The *Heat Game*:

An Augmented Reality Game
For Scientific Literacy

By Carol Rees

Dedication

To Drs. Spacey, Daman, Acre, Justice, Hudson, Noot, Peff-Puff, Huggatree, and Leets

The student participants who volunteered for this study entered this world every science class for two months in the guise of scientist teams competing for the contract to design housing for sustainable living for their city. These students also submitted themselves to endless seemingly inane questions, and this work is dedicated to them in recognition of their patience and tolerance.

Abstract

If we are ever to achieve the goal of redirecting scientific investigation and technological development along more environmentally and socially responsible lines we need to provide students with an opportunity not only to understand information generated through scientific inquiry and technological innovation, but also to understand something of the processes and possible costs and consequences of this work. This kind of understanding might be best achieved by allowing students to gain experience in the real world of science and technology, working to solve real-world challenges and reflecting upon environmental and societal impacts, but such a real world setting is difficult to reproduce in a classroom. This study utilizes an augmented reality game called the *Heat Game* to provide a simulation of such a science and technology world. The *Heat Game* is modeled on the augmented reality game *Mad City Mysteries* (Squire and Jan 2007). In the *Heat Game* student-participants role play junior professional scientists and engineers working as part of a team to design energy efficient housing. They correspond with virtual expert professionals on laptop computers while engaging in science inquiry and technological design work in the classroom. This preliminary study presents evidence that after participation in the *Heat Game* students develop some new understandings values and attitudes about the science process, how it is used to construct science knowledge, how science knowledge can be used for technological development; and how making 'wise' technological choices can lead to a reduction in human environmental impact.

Acknowledgements

Thank you to Andy Manning for his patience with reading drafts and responding to the many e-mails generated through the course of this work; to Michele Knobel and Colin Lankshear for their discussions that inspired the project; to Blye Frank for the conversations about science that suggested the need for the project, to Jerry Harste for the encouragement that got the project started and to my husband Paul and daughter Kate for their tremendous support; without them the project would never have been possible.

Table of Contents

List of Tables

Chapter 1

Introduction

We live in a time when we can no longer ignore the environmental crises that result from our dominant mindset that sees the natural world as a collection of resources waiting to be exploited. The concomitant belief in the possibility of ever-increasing production and unlimited expansion can no longer be sustained. For many, this mindset is associated with scientific research and technological development since these are the tools upon which it depends.

Many people indeed have come to see science as being *responsible* for the environmental degradation and assorted threats of disaster. A recent MORI poll found that less than half of people surveyed disagree with the statement that "the risks of science outweigh the benefits" (Tallis 2007). There is a growing distrust of science's methods as well as its findings. Thus we see that many people are turning away from science and looking for alternative methods to explain the natural world. This reaction against science is revealed in attitudes towards standard medicine and the increasing popularity of alternatives such as homeopathy (Dawkins 2003). It is also made evident in reduced enrollment in high school and university science courses.

Public *comprehension* of the nature of science, of its methods of approach to understanding the natural world, and of the status of scientific knowledge is in general decline. In a world where an understanding of so many public issues (e.g. climate change, environmental degradation, toxic chemicals in the environment, illness and disease) is so critical, it is of paramount importance that the citizenry be in a position to evaluate these issues soundly. To do this the general public needs to be able to comprehend and evaluate science knowledge. To put this another way: scientific literacy is critically necessary if people are to ask appropriate questions of science knowledge claims, such as: How well is this science claim established? What experiments were done? What observations were made? Were they adequate?

Science education needs to change to meet this challenge. If we are to encourage young people to be interested in science and technology, or anything else for that matter, we need to present the fields of inquiry in new ways using the new methods of communication that are embedded in their way of thinking (Lankshear and Knobel 2006). We need to engage students so that they can see possibilities for the usefulness and relevance of science in their own lives (Hodson 2003, Roth 2004). Most important, if students are to learn to read scientific knowledge critically, is the necessity that they learn how science knowledge is constructed through the science process. To learn this they need a chance to do real inquiry-based science in a science setting (Rocard Report 2007) and they need a chance to *talk about* their science process work so that they can understand how science knowledge is constructed from it (Driver et al 1996).

An exciting new approach that offers a way to incorporate all of these ideas is the augmented reality game approach (Squire and Jan 2007). The aim of this study is to construct and try out an augmented reality game for science literacy. It is called the *Heat Game*.

