it.

To study something in more detail, in more depth

To study scientifically all of the subject (eg EXPERIMENTS)

To study something's beginnings and origins, and to see how something works.

To study scientifically is to study something in extreme detail.

To understand exactly what something is and how it works.

To study what a certain subject with how it works

To ANALYSE or find out something unknown about the object studied. Or to learn about the object studied.

To study scientifically means to study something in extreme detail.

Studying something scientifically is looking at something from every aspect, angle and point of view.

Looking at something at every possible angle/aspect to determine whatever you want to know.

I think it means that you study something like a scientist.

It means that you think of something in more depth and in extreme detail.

To look at something in a lot of extra detail finding out what happens, why it happens etc.

To study something at its most basic level

ANALYTICALLY and in relation to other things. To view things IMPERSONALLY.

When you are studying something scientifically, you are looking at how it works and why it exists.

To study all the scientific aspects of the subject.
An attempt to PROVE and THEORY.

To break down the facts, to look at something either an object or a pastime from a different view.
To study something scientifically is to ANALYSE and breakdown the facts we gains from our results and attempts. There must be VARIABLES in the EXPERIMENT but some must remain constant.

To develop a THEORY about it and carry out OBSERVATIONS or INVESTIGATIONS to find whether your theory was correct. Taking into consideration all scientific elements.

Project Group 2006: *n=113*

Studying scientifically means studying in an UNBIASED way and finding all the facts out before you come to a conclusion.

To study something scientifically means to look at it in the context of science and how it will affect the environment.

This means when you are studying something scientifically you either are DISCOVERING something or testing something.

To learn and study about the makeup of our world (how it is made up eg humans, plants, animals, minerals, cells etc), our universe and life in all different ways. Also studying ways of improving our life (medicines, technology etc).

I think to study something scientifically is to look at something in depth in relation to how it was made, how it works etc.

To study scientifically is to study while looking at all VARIABLES to come to a conclusion that is as accurate as possible.

To research on a particular scientific view to gather scientific information on something.

To gather research on a particular area, study it and complete results on the science undertaken.

To studying something scientifically means that you study technical and interesting things and mostly studying science can get you very high skilled jobs eg engineer, astronaut etc.

Science is all around us and we have to accept that we live in a world of science and that it provides us with answers.

To look at it in depth and to conduct EXPERIMENTS.

To study something scientifically means to carefully examine and OBSERVE the occurrence WITHOUT BIAS.

Studying something scientifically refers to providing an INVESTIGATIONS, facts, THEORY and PROOFS.

To look at a subject in a NON-BIASED way and to study it to find all possible answers.

To study something scientifically. I think it means to study for an answer to something and to do it fairly.

To study something scientifically means to understand your topic to the best of your abilities using all aspects of science.

To study something scientifically you must record everything that you OBSERVE.

To study something WITHOUT BIAS, putting into account all facts and constructing TESTS to base THEORIES or explanations on.

Look at it from all possible scientific points of view using scientific elements and tools.

I think this means to study scientifically is to understand how things work with depth.

Answers my doubts or question. Gives a better understanding of our work today. Knowledge is power.

To look at it from all possible scientific points of view using scientific elements and tools.

To study the facts surrounding an object or place. Also to ANALYSE and draw conclusions from it.

To study something scientifically, to me it means to learn new and interesting things.

Studying something scientifically means studying it from a scientific view eg volcano, looking at the chemical makeup rather than the history. Studying scientifically also means using scientific techniques eg EXPERIMENTS.

It means to study all the elements of what you are studying like everything about it physically.

To study something from a scientific perspective, eg how it works instead of a more emotional side. To question it to a higher degree.

To observe the different functions of certain objects. How things work, what they're working for, why etch. To draw conclusions about these things to help all get an understanding.

To look at all the facts. To conduct EXPERIMENTS in a CONTROLLED environment. To be practical/SCEPTIC. To focus on one thing until you find the answer.

To research.

To study something with all VARIABLES considered. To display findings in a certain format.

To study something scientifically is to OBSERVE something closely and to record results.

To study something scientifically means to OBSERVE it, and look for changes when different VARIABLES are imposed.

To studying something scientifically means that you do a careful and accurate study and using the results to get your answer. It may take more than one study to do it.

Studying scientifically means to approach something which is to be believed and the outcome is true.

To study something scientifically is to OBSERVE and make TESTS and results. It is to understand and find out things in the most accurate way possible and most plausible.

To examine something thoroughly and find out all we can know by PREDICTING and EXPERIMENTING.

ANALYSING it carefully, making notes etc having HYPOTHESIS etc.

To study something scientifically is finding out how and why things happen.

ANALYSING things around us in a logical way.

To deconstruct something and EVALUATE how it works, why it works and where it comes from. Also to look at the correct way.

To study something scientifically is to study something to DISCOVER how it works, and how this can be useful. Its all about understanding things.

To study something scientifically EXPERIMENTS are to be made and OBSERVATIONS conducted.

I think the study of science is like studying how things work in life, the world, about people and the universe. You find out new things about living and non-living things in THEORIES and through the year the theories may chance completely on even just a bit.

To study something scientifically the person(s) studying would have to look at what they are studying and trace it all the way back to its beginning to get a full understanding and background knowledge of the things around them, how they were created, what they do and how etc.

To study things, what they are made of , how they work, if they can be used for anything else.

To try and find out how something works, but also PROVING it by TESTING THEORIES.

To study something scientifically is to research and dig deeper into certain issues in life relating to anything. It is also to improve current situations for the better of the society.

To undertake INVESTIGATIONS to PROVE THEORIES right or wrong.

To study the facts and try to PROVE or DISPROVE ideas related to a fact or object.

ANALYSE it in all areas, work out all possible outcomes. Undertake EXPERIMENTS.

To study something scientifically is when you use SCIENTIFIC METHODS for equipment to find things out. These methods are used to find out THEORIES and facts.

Studying something scientifically means to learn and understand things by doing scientific research and EXPERIMENTS.

To study something scientifically it means to find a logical answer for everything which occurs in the universe.

To study something in great detail in order to find or OBSERVE certain things about the thing. Also to conduct EXPERIMENTS.

To study something scientifically means to me to research something using facts and scientifically PROVEN EVIDENCE.

Studying something scientifically refers to studying a problem or a solution and creating PROOF.

To perform research and tasks to understands better of the world.

Explore all aspects of something to find out as much about it as is possible.

It is interesting and you know you are dealing with facts.

To study something scientifically I believe it involves studying the whole aspect of the topic as well as create THEORIES regarding it.

To research others work, then conducting TESTS and EXPERIMENTS to further your knowledge making sure to record and compare results and OBSERVATIONS.

Using EXPERIMENTS and looking from the scientific perspective.

To examine thoroughly.

To study something scientifically means to study something in depth or why something works.

To find out and DISCOVER different things and learn about the world.

To study something using scientific ways. About the science of the thing. All of the interesting facts about us.

I think to study something scientifically means to look at something from every angle. It means to classify, understand, examine, find what it is made from and find how it works.

Studying something scientifically allows us to see a different perspective of it in such a way that we relate to the other things around us. It is also then that we learn to understand and appreciate what it is and how it contributes to our society.

To studying something in depth. DISCOVER things in places everybody has seen but haven't found to keep notes and do EXPERIMENTS.

If something is studied scientifically, it means that it is being explored in a SCIENTIFIC METHOD, or studied using science as an aid to reach a conclusion.

To look at how and why an object fits into our society and the role it plays in our life.

Studying something scientifically involves finding EVIDENCE to support a THEORY. This is done through research and EXPERIMENTS.

To study something scientifically is to learn more about the world around us and to make a contribution to the knowledge of Man
Studying science to learn more about things deeply.

Getting facts on things like how stuff works
To conduct an EXPERIMENT trying to PROVE something.

To look at something nobody else has and finds unique features.

I think it means that you study the sciences that are involved and use them to come up with a conclusion.

To study something scientifically means that the study is carried out accurately to find out what happens.

To look at something in a different way and INVESTIGATE new things.

I think studying something scientifically is to perform TESTS on it and to find out the way it works.

To find PROOF that is able to be seen about an object or thing to show that they thing is real.

To look at it and propose ideas.

Science is looking at all factors that can effect what you are studying. Studying scientifically is like studying from our point of view.