Chapter 2

Literature Review

> *A scientist is a man who has cultivated (if indeed he was not born with) the restless, analytical, problem-seeking, problem-solving temperament that marks his possession of a Scientific mind. Science is an immensely prosperous and successful enterprise …..because it is the outcome of applying a certain sure and powerful method of discovery and proof to the investigation of natural phenomena: The Scientific Method….An episode of scientific discovery begins with the plain and unembroidered evidence of the senses – with innocent, unprejudiced observation, the exercise of which is one of the scientist's most precious and distinctive faculties – and a great mansion of natural law is slowly built upon it. Imagination kept within bounds may ornament a scientist's thought and intuition may bring it faster to its conclusions, but in a strictly formal sense neither is indispensable (Medawar 1982, p115).*

Key reasons for supporting a new approach to education for science literacy were advanced in the first chapter of the thesis. This chapter reviews literature pertaining to the development of a fresh approach that involves the construction of an augmented reality game for scientific literacy. There are three sections in this chapter. The first section is a review of the literature that informed the choice of the particular blend of views, values and attitudes to science incorporated into the definition of scientific literacy used in this work. The second section reviews literature concerning education for science literacy. The final section reviews literature pertaining to the development of the augmented reality game.

Defining Scientific Literacy

One way to help identify the views, values and attitudes to science that are typical of a scientifically literate person is to examine the views, values and attitudes of a person who is not; thereby throwing the attributes of scientific literacy into clear relief. The kinds of views on the nature of science embedded in Medawar's 'portrait of a scientist by an educated layman' (epigraph to this chapter) serve as a good starting point. Some of these 'traditional common sense' views of science are listed here (McComas 1996, 2004, 2005, Aikenhead and Ryan 1992).

- There exists a scientific method that is general and universal
- The scientific method leads to absolute truth.
- High objectivity is the hallmark of science
- Certainty results when facts are accumulated and analyzed.
- Science is less creative than it is procedural.
- Science is a solitary pursuit
- All questions posed by the universe can be answered via the scientific method
- Science and Technology are the same thing
- The effects of science and technology are inevitably destructive
- Science is useless in everyday life

The purpose of this section of the chapter is to review literature pertaining to these traditional common sense views of science, in order to construct a set of opposing views, values and attitudes that define scientific literacy, as the term is used in this study.

1) There exists a scientific method that is general and universal

The origins of *The Scientific Method* lie in a study done in the 1940s that asked scientists for information about the processes they used in their work (McComas 2004). This study eventually produced the formulaic version of the scientific method that is a commonly printed in text books. Students learn that the scientific method involves the following steps:

Step 1 Ask a cause and effect question
Step 2 Restate the question in the form of an hypothesis
Step 3 Develop a procedure to test the hypothesis
Step 4 Carry out the procedure and collecting data
Step 5 Analyze and interpret the data
Step 6 Form conclusions based on the data, and compare them with the hypothesis
(Science & Technology. Addison Wesley 2000, p 400).

The style makes it appear that scientists follow a standard research plan. McComas suggests that students might expect to find framed copies of *The Method* hanging on the wall of all science laboratories. In real science laboratories, scientists might roughly follow this basic plan if they were conducting an experiment. However the *formula* is most often imposed upon the work when the scientist writes a report (McComas 2004).

2) The scientific method leads to absolute truth

The idea that the process of science leads to the discovery of ‘the truth’ is probably the most widely disputed of all of the traditional common sense myths. In a recent article about the nature of science Robert Ehrlich makes the comment that it is the tentative nature of science that makes it so useful (Ehrlich 2007). Science is not supposed to produce absolute truth; scientists are expected to continually question current theories in the light of new evidence (Popper 1963). As Medawar (1982) explains, rather than hunting for ‘facts’ or formulating ‘laws’, scientists ‘build explanatory structures’. In other words they *tell stories* which they then go on to test using critical analysis (scrupulously; it is hoped). The huge importance of creativity and imagination in the scientific process is often overlooked. It is the ‘standard methodology’: ‘testability, evidential support, precision, quantifiability, consistency and repeatability that is stressed. Medwar (1982), like Popper (1963), believes that the scientific process actually involves the putting together of ‘explanatory conjecture’ or story telling *with* this methodology of ‘energetic critical analysis’. The ‘explanatory conjecture’/ ‘energetic critical analysis’ cycle is repeated over and over again. Old conjectures are rapidly supplanted by new ones in successive steps that are often difficult to trace (Medawar 1982). Science knowledge, being the result of explanatory conjecture, is necessarily tentative; and scientists must be prepared for it to be struck down or falsified (Popper 1963).

3) Certainty results when facts are accumulated and analyzed

When scientists find a discrepancy between theory and experiment or observation they are expected to show that either they did the experiment incorrectly or that the theory is flawed. Of course scientists will do everything in their power first to attribute the discrepancy to experimental error. An example of this comes from the work of Penzias and Wilson who first detected Cosmic Background Radiation utilizing a horn reflector antenna built to study radio astronomy (Penzias and Wilson 1965). The story goes that they were attempting to 'zero' the instrument to make measurements of something else entirely. They repeatedly checked their work and checked their instrument. It was only after they had established that there was no possible way that the 'noise' could be attributed to experimental error that they began to postulate the existence of Cosmic Background Radiation. Today Cosmic Background Radiation is considered by most cosmologists to be the best evidence for the *Big Bang* model of the universe.

Scientists are supposed to propose alternative theories when new evidence does not fit prior explanatory theory. Science knowledge is not supposed to be fixed. As Ehrlich (2007) puts it; "It is the open-ended and provisional nature of scientific explanation – ever subject to new evidence and testing – that gives science its power and utility". Science knowledge by its very nature is tentative and science cannot lead to absolute truth.

4) 'Discovering the facts' once is enough

This common sense understanding is evident in some classrooms but is not included on McComas's list. Since students sometimes believe that facts are absolute and certain, they can believe something is 'true' even when it cannot be repeated. The importance of precise reporting and repeatability to the process of science is included in McComas's list of core ideas about science (McComas 2005).

> Knowledge production in science shares many common factors and shared habits of mind, norms, logical thinking and methods (such as careful observation and data recording, truthfulness in reporting, etc.) McComas 2005

5) High Objectivity is the Hallmark of Science

It is not surprising that most people believe that science is objective. Most scientists working today were educated to believe that they were capable of objectivity. Scientists do their best to reduce bias or subjectivity in their work; they develop standardized measuring tools and methods; they demand that evidence and observations are demonstrable and repeatable for others to see; they subject their work to peer review and checking by others in cases where claims contradict important accepted theories. But subjectivity cannot be eliminated; scientists approach the world as human beings from a particular time and place and because of their particular mindset they will ask particular questions and interpret results in particular ways. Sometimes this aspect of our condition is termed 'theory laden' which seems an apt term to use. Hansen (1958) was the first to point out that all human observations occur through the lens of our preconceptions in his work *Patterns of Discovery: An Inquiry into the Conceptual Foundations of Science.* Kuhn elaborated on this work to produce *The Structure of Scientific Revolutions* (1962). He points out that science disciplines themselves impose 'theory laden-ness' on the scientists who work within them. Various branches of science have been reexamined in the light of this relatively new understanding, for example Primatology (Haraway 1989).

> The women and men who have contributed to primate studies have carried with them the marks of their own histories and cultures. These marks are written into the texts of the lives of monkeys and apes, but often in subtle and unexpected ways (Haraway 1989 p2).

For many, including Donna Haraway, science should be reinterpreted as an elaborate story-telling craft that is only one among many ways of knowing (Haraway 1989). However as the philosopher of science Hacking (1983) points out the demonstration of the close approximation of at least some science principles to 'reality' are the machines that are built using those principles.

> There are surely innumerable entities and processes that humans will never know about. Perhaps there are many that in principle we can never know about. Reality is bigger than us. The best kind of evidence for the reality of a postulated or inferred entity is that we can begin to measure it or otherwise understand its causal powers. The best evidence, in turn, that we have this kind of understanding is that we can set out, from scratch, to build machines that will work fairly reliably, taking advantage of this or that causal nexus" (Hacking 1983).

The point is that although scientists cannot be objective, this does not mean that astrology gives us just as valid a story about our place in the cosmos as astronomy and cosmology or that creationism and Darwinism give us equally useful information about the origin of man. Nor does it mean that scientists should give up their attempts to discover generalizations or principles about the behaviour of natural phenomena. What it means is that we all need to recognize the limitations of the process as well as its strengths.

6) Science is more Procedural than Creative

Because science often involves precise measuring, testing and analytical procedures, the huge importance of imagination and creativity often goes unnoticed. Medawar (1982) points out that science would not proceed very far unless researchers proposed meaning for their observations. This act of attaching meaning sets up possibilities that researchers can test. Whether we see scientists as creating explanatory models that they attempt to overturn through critical analysis (Popper 1963, Medawar 1982) or integrate into previously constructed paradigms (Kuhn 1962) there is no question that lots of imagination is required.

7) Science is a solitary pursuit

Although individual scientists are awarded prizes like the Nobel Prize for their work, scientists today usually work in teams. In addition, scientists work as part of a larger community. They must communicate their findings to other scientists for peer review before they are accepted as scientific knowledge. Although it would be misleading to suggest that all work done by scientists is checked and reviewed for accuracy (McComas 1996) it is true that when scientists make claims that are important and unexpected those claims will be checked. Scientists write their reports in a manner which allows checking. Their procedures are expected to be accurate and precise so that experiments can be repeated.

8) All questions posed by the universe can be answered using the scientific method

Many people assume that science can be used to test all sorts of processes outside of its scope (Ehrlich 2007). Science is a process that has evolved for the study of natural phenomena and it cannot provide even tentative answers to social, metaphysical moral or ethical questions. Since science operates through developing conjectures that can be tested it requires that all conjectures are falsifiable. If the conjecture is not possible to falsify then the science process cannot be used to test it. There was a fashion for a time of applying the term science in unusual directions. Domestic science and homeopathic science are two such examples and there are some who would argue that even social science is such a misnomer.