Researching background information on the topic before conducting your own TESTS to find out more first hand. This can be REPEATED multiple times.

I think it means to study something in depth and everything to do with that something. Also finding out why, when and how something came to be formed on earth or another planet.

Perform scientific EXPERIMENTS.

REPETITION of data collection, researching and EXPERIMENTING.

You have to do EXPERIMENTS and find information.

Lots of EXPERIMENTING and trial and error.

To research ,EXPERIMENT and trial and error.

I think that it is doing research on the topic and EXPERIMENTING.

I think it means to research and EXPERIMENT about certain things.

To research it by doing EXPERIMENTS and getting information.

To study something scientifically you need to research as well as complete various EXPERIMENTS. Experiments may need to be REPEATED for accurate RESULTS.

To EXPERIMENT with something to find out the scientific reason for it.

I think to study something scientifically means to find PROOF and correct methods to find a result useful to anyone.

To conduct a practical test from theory work to prove a THEORY correct or to undertake a field TEST to study a certain situation or event.

I believe to study scientifically you are studying something in depth.

To look at something and write down all possibilities and then try to PROVE them

To research, study, EXPERIMENTAL projects, conclude something

Use EXPERIMENTAL methods to ANALYSE an object.

Do EXPERIMENTS.

To explore the topic in every way. research, EXPERIMENT etc.

Do EXPERIMENTS to find facts.

Do research.

EXPERIMENTS and research.

To study an object unattached and OBJECTIVELY.

To find the in and out of a particular thing, lots of very detailed research, trial and error.

To find actual facts of how or why something works.

Doing research and EXPERIMENTS to learn about different things.

Think of a thing that you want to find out. Research different approaches. Come to a logical conclusion.

I believe its researching then EXPERIMENTING on the topic you wish to study. Finishing the study with finding and concluding the project.

Research, EXPERIMENTS, conclude

To TEST a theory or to find answers to a THEORY.

University Group 2006: *n=150*

To study an object of the environment OBJECTIVELY with no pre conceptions that will blur the result, although HYPOTHESES may be beneficial. The study of science is to measure the sum total of human knowledge and in doing so measure the quality of life for the inhabitants of Earth.

To study something scientifically is to study in depth and make-up substance of subject. (sic)

I think it means the process whereby you remove all other options. You test your THEORY/HYPOTHESIS on the subject by showing that all other options cannot be.

It means to study the THEORIES of science, conduct EXPERIMENTS using formulas, DISCOVER the answers to questions

To ANALYSE something in order to find an answer that depends upon PROOF and logic.

Do EXPERIMENTS to TEST many THEORIES.

Pay attention to facts and detail. To raise questions and try to find answers. To develop THEORIES and then run TESTS to check and recheck the results and know how they company to your theory HYPOTHESIS.

To ANALYSE CRITICALLY and deconstruct the data so that a logical explanation can be forged.

An accurate and academically approved TEST has to be taken out so that the subject being studied can produce the least BIASED accurate result.

It usually involves formulas and looking CRITICALLY at an EXPERIMENT.

To ANALYSE it, pull it apart, see what effects it, draw conclusion from studying something scientifically.

To study something in a logical ordered fashion in order to answer a specific question with supporting EVIDENCE.

Studying a subject scientifically means to go about an INVESITGATION of a subject with an objective of DISCOVERING facts about its nature from which further studies may be based.

In an OBJECTIVE stance - more do (sic) with facts, PROOF etc.

Looking at a process in depth - how it works, the affects, the outcome - the importance is great too - trying to help humanity.

To undergo study with an open mind. To study and learn by doing EXPERIMENTS to come to satisfactory conclusions.

Involving measurement and technology, EXPERIMENTS and examination.

To study phenomena in an OBJECTIVE manner.

To INVESTIGATE into the reasons why something is the way it is and exactly what this means to us as individual and a society. The final outcome, or results, is very important.

To look at something with logic to explain why an event happens and how it occurs within an environment.

Studying METHODICALLY to gain accurate information.

To examine a HYPOTHESISED goal in relation to biological, chemical, movement, etc activities.

To study something scientifically is to study it OBJECTIVELY using the facts available to you at the time.

To study scientifically is to observe some phenomena and to strive to understand how it occurs but more importantly why.

To EXPLORE the field of science.

Look at in in depth break down the issue.

To see how something works. To understand why things happen.

Studying in depth how something works.

It means that time of all (sic) determine closeness of objects or figure out elements which cause some degree of effect and which might be out interest to study?

To examine how something was created, its effect on the environment and how it could be destroyed.

To solve problems whether it be ANALYTICALY, practically etc as well as finding a reason for aspects of existence.

To study something scientifically connotes OBJECTIVITY, having a CONTROL and TESTING HYPOTHESES (although no doubt we often fall short of this). So it isn't just 'the sciences' which can be studied in this manner.

It means to ANALYSE something CRITICALLY from an OBJECTIVE point of view. To look at the origins and each fact of it.

To think CRITICALLY and PROVE THEORIES with equations.

Basing OBSERVATIONS or EMPIRICAL EVIDENCE to ascertain a result based on changing VARIABLES. And comparing this to a HYPOTHESIS.

To ANALYSE with recordable RESULTS

Look at something OBJECTIVELY, OBSERVE and INVESITGATE what is going on.

To find out how something works in a precise and logical way.

To OBSERVE where it comes from, why it does, what it does, when it does etc.

It means OBSERVING, looking at the detail, getting the facts but it also means stepping outside of the box sometimes being irrational to get answers.

It means to look at a problem, object, enigma or action/reaction and ANALYTICALLY reach conclusions about is qualitative and quantitative features as well as the reasons why some actions occur.

To question something in the world around us, and by questioning it we gain a better understanding and appreciation of its nature and role.

To undertake a specialised subject upon which a specific scientific field is EXPLORED.

There are three sides to an argument, my side, your side and the facts. Science seems to look for the facts (answers) to philosophers questions, which in turn allows us as complex beings to advance and understand.

To study something at a detailed level.

Find cause for research, OBSERVE, report, EXPERIMENT, EVALUATE and implement. Continuing checking results against HYPOTHESIS. Being ready to absorb new data and information to gain a larger view and better understanding of the study in question.

To study something scientifically in depth, finding out all possible results, which can be obtained through thorough TESTING and ANALYSIS, in order to create factual knowledge about study.

To study a topic using a SCIENTIFIC METHOD with a HYPOTHESIS and an order in the most OBJECTIVE way possible.

To apply a method which is soundly based to record results or DISCOVER something.

TESTING more than once under CONTROLLED circumstances to PROVE or disprove THEORIES.

ANALYSE the topic in a more thorough METHOD by finding an answer to the HYPOTHESIS or statement.

To research topics in a scientific way that explains the origins with no THEORIES but PROVEN results.

To research unknown or HYPOTHESISED fields, gaining results to help understand the subject and thus constrain futher questions to research.
Using methods and equipment - having a HYPOTHESIS and resulting conclusion, finding out or PROVING said hypothesis is a means by which something is studied scientifically.

Scientific study means using facts, CONTROLLED EXPERIMENTS to INVESTIGATE and HYPOTHESISE.

Studying something scientifically means to try to DISCOVER or PROVE rules which define the ways objects and materials act and interact. These rules can be expressed quantitatively and qualitatively.

To ANALYSE,OBSERVE, EXPERIMENT with subjects and participants to help in understanding it with a scientific context.

Studying something ANALYTICALLY, without creativeness. It involves proving a THEORY or DISPROVING a theory.

To use EVIDENCE to find out how things work and to DISCOVER new methods of doing things.

To study it in depth and accurately - to PROVE things using examples and EXPERIMENTS ie - scientifically proven.

To look and EVALUATE things OBJECTIVELY and gather info and make evaluations regarding the data collected.

To study something scientifically means to research and EVALUATE EVIDENCE.

A CRITICAL ANALYSIS using VARIABLES and CONTROLS.

To study a subject or conduct an EXPERIMENT in a METHODOLOGICAL process to OBSERVE RESULTS usually done in CONTROLLED circumstances.

To study something CRITICALLY, OBJECTIVELY, by looking at the facts and EVIDENCE without impairing professional ideas on the subject.

To collect data often through EXPERIMENTS to PROVE a HYPOTHESIS, THEORY, rule or to see if there is any pattern or answer.