9) Science and technology are the same thing

Science and technology are distinct enterprises with different ends. Science seeks to explain the natural world while technology seeks to make human life easier. Many young people assume that science and technology are the same thing (Aikenhead and Ryan 1992). Science and technology are related but the exact nature of the relationship is disputed. In his soon-to-become three volume work on the historical significance of science on western culture, Olson (1990) points out that if science is seen as a *process* rather than as a *body of knowledge* the relationship between technological development and scientific thought becomes more obvious. As well as using the body of scientific knowledge that results from the scientific process to design machines, engineers use the scientific process when they test their devices or when they use new information about properties of materials (Olson 1990, p323). In addition new developments in technology can influence and make possible new conjectures in the domain of science.

10) The effects of science and technology are inevitably destructive

Together, science and technology can form a very productive partnership. However there is little doubt that they can generate findings and processes that, if deployed by society (often a political choice rather than one in science and/or technology *per se*) present dangers to human life, even to that of all life on the planet. Although we might initially consider advising scientists and engineers to behave responsibly and direct their attention to doing only good in the world, the problems that arise from science and technology can come from good intentions as well as bad (Medawar 1882). This raises the issue of responsibility and control of science and technology (Ralston Saul 1993). Corporations use the products of science and technology for profit and governments seem unwilling or unable to place the safety of citizens or the health of the planet before the interests of corporations. Hazards from industries built on the development of nuclear power, agrochemicals and pharmaceuticals go unchecked. Scientists and engineers working for corporations do not speak up and demand safe development of their products and ideas.

To many, including Ralston Saul (1993), all scientists should be 'tarred with the same brush' and the 'scientific community' acts as a single voice. But when Ralston Saul (1993) refers to the scientific community he is actually speaking about the community of scientists connected with science-based industry or government ministries; the scientists of the establishment. As well as scientists working for large corporations and government ministries there are those who strive to keep the activities of these organizations in check; many scientists work independently to this end. Ralston Saul (1993) sees the problem as being the result of the science way of thinking.

> The problem is not green or anti-green any more than it is environmentalists verses capitalists. The problem is the whole approach to truth and knowledge retention and power which goes far beyond these movements" (Ralston Saul 1993 p316).

Maybe it is too simplistic to ask why something as useful as science and technology can't be used safely with appropriate checks and controls. Scientists and engineers can direct their attention to those issues that pose greatest problems for society and the environment (Hodson 2003) and they can place their efforts into producing technologies that can make a difference. Although there is always the possibility that solar powered cars or water heaters might pose an unforeseen threat, and there is evidence that wind turbines may kill bats, few (except those with a vested interest) would dispute that these inventions are a lot less harmful to life on the planet than nuclear reactors.

11) Science thinking is useless in everyday life

Many young people believe that science thinking has no value in everyday life (Aikenhead and Ryan 1992), but science thinking is necessary if we are to interpret the science information delivered to us by the media. An example is the issue of global warming. Over the last twenty years the conflicting reports in the media concerning the magnitude of the problem of global warming and climate change have caused many people to simply ignore this critical issue (Monbiot 2006). As Hodson (2003) says, helping young people acquire scientific literacy means helping them acquire the capacity to critique scientifically derived knowledge. To understand scientists' predictions and warnings we need to understand the science they are based on. It is crucial that we pass on to young people the ability to judge the validity of reported data and it is also crucial that we teach them to ask questions such as; who funded the research?, and what interests might these sponsors have in the results?

Table 1 below summarizes the *Traditional Common Sense* and the contrasting *Reflective Scientist* views of the scientifically literate person. The aim of the learning game to be constructed will be to provide an opportunity for students to take on the reflective scientist perspective thereby gaining a deeper understanding of this point of view. In the next section of this chapter some approaches to science education that might be incorporated into the science literacy game will be reviewed.

Table 1 A comparison of Traditional Common Sense (TCS) and Reflective Scientist (RF) Understandings about Science

Traditional Common Sense Understandings	**Reflective Scientist Understandings**
1) The scientific method is general and universal	Science inquiry does not proceed using a prescription
2) The scientific method leads to absolute truth	Science knowledge is necessarily tentative
3) Certainty results when facts are accumulated and analyzed	Science cannot produce certainty
4) 'Discovering the facts' once is enough	Repeatability of evidence is crucial
5) High Objectivity is the Hallmark of Science	Science cannot be truly objective; it attempts to limit its subjectivity to provide general explanatory theories
6) Science is more Procedural than Creative	Science is a highly creative process but it uses rigorous procedures to test conjecture
7) Science is a solitary pursuit	Communication among peers must be frequent & open
8) All questions posed by the universe can be answered using the scientific method	Science is a process used to increase understanding of natural phenomena
9) Science and technology are the same thing	Although connected science and technology are separate institutions with different aims
10) The effects of science and technology are inevitably destructive	Science and technology can work for the good of people but they need to be controlled.
11) Science thinking is useless in everyday life	Science thinking is the kind of thinking we need to interpret science information in the media

Education for Scientific Literacy

In addition to the question of how to *define* scientific literacy (reviewed above) much debate in science education over the last twenty years has focused on how best to help students *achieve* it (Hodson 2003). In the early 1980s, following calls for major reform in science education (National Commission on Excellence in Education, 1983) the president of the National Academy of Science stated that the problem with science education was the emphasis on teaching "facts" that students had to memorize (Press 1982).