To use ANALYTICAL reason and logic to apply formulas and TEST THEORIES METHODICALLY, to strive for OBJECTIVITY and disregard EMOTION, art, beauty etc EXPERIMENT, OBSERVING, research recording results.

To study something scientifically means to OBJECTIVELY and with as little BIAS as possible OBSERVE phenomena and record findings in a METHODICAL and standard way.
To research it both first hand also to gather information on it through the work often to exclude their opinions. Then HYPOTHESISE all alternatives, find EVIDENCE - in other words, doing things METHODICALLY and less likely to focus on one perspective and to use speculation as little as possible.

Studying something scientifically means to ANALYSE a certain topic in a METHODICAL manner to given end conclusions. It means to thoroughly research and keep records of your research in a professional manner.

To look at it carefully finding PROOF in the study through EXPERIMENTS.

I think it means to go through a process in order to come out with an outcome or answer to a HYPOTHESIS.

To use reason, fact and possibly numbers to PROVE or DISPROVE something.

To look at a certain subject from different perspectives. Conduct an EXPERIMENT to see which perspective is correct and make a conclusion.

In depth using CONTROLS to ensure results are correct
Something that involves the INVESTIGATION through practical and mathematical METHODS to reach a conclusion.

To pull it apart, look at facts, question how and why things work, EXPERIMENT, apply THEORY, to work out what is involved in the study, ie chemicals, components.

To study without EMOTION - relying only on data
To study something scientifically is to SYSTEMATICALLY and subjectively ANALYSE something and describe the results.

To find or ANALYSE the process METHOD and truth behind all things physical and metaphysical in this world and others, like looking into the future, the ability to advance things whilst learning and DISCOVERING new truths.

To INVESTIGATE what you are studying using scientific methods. Then taking what you have learnt and using it to teach others and increase the knowledge of science as a whole.

To take measurements and ANALYSE the chemical makeup of the substances involved.

To look at a given topic, UNBIASED and to come up with a possible HYPOTHESIS as to what its function may be or how it works to better help us.

To question, INVESTIGATE and research

To pragmatically look at something/problem and logically deduce answers/solutions from the EVIDENCE.

To perform EXPERIMENTS and gather results

To study something scientifically is to CRITICALLY view a problem or issue and to make HYPOTHESIS (sic) or judgements on the issue.

To study the effects of something based on TESTING data etc (sorry a bit brain numb to answer this question properly).

To study something scientifically is to OBSERVE processes occurring and their subsequent reactions, effects and causes.

To be logical, SYSTEMATIC and mathematically minded

To study something which is generally accepted as being true and PROVABLE.

To study with a credible METHOD.

To ANALYSE CRITICALLY how the processes of certain elements of humanity, space and time operate.

Applying the SCIENTIFIC METHOD to any research.

To ANALYSE cause and effect as well as finding answers to things or questions that are not known to the modern day sciences.

ANALYSE every aspect of an item/incident and conclude how and why it occurred this way and what effects this has on surrounding items/incidents.

To use scientific principles such as THEORIES to approach an area of study.

It means it is studied in a precise METHODOLOGY to determine a preconceived outcome. The methods applied should be able to be replicated by the same or another party to compare results to see if the preconceptions are achievable or revise for different results.

To ANALYSE the subject breaking it down into parts to understand the system as a whole.

Study according to facts, reaching core or exact answers and value. Try to eliminate BIAS and personal opinion.

It means to focus on something's scientific properties. To ANALYSE, explain and try to understand, sometimes with the aid of technology.

ANALYSE the thing that you are study in greater depth and relate it to other factors also.

To look at the reasons behind why certain things occur and how different elements and factors impact and the outcome.

To study something scientifically is to ANALYSE and find out how and why that thing works.
To study matters ANALYTICALLY and factually.

I think it means to study something from an OBJECTIVE point of view focussing on the main questions how or why.

To study scientifically means ANALYSING, solving questions scientifically.

To asses or attempt to understand a subject from a very factual ANALYTICAL point of view.

To ANALYSE particular information in order to answer a certain scientific question.

Use formulas to find solutions to questions. Think about study, something is a more complex way which leads to confusion (sic).

To ask a question and use SCIENTIFIC METHODS to DISCOVER the answer.

To study something scientifically is when it involves different mechanics and methods then other studies.

To understand the processes that allows thing to work, interact, change their state etc and to understand the makeup of objects.

Don't know.

You undertake the study with the aid or point of view that involves a scientific knowledge.

To study the makeup of whatever you are studying.

It is science.

To understand how things work.

To study something scientific is to study the way in which things are created, formed and how they function, whether it be the human body, psychology, flora and fauna or the galaxies and universe. This information is, unlike religion, PROVEN by scientific examples.

Look at the elements which make up that something.

To study the foundation of something and why or how it exists in the world today.

To look at how and why something operates, works.

It means studying why something happens the way it does and being able to PROVE why it happens OBJECTIVELY.

To study something scientifically means that one can improve or better understand something.
To study something scientifically means to study it at a level not visible to the human eye.

To look at the objects more minute workings.

It means you study the science of that thing how its created how it works how to look after it eg the science of animals, studying everything to do with an animal from its environment to its structure.

It means to look at how things work and to understand why.

To study the facts and knowledge in order to draw conclusions of an activity.

To look at how something is made, to look at how something interacts with the physical world. To look at the effects that this certain something on other objects.

Looking at things in detail. Too much detail.

To study something when thinking about all the facts relating to how and why something happens/happened.

To look at explaining why and how things occur.

To go into excruciatingly technical detail about something relatively simple.

To study scientifically is to study from all angles so as to get the best possible outcome for any questions posed.

Unsure. I'm sure there are many different degrees to which one can study something scientifically. It may be human interactions, developments and environmental issues that relate to it.

To see how something operates.

To study something scientifically means to go into extreme depth in answering the question.

Related to people, earth and living/non living things
I (sic) might mean a lot in terms of its reach to all aspects of modern life but I haven't studies (sic) any.

To study the scientific details of something, such as its technological aspects or environmental make-up.

To study the reasons and their effects on a specific subject.

Researching the reasons for the outcome.

To find out how things happen and why.

To look into how it works or became to be how it is today.

Figure out how something works in great depth/detail.
To study something using techniques and repeated research.

To understanding the workings of objects, things or equations.

APPENDIX C: Terms

Terms project group 2005 dataset

Students in this high schools group generated these terms in answering the question, “What does it mean to study something scientifically?”

Investigate, investigation
Analyse
Prove, proven, proof
Evidence
Hypothesis, hypotheses, hypothesising
Testing, Test(s)
Without bias
Theories
Observe, observations
Predictions
Repetition
Systematic
Variables
No bias
Experiment, experimentation
Evaluate
Interpret, interpretation
Control

Terms non-project 2005 dataset

Students in this high schools group generated these terms in answering the question, “What does it mean to study something scientifically?”

Discovery, discover, exploring, discovered
Theory, theories
Prove
Disprove
Observe, observations, observing
Analyse, analytically
Experiment(s), experimentation
Evidence
Evaluate
Investigate. Investigating
Probability
Hypothesis
Controlled, control(s)
Repeat
Variables
Unbiased
Non-emotional
(not looking at it) Subjectively

Terms 2006 project dataset

Students in this high schools group generated these terms in answering the question, “What does it mean to study something scientifically?”

Unbiased
Discoveries
Observe
Without bias
Investigations
Theory, theories
Proofs, prove
Non-biased
Tests
Analyse
Experiments, experimenting
Variables
Evaluate
Investigate
Repeated, repetition
Objectively
Explore
Interpreted
Evidence
Discover, discovered
Without any attachment

University 2006 dataset

Students in this university group generated these terms in answering the question, “What does it mean to study something scientifically?”

Observe
Experiment(s)
Evaluate
Hypothesis
Objectivity
Control(s), controlled
Testing, tests
Methodical
Discover
Prove, proven, provable
Theory, theories
Analyse
Critically, critical
Disproving
Variables
Evidence
(least) Biased
(without) Emotion
Unbiased
Empirical
Investigate
Systematic
Explore, explored, exploring, explorations
Verifiable
Interpretation

APPENDIX D: RELATED PUBLICATIONS

PERGAMON

Available online at www.sciencedirect.com
ScienceDirect

Acta Astronautica 61 (2007) 716–723

ACTA ASTRONAUTICA

www.elsevier.com/locate/actaastro

Astrobiology: A pathway to adult science literacy?