> Too many textbooks emphasize the students' ability to memorize, to remember facts, to regurgitate information rather than to think" (Press 1982).

Major efforts on the part of researchers (Hofstein and Lunetta 1982, Aikenhead 1990, Millar 1989, Driver 1997, Hodson 2003, Roth 1995) have led to a shift in the curriculum goals for science literacy education as can be seen in recent curriculum documents such as the new Ontario Curriculum for Science and Technology Grades 1-8, published in 2007.

> The goals are the following:
>
> 1. to relate science and technology to society and the environment
> 2. to develop the skills, strategies, and habits of mind required for scientific investigation and technological problem solving
> 3. to understand the basic concepts of science and technology (Ontario Curriculum for Science and Technology 2007, p1)

The authors of the curriculum guidelines go on to remind the reader that science and technology education cannot be viewed as the learning of facts:

> …..science and technology cannot be viewed as merely the learning of facts. Rather, science and technology is a subject in which students learn, in age appropriate ways, to consider both the knowledge and skills that will help them to understand and consider critically the impact of developments in science and technology on modern society and the environment. (Ontario Curriculum for Science and Technology 2007 p11).

The new curriculum emphasizes three related approaches for science education : authentic inquiry-based science education (Roth 1995) ; science education that relates to real life problems for society and the environment (Aikenhead 1990, Hodson 2003); and science education that provides opportunities for students to talk *about* the science enterprise (Driver 1996). These three approaches will be considered in turn.

Many scientists and researchers in the field of science education believe that the best why to build science literacy is to give students an opportunity to do *authentic inquiry-based science* (Millar 1989, Dawkins 2003, Roth and Roychoudhury 1993). This approach to science education has been around for a long time as is made evident in Dawkins essay

"*The Joy of Living Dangerously: Sanderson of Oundle"* (Dawkins 2003). Sanderson was headmaster of Oundle from 1857-1922. Under his care, pupils at the school were given free access to science laboratories and workshops to pursue their own authentic inquiry-based research investigations and technical design projects, with assistance and guidance from their teachers. The spirit of inquiry-based science learning lived on at the school until Dawkins was a pupil there. He relates a story from one of his classes where the teacher asked the question 'what animal eats Hydra?' The boy who was addressed did not know the answer so the teacher asked another boy. The teacher ended up going around the whole class but no-one knew the answer. By the time the teacher got to the last student everyone was focused on him waiting to hear the true answer. After a dramatic pause the teacher announced, "I don't know!" Dawkins tell this story to illustrate the manner in which teachers can encourage young people to ask questions that become a starting point for their own independent science research projects.

Roth (1995) explains that, in the tradition of Dewey and others, school activities need to share key features with those worlds about which they teach in order to provide the kind of authentic model Dawkins describes. In *Authentic School Science : Knowing and Learning in Open-Inquiry Science Laboratories,* Roth (1995) defines authentic science education as possessing five particular characteristics : 1) ill defined problems, 2) the social nature of scientific work and knowledge, 3) builds on students' current knowledge state, 4) students experience being part of a community of inquiry 5) in these communities members can draw on more knowledgeable others. The science environment that Roth (1995) describes, presents real-life problems with all the uncertainties and ambiguities that they present.

As well as science problems being authentic they need to be *real life problems* (Hodson 2003, Roth 1995). Hodson (2003) advocates a politicized, issues-based curriculum through which students would not only come to understand the interconnection between science, technology, society and the environment, but become prepared for the action they need to take to deal with present day crises (Hodson 2003). Roth (1995) suggests that such critical science education should focus authentic science investigations on real life issues that are of immediate concern, such as community water problems.

> One goal for critical science education would be to foster students' development of keen appreciations of places where science and technology intertwine smoothly with one's experience of life. The emergence of broader visions is supported when school children focus on issues and problems that are of immediate concern to their own lives and community (Roth 2004).

Hodson (2003) advocates linking science education to technological problems so that young people can focus on developing solutions. He makes the point that students need to feel that they can make a difference (Hodson, 2003).

A growing number of science educators make the valid point that students need time to *reflect on the scientific enterprise itself* if they are to understand " the power and limitations of science knowledge claims," (Driver et al 1996).

> Students in science courses should be given ample opportunities to develop a sound understanding of science, the Nature of Science, and the interrelationships among science, technology, society and the environment (Science Teachers Association of Ontario (STAO) position paper 2006).