C.A. Oliver[a,*], J. Fergusson[b]

[a]Australian Centre for Astrobiology, Macquarie University, North Ryde, NSW 2109, Australia
[b]Macquarie ICT Innovations Centre, Macquarie University, North Ryde, NSW 2109, Australia

Received 15 February 2006; accepted 11 December 2006
Available online 12 April 2007

Abstract

Adult science illiteracy is widespread. This is concerning for astrobiology, or indeed any other area of science in the communication of science to public audiences. Where and how does this scientific illiteracy arise in the journey to adulthood? Two astrobiology education projects have hinted that science illiteracy may begin in high school. This relationship between high school science education and the public understanding of science is poorly understood. Do adults forget their science education, or did they never grasp it in the first place? A 2003 science education project raised these questions when 24 16-year-olds from 10 Sydney high schools were brought into contact with real science. The unexpected results suggested that even good high school science students have a poor understanding of how science is really undertaken in the field and in the laboratory. This concept is being further tested in a new high school science education project, aimed at the same age group, using authentic astrobiology cutting-edge data, NASA Learning Technologies tools, a purpose-built research Information and Communication Technology-aided learning facility and a collaboration that spans three continents. In addition, a first year university class will be tested for evidence of science illiteracy immediately after high school among non-science oriented but well-educated students.

Keywords: Science illiteracy; Pilbara; Mars; Virtual Field Trip; High school; Civic science literacy; NASA collaboration; Analogue site

1. Introduction

It is generally accepted that the majority of adult public audiences are scientifically illiterate. Regular US and European surveys [1,2] indicate public audiences are ill-equipped to either integrate science content into their worldview or to understand what constitutes science [3,4]. Why does adult science illiteracy remain ubiquitous in spite of several decades of improvements to science communication and science education aimed at increasing science literacy? Two experiences of the authors hint of a possible new research avenue and that the best pathway to exploring it might be astrobiology because of its inherent multi-disciplinary and inter-disciplinary nature.

This first came to light in 2003 after an experience involving 24–16-year-old students from 10 Sydney high schools in a NASA and Macquarie University astrobiology research expedition. It was surprising that most of the 24 students, although mostly either competing for a place or being selected by their teacher, appeared to lack even a broad insight into the actual processes of science as well as the often interconnected nature of science. This seems basic to adult science literacy, but was apparently missing among these 24 high school students who were considered to be good at science [5].

* Corresponding author.
E-mail addresses: carol.oliver@mq.edu.au (C.A. Oliver), Jennifer.Fergusson@det.nsw.gov.au (J. Fergusson).

0094-5765/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.actaastro.2006.12.010

The reaction of the students to their learning experience on the project was encouraging. Students provided a written and verbal evaluation of their experience that indicated they had gained a better picture of how science was undertaken as a result of the experience. Two-thirds of the group said they were influenced or reinforced in their science subject choices for Year (Grade) 11 and two changed their minds about ending their science education in Year (Grade) 10, as is possible in Australia.

These were results we were not looking for—rather aiming to provide an opportunity for high school students to work with scientists in an interesting mission involving NASA, in which Macquarie University was participating, and to test the potential of a collaboration between two research centres at Macquarie University. It prompted us to consider undertaking a larger high school science project to open a similar science learning experience to potentially hundreds of, thousands of students around the world. Oliver is also exploring the hypothesis that, for whatever reason, adult science illiteracy may begin in high school, underpinning the project with research.[1]

The new astrobiology-related Pilbara education project involves 87 students from seven high schools. Early results suggest similarities to our findings with the 2003 project, with 25 of the 87 students saying that they will now undertake some science subjects at university or a full science degree.[2]

While a follow-up study is required to see if that follows through, another impact is seen in some student responses to the question '*what does it mean to study something scientifically?*' between the entry and exit surveys. Most of the 87 students are top science class students from across a broad socio-economic demographic. Much analysis is required yet to determine whether their understanding of how science is undertaken is any better or any worse than the same surveys[3] taken at approximately the same time in the seven high schools among around 400 students.

In addition to the surveys, students were asked to evaluate NASA Learning Technologies tools, including a Virtual Field Trip tool currently under development jointly between NASA and Macquarie University with the tool intended to be open source and freely available to all. These evaluations and some more early results from the entry and exit surveys are reported later in this paper.

2. Powerful partnerships

The Pilbara Science Education Project is the result of the same partnership between two Macquarie University centres that produced the 2003 project—the Australian Centre for Astrobiology (ACA) and the Macquarie ICT Innovations Centre (MICTIC). The ACA, one of only two international Associate Members of the NASA Astrobiology Institute, is an interdisciplinary science research centre with a strong education, media and public outreach program directly linked to the research. MICTIC is a collaborative project between Macquarie University and the New South Wales Education Department to gain an understanding of the impact of ICT (Information and Communication Technologies) on learning experiences for primary (elementary) and high school students from 170 feeder schools around Macquarie University. The partnership between the ACA and MICTIC is therefore one of a potentially powerful joining of the exploration of the use of ICT in science education together with astrobiology and science communication research.

The 2003 project involved the partnership of the two centres in collaboration with the NASA Johnson Space Center in an expedition to 'black smokers'—ocean floor hot spring vents—in the Atlantic and Pacific Oceans with the movie maker James Cameron, who was engaged in making an educational IMAX movie, 'Aliens of the Deep'. NASA researchers were on board the research vessel Keldysh with Cameron and carried out experiments on behalf of several NASA centres and the ACA. The brief for the 24 high school students was to extend the limited knowledge of 'black smokers' and to design an experiment that would be carried out on their behalf by researchers on the submersibles at the ocean vents.

The Pilbara Project involves a collaboration between the ACA and MICTIC with NASA Learning Technologies and the University of Glamorgan in Wales. It was begun in August of 2004 and is the subject of a NASA Space Act Agreement with the NASA Astrobiology Institute, which itself was developing the concept of a museum exhibit based on astrobiology 'hot spots' around the world, beginning with the Pilbara, in Western Australia.

The latest project is based on an Australian analogue site for searching for past life on Mars, the North Pole

[1] Data collection and analysis from the Pilbara Science Education Project is mostly by Oliver, forming a major part of her Ph.D. 'Communicating Astrobiology in Public' but the development of the project itself has been undertaken by both Oliver and Fergusson.

[2] Most universities in Australia do not require non-science students to take at least one science subject.

[3] Surveys taken by the 87 students involved in the project differed in the second survey among the control group only in three extra open questions related to their reaction to the project.

area of the Pilbara. Stromatolites are structures made by succeeding mats of millions of microbes, usually in extreme conditions such as high salinity, acidity and temperature and are found in both the modern and ancient environments. Stromatolite-like structures 3.5 billion years old are found in the Pilbara, suggesting life got going relatively quickly after the heavy bombardment of Earth, and at a time when life may have also appeared on Mars.

The Pilbara is therefore an analogue for looking for life on Mars, and therefore relates to our understanding of our place in the universe. In addition, research and scientific debate continue on the biogenicity of the Pilbara's putative stromatolites making it topical and likely to become a subject of more scientific debate, and possibly public debate, if evidence for life on Mars is found [6]. The methodology we are creating will have multiple uses specifically in astrobiology related projects as well as more generally in space and science education both in formal and, potentially, informal settings.

3. Virtually real science: the methodology

The backbone of the project is the creation of a scientific virtual field trip to the Pilbara, which will open to students, the learning experience of preparing for the trip, developing hypotheses, and planning and undertaking the virtual trip from computers at school and/or at home. This tool is in the process of construction in a collaboration with NASA that will result in the VT tool being available for the Pilbara, field trips to other areas of astrobiological interest and to educators worldwide.

Almost the entire suite of NASA Learning Technologies tools are being employed to allow students to zoom into the Pilbara from space via a dynamic global interface that is supported by Landsat images of the Earth. A new virtual field trip tool is being developed to enable students to look around the geological setting using the images, which contain three-dimensional data on the landscape. From this they will be able to zoom in all the way to ground level via a series of panoramas, each in context with zoom capability and 360 degrees of freedom, with a resolution down to large grains of soil. Areas of the landscape will be hot-spotted with information that may help support the hypotheses of the student.

The project will also include an electronic, mostly visual and/or multi-media, wiki website-driven library to be explored by the student to the level appropriate to each individual's ability and time. This library http://pilbara.mq.edu.au and the Virtual Field Trip are being built from joining an intensive workshop and field trip to the Pilbara in June/July 2005 with a five-strong education team including television producer Geoffrey Haines Stiles, who has provided 17 h of footage from capturing 'science in the making' during the field trip for US public television; Geoffrey Bruce from NASA Learning Technologies made a suite of images and sound, and created the Virtual Field Trip from them; Seth Shostak of the SETI Institute contributing more images, and gathering data to use in his work as a US-based science communicator and the authors of this paper made their own visual and audio record of the trip.

The project will also include another NLT tool, *What's the Difference?*, which will allow students to populate their own personal databases with text, visual and multi-media elements to allow them to quickly compare the data they collect. This tool also allows teachers to immediately understand and grade the progress their students make. Students everywhere will also be able to access and consult with scientists directly via a web site, which will be created in due course.

Essentially, students will have access to the Pilbara virtually in much the same detail as scientists experience in an actual visit. The debate on the biogenicity of the stromatolite structures opens the students to the different scientific interpretations of the same evidence and to hypotheses that not even we as designers of the project could anticipate. This means that, as in science, there are no definitive conclusions, only ongoing and improving interpretation of the evidence. It is very much a case that arrival at any one or more conclusions is perhaps less important than the journey itself—the process of science—that becomes the learning experience rather than the content, which will inevitably change with time.

The aim is to provide a project that can be undertaken independently by brighter students at school and at home, or in a teacher-facilitated classroom approach. In the latter case, inter-class, inter-school, inter-state and inter-nation collaboration is encouraged, much as science is done in universities and other institutions nationally and internationally. Partly to engage as wide a range of capabilities as possible, entry into the project will probably be via a series of challenges varying from simple field tasks to the more complex interactions required in hypothesis making, collecting evidence, analysing and interpreting.

3.1. The testing

At all points on our own journey we have felt that the final arbiters of the look, feel and construction of the virtual field trip should be the end users—the students

Fig. 1. NASA Deputy Administrator Fred Gregory with some of the students. Mr. Gregory visited in August 2005 to view the project.

Fig. 2. Some of the students engaging with ACA researcher Adrian Brown at MICTIC. Note the one-way mirror system allowing researcher access to the learning environment.

themselves. So we have taken the step of testing our concepts with students from seven Sydney high schools before putting the project together. One of the schools was chosen by the NSW Science Education Directorate early on during our quest to find a science teacher prepared to guide us. That teacher encouraged additional participation by her former high school, and the remaining five schools approached us as a group wanting to engage their students with scientists at Macquarie University, so were self-selected. The seven schools were split into three groups, with one group having three, rather than two schools in it. The maximum number of students in any group was set at 30. In the end it settled out at 28, 29 and 30 making a total of 87 students and seven high school science teachers participating in the project, though numbers varied by one or two per group due to absences (Fig. 1).

Each group visited the university three times.

3.2. Visit 1

This provided an overview of the project by engaging them with three of the ACA's scientists in a series of eight activities at the ACA and a presentation by one of the three scientists at MICTIC, where the students also engaged with some of the NLT tools. Two of the three groups uploaded a survey to NASA on their reaction to *What's the Difference?* with the third group undertaking that on their second visit. With two-thirds of the student responses in at the time of writing this paper, there was an overwhelming number saying it was helpful to very helpful, that they would rather learn about Mars and the Pilbara this way rather than ways they usually learned about things in school, that they learn more this way than by usual ways and that they would use this tool for an independent project. All but six of the students found learning more interesting using *What's the Difference?* (see Figs. 5–9 in the section 'early results' below).

3.3. Visit 2

For this the students were divided into two debating teams, one to build the case for the biogenicity of the Pilbara fossils and the other, the abiogenicity. An ACA scientist was assigned to each team to spend several hours discussing and researching the available information. They were able to use NLT tools and actual samples from the ACA to make their case. The object of this was to understand how students approach the task and what level of information they require. In our 2003 project we were surprised at the level of complexity students were able to grasp and integrate, given a free hand. From the student perspective we hope to provide a feeling for actual scientific debate, to impart that it is possible to have different interpretations of the same evidence and what the implications may be for the search for life on Mars (Fig. 2).

3.4. Visit 3

In the last visit the students were encouraged to consider their own hypotheses about the Pilbara stromatolites and to begin to build their own databases. They were able to take some of the Virtual Field Trip, which is still in development. We hoped to be able to see, in a final survey, that the experiences of these three visits have changed their perspectives on how science is undertaken, as well as having provided them with an enjoyable learning experience using ICT tools such as those developed by NLT (Fig. 3).

Our next step will be to test the project with a number of UK schools, in situ, during a 12-day visit to the University of Glamorgan. We will take the opportunity to see how the project fares when students do not have the experience of going into the university environment or the opportunity to interact with Pilbara-specialised

Fig. 3. Researchers participating in a Pilbara field trip in July 2005 from which a Virtual Field Trip tool is under construction in collaboration with NASA Learning Technologies.

Fig. 4. Professor Malcolm Walter, Director of the ACA discusses with a young student a 3.5 billion year old stromatolite-like structure.

scientists face-to-face. Finally we will bring the project together with the knowledge we have gained from testing to make it field-test ready, probably by early to mid-2006 (Fig. 4).

Teacher professional development will be offered and to learn from that to produce teacher-guidance notes.

4. Early results

Data collection has barely begun at the time of writing this paper. However, as stated already, we are beginning to see similarities to that in 2003. If these bear out it tends to suggest science outcomes at high school level in relation to adult civic science literacy are worthy of further investigation.

An additional experiment with a first year university class early in 2006 aims to further probe the idea that non-science focused students are leaving school with a minimal degree of civic science literacy at best, even

Survey question: *What does it mean to study something scientifically?*

Student A (indicates undertaking science at university)

Entry survey: "When you are studying something scientifically it means you are using information around and your own to come up with theories and solutions."

Exit survey: "To study something scientifically is to investigate, research and to interpret. When we study something scientifically we create our own hypothesis which will lead to more until we have a distinct answer. When we study something scientifically we are expanding knowledge and asking why."

Student B (indicates not undertaking science at university)

Entry survey: "To study something in detail eg to study how a plant grows is scientific."

Exit survey: "To analyse something in extreme detail to find out as much about it as you can usually by using a number of tests."

Fig. 5. Entry/exit survey result.

those educated to a level that allows them entry into university.

Oliver's initial survey of the 87 students involved in the testing showed that at the start of the project the majority could not offer any or more than one common descriptive term such as 'experiment', 'evidence', 'hypothesis', 'analysis' and 'interpretation', when asked what it meant to study something scientifically. Answers were scanned for the possibility of responses that implied an understanding without using any terms, but none were found. Yet the majority of these same students also scored highly when asked content-related questions aimed at understanding their scientific thinking abilities.

Further study is required though, not least because it is unclear as to whether these results are linked to fundamental literacy, science literacy or a combination [7].

Nevertheless some students among the 87 appear to have gained an understanding between the entry survey and exit survey results. Two of the examples are presented in Fig. 5.

4.1. Reactions to the project

The students were asked about their reactions to the testing of the project. Here are some of the responses:

Question 1: *What were your overall impressions of your experience with us on this project?*

- "The Virtual Field Trip project was great. It was full of information along with interesting facts and lots of pictures to make research more fun and applicable to real life."
- "I thought that it was a better way of learning. With advancements in computers and communication I can't see why this aspect of learning hasn't been used as often. I thought it was easier to understand."
- "Studying the Pilbara Virtual Field Trip project has taught me more about the geography of certain places like Mars and has helped me understand the ways life can exist."

Question 2: *What were your overall impressions of the NASA tools?*

- "The NASA tools were very helpful and I would find them very helpful in completing assignments."
- "They were easy to understand. I understood the differences and similarities between the Pilbara region and Mars. It was helpful in gaining information."
- "The NASA tools were very useful and enhanced my knowledge."

4.2. *'What's the difference?' tool*

Students were asked five questions specifically related to *'What's the Difference?'*, each with a quantitative response across a range of possible replies and an invitation to explain the response. The tool was loaded with a new suite of Pilbara-related data utilising the four comparative windows, and the students explored the tool via this data. Teachers and students can enter their own attributes for the four windows but this was not tested due to time limitations. The results are given in Figs. 6–10.