When students are doing inquiry-based science they are focused on using science to come up with possible answers to questions they have addressed. Their inquiries do not necessarily lead them to understand philosophical questions such as 'can science lead to absolute truth or certainty?' or 'can scientists be truly objective?' An understanding of these aspects of the nature of science only comes when students have a chance to reflect upon what it is they are doing (Driver et al 1996). If young people are to understand how science knowledge is constructed they need to look at the science enterprise from the outside (Gee 2007). As well, the complex interplay between science research, technological development, government funding choices and corporate interests (Greenberg 2007) needs to be discussed in the classroom.

Although many science teachers agree that they would like to incorporate authentic real life inquiry-based science, and reflection upon the nature of science into their classes, as well as ‘covering’ curriculum requirements for science knowledge content, most find it difficult to see how to fit everything into their science-education time-slots, and many find that they lack the training/time needed to develop and implement appropriate science curricula (Hofstein and Lunetta 2002). If we are to be effective at achieving these laudable goals for science education we need to explore new approaches. One such exciting new approach comes from ideas in literacy education (Gee 2004, 2007)

A Game for Scientific Literacy Education

Recent exciting work that applies understanding of learning in a videogame world (Gee 2004, 2007) has led to the development of new types of learning games (Squire and Jan 2007, Shaffer 2006) that could revolutionize science education.

Gee’s work on literacy learning places it in the context of the Discourse where it is situated. Gee (1994) points out that it is only through our understanding of the *in vivo* utility of a literacy that we can hope to use it effectively.

> Any literacy must be defined as fluency in a given social practice and cannot be defined in terms of “the ability to read and write” (Gee 1994, p288).

The term Discourse (with a capital D) refers to the myriad of operations one performs to communicate or interrelate effectively within a specific social network that exists for a particular purpose (such as ‘lawyer in court’ or ‘doctor in his surgery’ or ‘physicist in her lab’).

> Discourses are ways of being in the world, or forms of life which integrate words, acts, values, beliefs, attitudes, and social identities, as well as gestures, glances, body positions, and clothes. A Discourse is a sort of identity kit which comes complete with the appropriate costume and instructions on how to act, talk, and often write, so as to take on a particular social role that others will recognize (Gee 1996)

Good videogames create a model world that is a re-creation of a specific social network or domain in which players learn how to proceed through trial and error runs. Players succeed when they find the mesh between their trial actions and the videogame world. After much practice players can internalize the model world for that game and ‘know’ how to proceed and succeed at the game.

Some good videogames have something additional to offer in terms of identity; the opportunity for players to identify themselves as authentic professionals in the virtual world of the game (Gee 2007 p. 68). Authentic professionals are experts within a particular domain. Normally they have earned this distinguished title through years of experience and major effort. By setting up the player as an authentic professional (who has help) the player has an opportunity to experience deep expertise (Gee 2007, p.68).

In such video games the player takes on the identity of a virtual character with whom s/he shares expertise or distributed intelligence. The virtual character has certain kinds of expertise and the player has others. The player/virtual character team work together to find their opportunities for positive action (or affordances) in the virtual world of the game. Finding affordances through effectively engaging in actions together with the virtual character provides the player with feelings of great satisfaction because of the achievement of mastery and control in the context of the game. The game *Full Spectrum*

Warrior is an example. In this game the virtual character in the game knows about being a professional soldier (attitudes, practices and strategies) and the player comes to know that too.

> By creating a joint authentic professional identity (in terms of knowledge, values, attitudes, practices, strategies and skills) games like Full spectrum Warrior and Riddick demand that the player learn to see the world in a certain way, different for each game" (Gee 2007, p. 77).

Gee examines *Full Spectrum Warrior* as a model for learning and through application of his earlier work on literacy learning he provides an outline of the way in which students might learn by taking on the identity of authentic professionals in a science discipline like physics.

> The recipe is simple: Give people well designed visual and embodied experiences of a domain, through simulations or in reality (or both). Help them use these experiences to build simulations in their heads through which they can think about and imaginatively test out future actions and hypotheses. Let them experience consequences, but in a protected way when they are learners. Then help them evaluate their actions and the consequences of their actions (based on the values and identities they have adopted as participants in the domain) in ways that lead them to build better simulations and better future actions. (Gee 2007, p. 81).

The player in *Full Spectrum Warrior,* through his/her engagement as an authentic professional, can experience what it is like to be a professional soldier. The player adopts, for a while at least, the values of a professional soldier in order to succeed in the game. The player learns by being immersed in the virtual world of the game and taking action guided by the structure of the game itself (Gee 2007, p. 78). In order to create a learning game for science the professional soldier needs to be replaced by the professional scientist and the virtual world domain of *Full Spectrum Warrior* needs to be replaced by a science virtual world.