Here is a selection of comments from the students about *What's the Difference?*:

- The information was easily accessible and grouped together in clear categories. I found that it was fairly interesting as you could interact with the program (rotate pictures, click on things, have word definitions, etc.) so it captured my attention and kept it.

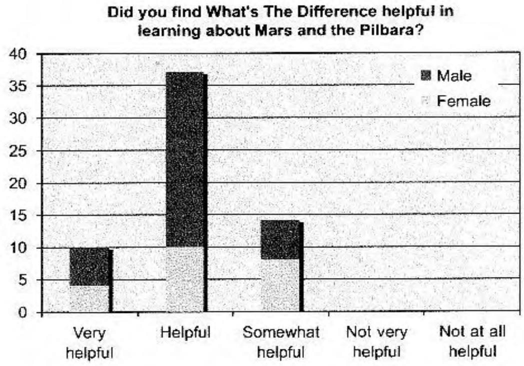


Fig. 6. 'What's the Difference?' Question 1.

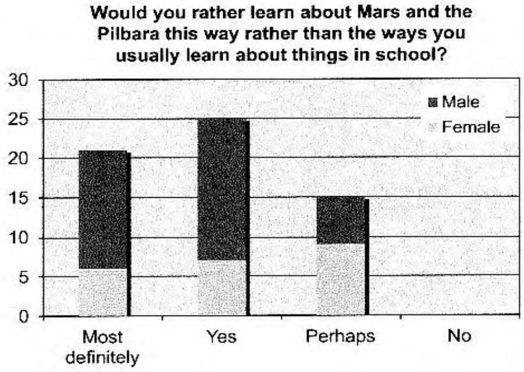


Fig. 7. 'What's the Difference?' Question 2.

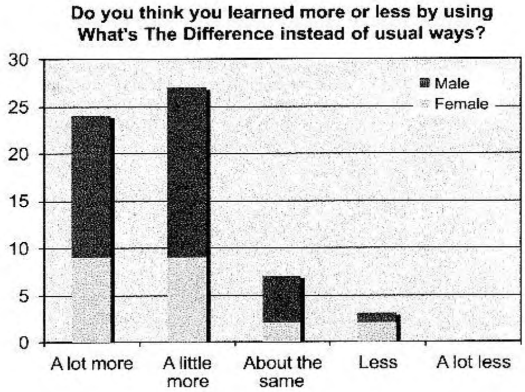


Fig. 8. 'What's the Difference?' Question 3.

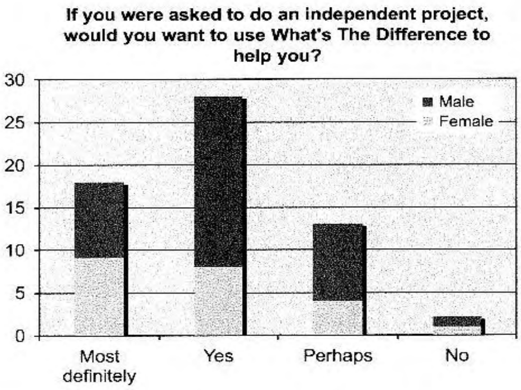


Fig. 9. What's the Difference?' Question 4.

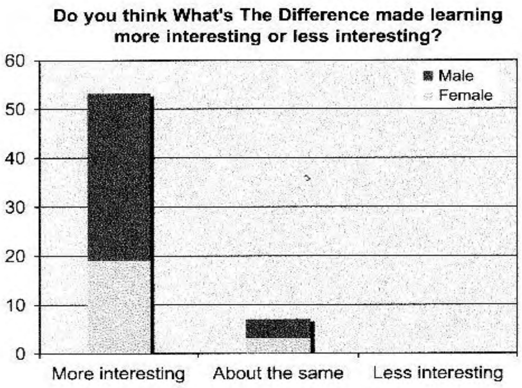


Fig. 10. 'What's the Difference?' Question 5. ('What's the Difference?' surveys were the result of a collaboration between Oliver and Tom Gaskins.)

- I would rather learn this way because at school we learn out of books instead of using a computer.
- I think I learnt about the same amount but a lot quicker than when taking notes and listening in a normal classroom environment probably because this caught my attention and was easy to use.
- The pictures and real life interaction is much better than a text book. It engages students more readily and is an easy medium to use.

5. Conclusion

Early results and interaction with NLT tools suggest that whether or not the hypothesis that science illiteracy begins at high school bears out, the project methodology will provide high school students with a learning experience that mimics how science is actually undertaken. It is also a project that can mostly transcend local and national science curriculum requirements, and on an international basis because it is not tied to any specific content but on the processes of science, which tend to be common to most science curricula. This is an important aspect in being able to share good quality projects across international borders and the potential to attract funding to undertake the making of them alongside understanding the impact of the projects both on students and teachers.

The project also opened the door to the creation of a new NLT Virtual Field Trip tool, which has the potential to join the suite of open source tools freely available to all others.

In addition, actual data will exist to guide and encourage others into new and more adventurous projects with the aim of improving science literacy at school and ultimately to future generations of adults.

In an increasingly science based world, we feel it is important for scientists and educators to continue to find novel ways of working together for a more informed public in the future. Astrobiology, ICT and NLT tools have come together to provide a strong foundation.

Acknowledgements

The authors would like to acknowledge the Macquarie University Biotechnology Research Institute for its support in this work. We would also like to acknowledge a grant of $119,500 from the Federal Government's Australian Schools Innovation in Science, Technology and Mathematics fund. In addition, we would like to thank the large number of individuals who have also contributed to our work, in particular Geoffrey Bruce, Tom Gaskins and Patrick Hogan (NASA Learning Technologies); Shelley Canright and Tammy Rowan of the NASA Education Office; Rhodri Evans and Mark Brake (University of Glamorgan); Daniella Scalice (NASA Astrobiology Institute); the four New South Wales teachers and their colleagues who have guided our thinking; and the scientists and other experts who have given their time and expertise, in particular Malcolm Walter, Adrian Brown, Abby Allwood, Philip Butterworth, and Andrew Simpson (ACA) and John Hedberg (Australian Centre for Educational Studies, Macquarie University). Oliver would also like to acknowledge the guidance of supervisors, for her related Ph.D., Malcolm Walter, Paul Davies, Richard Dawkins and John Hedberg.

References

[1] National Science Foundation, Science and Engineering Indicators, 2002 ⟨http://www.cnc.ac.cn/gb/others/nsf/200201/home.htm⟩.

[2] Eurobarometer 55.2, Europeans, science and technology, 2001 ⟨http://europa.eu.int/comm/research/press/2001/pr0612en-report.pdf⟩.

[3] R.E. Borchelt, Communicating the future: report of the research roadmap panel for public communication of science and technology in the 21st Century, Science Communication 23 (2) (2001) 194–211.

[4] Office of Science and Technology, UK. Science and the public: a review of science communication and public attitudes to science in Britain, Wellcome Trust, 2002.

[5] C.A. Oliver, J. Fergusson, S. Ryde, R. Anitori, E. DeVore, High school students in an international NASA mission: unexpected outcomes, in: 8th International Conference of Bioastronomy, July 12–16, 2004, Reykjavik, Iceland.

[6] M.R. Walter, Earliest life on Earth and the search for life on Mars, in: 5th Australian Space Science Conference, September 14–16, 2005, Melbourne, Australia.

[7] S.P. Norris, L.M. Phillips, How literacy in its fundamental sense is essential to scientific literacy, Science Education 87 (2002) 224–240.

Further reading

[8] S.M. Friedman, S. Dunwoody, C.L. Rogers, Communication Uncertainty: Media Coverage of New and Controversial Science, Lawrence Erlbaum, New Jersey, London, 1999.

[9] W. Graber, P. Nentwig, Scientific literacy: from theory to practice, in: H. Behrendt, H. Dahncke, R. Duit, W. Graber, M. Komorek, A. Kross, P. Reiska (Eds.), Research in Science Education—Past, Present, and Future, Kluwer Academic Publishers, Dordrecht, Boston, London, 2001.

[10] J. Gregory, S. Miller, Science in Public: Communication, Culture and Credibility, Plenum Trade, New York, 1998.