Construction of some exciting learning games based on videogames has already taken place Squire and Jan 2007, Shaffer 2006). One such game is *Mad City Mysteries* an augmented reality game constructed by Squire and Jan (2007). An augmented reality game is constructed so that actions take place in the real world but the activities are augmented by a virtual world that the players can connect with. In the game Mad City Mysteries (Squire and Jan 2007) players use handheld computers to connect with the virtual layer of the game while they are out and about playing the game on the real world. The task for the players is to solve a fictional and mysterious death.

Players take on one of three professional identities (medical doctor, environmental specialist, and government official) they work as a team conducting virtual interviews and examining artifacts to obtain clues. There are 13 non player virtual characters in Mad City Mysteries. They are designed to be as interesting as possible because the game functions through the engagement players develop with them. They provide the leads, the documents and base storyline that the players interact with as they go through the game. Mad City Mysteries is designed to help students develop scientific argumentation skills. Players form hypotheses, collect evidence, discard/refine hypotheses and go around the cycle again until they develop a theory as to the reason for the mysterious death. The game is structured so that it supports or scaffolds the learning of scientific argumentation. This scaffolding occurs through the non-player virtual characters. The game Mad City Mysteries has been put through various trials with teams of players ranging from grade 4 students to students in high school and it has shown itself to be very successful (Squire and Jan 2007).

In *How Computer Games Help Children Learn* (Shaffer 2006), Shaffer describes the construction of *Epistemic games* each designed for learning about a different world including the engineering world (*Digital Zoo)* and the science journalism world (*science.net)*. Each game is designed to model the epistemology of a particular discipline. Professionals in training learn the particular way of approaching the world (epistemology) of their profession through immersion in it. They learn the knowledge, skills, attitudes and values through operating in that world. In Shaffer's terminology these constitute the epistemic *frame* of a profession.

Shaffer and his group developed their epistemic games through studying the way professionals in training learn the epistemology of their profession. These games allow young people to experience the world from the perspective of different professions. They allow young people to 'try on' different epistemic frames (Shaffer 2006).

The work to be described here brings together the epistemic game idea (Shaffer 2006) and the augmented reality game idea (Squire and Jan 2007) to create an augmented reality game that models a professional scientist epistemology set in an imaginary future world which student participants can explore. It focuses on the real life challenge of sustainability and environmental stewardship by making the goal the designing of energy efficient housing.

Professionals working within a particular domain exhibit their epistemic frame in a host of different ways (Shaffer 2006, Gee 2007) one of which is the way they speak about their work in their conversations. This game utilizes e-mail and blog conversations of student participants role-playing junior reflective scientists with virtual expert reflective scientists as they work together in an imaginary future scenario. The next section of this chapter will explain how the *Heat Game* was constructed based on *Mad City Mysteries* by Squire and Jan (2007).

Like *Mad City Mysteries* the *Heat Game* has a real world component in addition to the virtual world component. In the *Heat Game* participants actually engage in doing science and technology in the laboratory under the supervision of the teacher/researcher. The game is set in a future that acknowledges global warming and climate change, and where energy costs have sky-rocketed. The goal for the team of scientists and engineers is to conduct science investigations about heat that they apply to technological developments that reduce heat transfer in order to contribute to the practical task of designing energy efficient housing.

Through their assumed professional scientist characters, the participants communicate with their counterpart virtual experts via e-mail and a blog. Participants access the virtual world through laptop computers in the laboratory/classroom.

The virtual experts, played by the teacher/researcher, assist the participant teams as they conduct their investigations and apply their new knowledge. Assistance might be consultation on appropriate tasks such as experiments to conduct or models to build in the real physical space of their science lab. Participants send reports of their work to the virtual experts, and, after review, the reports are posted on the blog so that their content can be shared with other teams.

Students apply the science knowledge that they generate through their experiments to the real-life problem of designing energy efficient housing using SIMs. (installed on the laptop computers used in the lab.).

Student-participants receive the following information at the beginning of their participation in the game.

The scenario

The year is 2020: global warming continues to increase. Oil and natural gas reserves have reached a plateau so prices are prohibitive. Since we now recognize the limitations of natural resources, and the human impact on the environment, we have become a lot more careful. However, because of climate change, the temperature fluctuations in a given year are more extreme (SW Ontario: summer high 38°C to winter low -25°C).

In 2020, we in southwestern Ontario get the majority of our electricity from wind farms, although we still use hydroelectric generating stations. Because of the cost of developing new production methods the price of electricity is 100X than the 2007 prices, so we take great care with energy conservation. Our city desperately needs housing designs that can demonstrate the ability to maintain an indoor temperature of 20°C during winter and summer, but at the same time take care of environmental and societal concerns.