[11] E. Harcombe, N. Lane, The university as a partner in transforming science education, in: S.P. Marshall, J.A. Scheppler, M.J. Palmisano (Eds.), Science Literacy for the 21st Century, Prometheus Books, 2003.

[12] J. Hartz, R. Chappell, World's apart: how the distance between science and journalism threatens America's future, First Amendment Centre, Nashville, USA, 1997.

[13] A. Hobson, Teaching relevant science for scientific literacy, Journal of College Science Teaching, in press.

[14] K. King, Technology, Science Teaching and Literacy: A Century of Growth, Kluwer Academic, Plenum, New York, Boston, Dordrecht, London, Moscow, 2001.

PERGAMON

Available online at www.sciencedirect.com

ScienceDirect

Acta Astronautica 61 (2007) 548–552

ACTA ASTRONAUTICA

www.elsevier.com/locate/actaastro

The virtual space exploration education portal

C.A. Oliver

Australian Centre for Astrobiology, Macquarie University, North Ryde, NSW 2109, Australia

Available online 27 April 2007

Abstract

New information technologies have evolved from space exploration—3-D visualisation 'lenses' and a growing suite of tools that allow access to exploration, analysis and interpretation of often complex information by a range of end users including the public, communicators, and policy makers. These tools have only become viable in the past year or two with the combination of the availability of inexpensive, but powerful, personal computers and widespread use of the Internet. A new study group under Commission 6 has been established, entitled 'Future Directions of Space Exploration Education', to build a Virtual Global Space Exploration Education Portal (VGSEEP) to open this revolution to all audiences, not just students. This paper describes the initial stages of VGSEEP. The NASA Learning Technologies suite of 'lenses' and tools will be demonstrated: *World Wind*, a 3-D globe that provides insights into our planet from space and almost down to ground level; the *Virtual Field Trip* that explores at ground level in 3-D; the *Virtual Lab*, which allows a range of samples to be examined via a virtual light microscope and/or a Scanning Electron Microscope and *What's the Difference*?, which allows users to manipulate information in a multi-graphical interface.

1. Introduction

Science illiteracy among public audiences is an international issue. Nations around the world report concerns and major surveys in Europe and the US provide statistics that support the notion that the majority of public audiences are scientifically illiterate [1,2]. It raises the question of how this science illiteracy arises in societies that have made considerable effort to increase science literacy at high school level. Studies in Australia and the UK [3] suggest that this may continue to be a source of failure, depending on how science literacy is defined.

It is difficult to imagine why the circle of science illiteracy among high school students and science illiteracy among the adult public cannot be broken by the many innovative projects and approaches in high schools around the world. However, comments among hundreds of Australian and UK students undertaking a new hi-tech project, and among 175 first year Australian university students suggest a picture far removed from the actual business of science remains in the minds of young people. One university student, for example, captures the essence of what was seen in the 2005 study and in the later 2006 study.

> "Science is finite knowledge. I am interested in new knowledge. Therefore I am not interested in science."

One possible explanation for a perception that science is a finite knowledge may be the expectation that the teacher knows the answer, whether it is a classroom exercise or hands-on experiment. Ultimately the student's performance has to be evaluated. Yet knowing the answer is not descriptive of 'science in the making'. Among 114 Grade 9 and 10 students from five Sydney high schools only five used the word 'discover' or equivalent term in describing what it means to study something scientifically.

E-mail address: coliver@els.mq.edu.au.

0094-5765/$ - see front matter © 2007 Published by Elsevier Ltd.
doi:10.1016/j.actaastro.2007.01.062

2. Audiences

After formal education ends, the captured audience is lost. Often then the response to a scientifically illiterate public is to encourage scientists to connect and educate public audiences. There are many criticisms of this approach, not least of which is the lack of defining a specific message for specific audiences. According to Borchelt [4] there is no such thing as a general audience and that any message broadly cast will be lost.

Scholars have also pointed out that any learning, formal or informal, is subject to the preconceptions the intended receiver of the information has about any specific subject. The deficit model of communication, where it is assumed essentially the brain can be opened and knowledge tipped in, has been largely discounted [5]. A more accepted model is one of engagement where the communication taking place is more akin to an exchange of knowledge. There are questions, too, about whether science journalists—long considered the gatekeepers between scientists and the public—are educators. Many science journalists argue they do not educate, but rather inform [6] (Rensberger, 2003; Petit, 2003).

The advent of the Internet and its now widespread use has the potential to change the playing field. In the most recent Science and Engineering Indicators [1] statistics indicate that the public are still using print and electronic media for science news, but that they will also use the Internet to seek out information about specific areas in science. In other words, the Internet is becoming a powerful player as a repository of information, and has the potential to become a major force in the engagement with public audiences in space exploration.

3. Challenges of the Internet

There are now more than a billion people connected to the World Wide Web—one sixth of the world's population. When NASA landed two rovers, Spirit and Opportunity, on the surface of Mars in early 2004, it provoked an immediate public response. The Mars Exploration Rover website at JPL in California was flooded with requests for information. By the end of the first year the site had recorded 17 billion hits—more than all the hits put together for the entire NASA portal in the previous year.

However, in spite of a widespread use of the Internet, teachers in the UK, US and Australia continue to report poor technology access for students in their schools. Testing at Macquarie University during the creation of the NASA—Macquarie University Pilbara Education Project also suggests what is anecdotally and broadly known—teachers, especially more the more senior among them, are uncomfortable with the idea their students may be more adept at the technology than they are, so are reticent to deal with it. If something does not work on computers, teachers feel they should be able to fix it.

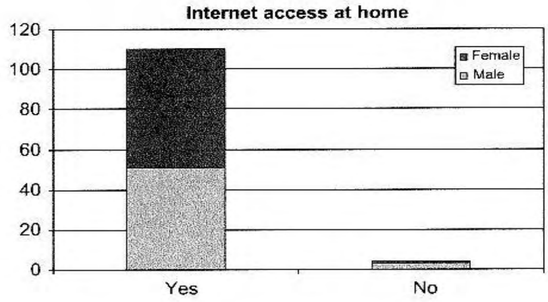


Fig. 1. A high uptake of home Internet.

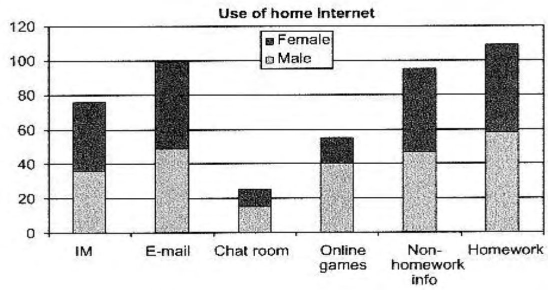


Fig. 2. A wide number of uses of home Internet.

At the same time students have increasingly good access to the Internet at home. Tests among the five schools mentioned above show most have access and most are connected via broadband (see Figs. 1 and 2). This is in spite of the fact that one of the five schools taking part in testing is considered to be in one of the lowest socio-economic areas in the whole of Sydney.

This suggests a window of opportunity to access a formal education audience outside of the formal education environment as well as inside it. Is it possible to leverage high uptake of Internet technology and its uses among high school students to encourage participation in science projects, whether or not directed by their teacher? And if so, is it possible to collect together products in this new breed of hi-tech project into a Virtual Global Space Exploration Portal to provide a single

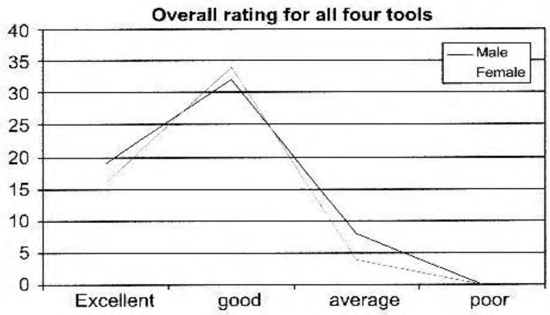


Fig. 3. Around 90% of students give the tools good or excellent rating.

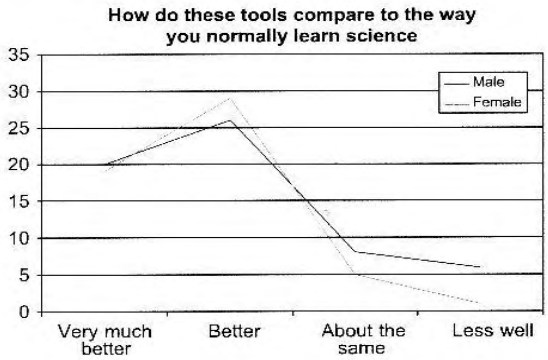


Fig. 4. More than 80% of the students indicate they would use one or more of the tools without direction from a teacher.

window into the hi-tech science and space exploration educational tools that students can easily access?

Final testing of the NASA-Macquarie University Pilbara Education Project suggests the answer to the first question may be yes. More than 80% of the 114 students said they would use at home one or more of the four tools that form the project, whether or not directed by their teacher (Fig. 3).

Approaching space exploration education using emerging technologies captures the imaginations of young people as well as their teachers. Fig. 4 shows that among the 114 students there is a clear preference to use technology to learn science as opposed to textbooks or 'chalk and talk' approaches commonly found in high schools.

In 2004, more than 55,000 K-12 American students were asked about how they saw the future of science education. Four themes emerged: 1. Personal digital devices; 2. Computers for everyone; 3. Intelligent tutor/helper with homework; 4. Experience a virtual world first hand [7]. This indicates the fascination with technology is not limited to any one nation, but is likely to be more broadly spread.

4. Impact on learning

During the course of the development of the Pilbara Project there were several hints, too, that further research should be conducted on the impact Information and Communication Technologies have on understanding the concept of the discovery nature of science. Among the 89 top science class 16-year-olds from seven Sydney high schools involved in mid-project tests, 25 reported that exposure to the project had persuaded them to study at least some science at university level.

In the final 2006 testing, one school reported a jump in the number of students for the Grade 11 subject Earth and Environmental Science from eight in 2006 to 20 registering for 2007—and most of those students had attended the testing of the Pilbara Project the week before. Another school reported a much higher than expected uptake of science subjects for Year 11 among those attending the Pilbara Project testing.

5. The Pilbara Project tools

The Pilbara Project captures 'science in the making' during a real field trip to the area in Western Australia where the earliest best evidence for life on Earth is located. It uses the *Virtual Field Trip* tool, developed in collaboration with NASA Learning Technologies, and employs other 'lenses' and tools already developed by NLT, including *World Wind*, *Virtual Lab* and *What's the Difference*? to allow users to experience cutting edge science. The Pilbara Project is open source and free. The beta version is available at http://pilbara.mq.edu.au. In the first three months the wiki website attracted more than 40,000 page visits with only low levels of promotion due to its beta nature. The completed version will be available via DVD and the wiki from early 2007.

These 'lenses' such as *World Wind* help drill down into the publicly available, but huge and complex, space agency databases. The tools, such as *Virtual Lab* and *What's the Difference*?, allow interpretation of the information. These freely available technological visualisations have become possible only recently with the widespread use of the Internet combined with access to inexpensive, but very powerful, desktop computing. For example *World Wind* makes use of these communication technologies to deliver a 3-D graphical visualisation of our planet to now more than five million users worldwide. It allows users to zoom in from space to within around 300 m of the ground, and, in areas of astrobiology interest, the *Virtual Field Trip* tool makes ground level views possible, beginning with the Pilbara.

6. Value of ICT in learning

Multimedia resources, by increasing visual impact, can improve scientific understanding. Hupper et al. (2003) investigated the impact of a biology simulation on high school students' academic achievement and their science process skills. The findings indicated that students in a simulated learning environment exhibited more complex and integrative reasoning. The simulation was found to benefit students with low reasoning abilities in particular, enabling them to cope with learning scientific concepts and principles which require high cognitive skills.

Similarly, Trindade et al. [8] found that visual modes of presentation aid understanding of concepts and processes. In order to realise their full potential, however, simulations need to be interactive, as the capacity to make predictions, test hypotheses and receive instant feedback helps to develop students' investigative and higher order thinking skills [9]. These are key aspects of the virtual field trip (VFT) tool and the other three NASA tools drawn together by the VFT.

7. Next steps

Pilbara Project team members are now working on the possibility of developing another hi-tech project that builds on the available tools to allow the public to contribute directly to the body of scientific knowledge. The thinking is that through making a contribution those participating will gain an insight into the discovery nature of science together with the selection and collection of evidence and its interpretation.

There is at least one forerunner to this project operated by the SETI@home team at the University of California Berkeley—the Stardust Mission. This engages the public in searching through 1.6 million images of a substance called aerogel fitted onto a space probe to collect interstellar grains. It is thought some 45 grains reside in the material, but require hand sorting to locate where they may be. Even before the material had been returned from space, more than 60,000 individuals had signed up to take a short web training course to get the go-ahead to search the images.

8. VGSEEP

Commission VI of the International Academy of Astronautics has set up a new study group to understand future directions in space exploration education. This seeks to explore the possibilities among both the formal and informal education environments, engaging students and the public in projects that utilise both emerging technologies and interdisciplinary connections that allow those technologies to be applied to the public environment. This requires the expertise of scientists, communicators, educators and technical people to understand and engage the wide range of perspectives across that expertise. This enables technology to be applied to scientific enquiry from the perspective of the public domain.

The aim of the group is to seek out existing and newly forming hi-tech projects and to make these available via a single Internet portal either directly within the portal or as a link to the web or wiki sites that support the project. It is hoped to utilise an IAA sponsored conference to bring together the relevant experts from around the world to consider how this might be best tackled.

9. Conclusion

Early research indicates that hi-tech education projects such as the NASA Macquarie University Pilbara Project, may mark a gathering wavefront of new technologies that may directly improve science literacy among public audiences. The author suggests that science illiteracy among school leavers may be changed not by the science curriculum, the school or the teachers but by the students themselves who indicate a clear desire to use technology as a learning tool in science whether or not directed to do so by a teacher.

Acknowledgements

The NASA-Macquarie University Pilbara Education Project is the result of work by three other individuals: Ms Jennifer Fergusson, Macquarie ICT Innovations Centre; Geoffrey Bruce, NASA Learning Technologies and Tom Gaskins, NASA World Wind. The project would not have been possible without their expertise and dedication. I would like to thank NASA, all those who assisted with the project, the schools, their teachers and the students for their time and input. The project was assisted by an Australian Schools Innovation in Science, Technology and Maths grant. I would also like to thank my Ph.D. supervisors: Professors Malcolm Walter (Macquarie University, Australia), Paul Davies (Arizona State University, USA), John Hedberg (Macquarie University, Australia) and Richard Dawkins (Oxford University, UK).

References

[1] National Science Foundation, Science and Engineering Indicators, ⟨http://www.nsf.gov/statistics/seind06/⟩, 2006.

[2] Eurobarometer 55.2. Europeans, science and technology, ⟨http://europa.eu.int/comm/research/press/2001/pr0612en-report.pdf⟩, 2001.

[3] C.A. Oliver, J.A. Fergusson, Does adult science illiteracy begin at high school?, in: 5th Australian Space Science Conference, Melbourne, Australia, September 14–16, 2005.

[4] R.E. Borchelt, Communicating the future: report of the research roadmap panel for public communication of science and technology in the 21st century, Science Communication 23 (2) (2001) 194–211.

[5] R.P. Hagendijk, The public understanding of science in regulated worlds, Minerva 42 (2004) 41–59.

[6] D. Nelkin, Selling Science: How the Press Covers Science and Technology, W.H. Freeman & Co, New York, 1995.

[7] J. Trindade, C. Fiolhais, L. Almeida, Science learning in virtual environments: a descriptive study, British Journal of Educational Technology 33 (4) (2002) 471–488 Netday (2004), Visions 2020, ⟨http://www.netday.org/news_vision2020.htm⟩.

[8] J. Trindade, C. Fiolhais, L. Almeida, Science learning in virtual environments: a descriptive study, British Journal of Educational Technology 33 (4) (2002) 471–488.

[9] L.M. Baggott La Velle, A.E. McFarlane, R.J. Brawn, Knowledge transformation through ICT in science education: a case study in teacher-drive curriculum development—case study 1, British Journal of Educational Technology 34 (2) (2003) 183–199.

Further reading

[10] S. Dunwoody, S.M. Friedman, C.L. Rogers, Scientists and Journalists: Reporting Science as the News, The Free Press, New York, 1986.