You are one of a team of three scientists (a physicist, an engineer and an environmental scientist/human rights advocate). You are competing against other teams for a contract to build houses for the city. The task for you and your team is to design the house by incorporating devices that reduce energy use for heating and/or cooling and to prepare a presentation for City Council to convince them to give your team the contract

City council has asked that your presentation include the following

1 A description of your plan

2 An explanation of your choices of devices and methods to reduce energy use in terms of :

- the particle theory of matter
- engineering
- environmental and societal impact
- budget
- comfort and ease of living

The virtual experts scientists who will help you with your work:

Dr Patrick Boyle: Physicist (Peggy and Dermot; his graduate students)
Mr G. I. Brunel: Engineer
Dr Rita Carson: Environmental Scientist

Other virtual characters:

Ms Chris Wren: Architect
Dr Stephanie Lewis: Human Rights Advocate
The Johnson family: Harry and Ida and their daughter Natasha
Mr Gordon Mc Phee: Financial Consultant
Mr Robin Garfunkel: City Councilor

The virtual people have distinct personalities. For example the expert physicist, Dr Boyle is quite detached from reality and the engineer Mr Brunel is stressed because of all the different interests he has to juggle. The family of course wants maximum comfort as well as lowest cost although Harry and Ida and their daughter Natasha are very nice. Dr Stephanie Lewis is very compassionate. Dr Carson is very down to earth. Each team of learners has three members: you may choose one of the following three roles.

Team physicist
You will interview Dr Boyle to help you decide the best experiments for your team to conduct to get information about heat transfer and to help you interpret your observations. He also fill you in on how the theories of the day explain what you see (such as the particle theory of matter). He assists you in making recommendations to suggest to the engineer for the energy efficient house. You are in close contact with Dr Boyle (expert physicist), his graduate students Peggy and Dermot.

Team Engineer
You will interview Mr Brunel to help you decide the best methods/devices for designing a house that uses as little energy as possible for heating and cooling. Sometimes you have to design experiments for your team to conduct, such as testing insulation. You are also responsible for the budget of the project.

Team Environmental Scientist and Human Rights Advocate
You interview Dr Carson to help you make judgments about the possible environmental impact of the building, including control of water pollution and indoor air pollution. You also interview Dr Lewis to help you make judgments about the societal impact of the building (e.g. are the materials made using child labour?)

The game was 'written' to have goals and scoring that allows participants to achieve the curriculum expectations for the Heat unit of the Grade 7 Ontario Curriculum. Files of information were collected to be used by each virtual expert including experiment protocols, information on devices and ideas for reducing energy efficiency, contact information for suppliers and prices.

In the virtual world of the game the teacher takes on the personalities of the individual virtual characters and communicated with the participants by e-mail and on the blog. In the role of virtual experts the teacher adopts a style of talking to the students as if they were colleagues working towards a common goal. The aim of the game is to set up conditions that *simulate* the manner in which real scientists and engineers *would* work and communicate in the *imaginary* world set up by the scenario of the game. The knowledge for this simulation comes from the teacher/researcher's own background as a professional scientist in an academic setting, from the advice of previous colleagues still working in this setting and from the advice of a professional engineer who volunteers at the school through the "Engineer in Residence" program.

In the real world of the laboratory/classroom the teacher played the role of Dr Rees, senior researcher, and participants and the teacher referred to each other by their professional "Dr." names. They spoke to each other as colleagues working towards the same aim, to design energy efficient housing. In order to understand the game, a 'mock-up' of a 'typical' class is given below;

> When the students entered the science laboratory on the first day they put on their laboratory coats and nametags. They were assigned laboratory space and provided with a few science necessities such as masking tape and a sharpie permanent marker. Each team had a laptop which allowed them to check their e-mails from virtual experts, access information directly from the internet, and design their houses using SIMS. Dr Spacey was the physicist for team C. She received an e-mail from Dr Boyle which provided her with a set of science questions about Heat and a set of protocols that could be used to address them. Dr Spacey asked Dr Rees where she might find the equipment she needed for the *Great Bolts of Fire* experiment (described in the case study). At the same time Dr Acre (environmental scientist for team C) was working on some information that Dr Carson (expert environmental scientist) had sent her about Green Roofs. Dr Hudson and Dr Justice worked on their house design on SIMs; Dr Noot set up an experiment to test the conductivity of different materials and Drs Peff-Puff, Leets and Huggatree prepared equipment for an experiment on testing different insulation types. All teams worked independently with Dr Rees's assistance throughout the work time in the Lab. Dr Rees circulated helping each team.

The role playing in the *Heat Game* allowed the teacher to act as a facilitator and at the same time set the tone that maintained the focus on the project.

Research Questions

The aim of the work described here is to explore the idea that the augmented reality game called the *Heat Game* might be useful for supporting elementary students' learning of science and technology in the classroom; particularly scientific literacy. This study is a preliminary investigation of some of the learning that occurred within the game play and concomitant debriefing sessions. It particularly focuses on investigating whether students adopted understandings, values and attitudes of the reflective scientist stance (as defined in an earlier section of this chapter) through engagement with the game.

The study investigates whether the game supports the adoption of any of the views, values and attitudes of the reflective scientist stance including attitudes of environmental stewardship, understanding of the nature and construction of science knowledge, skills of science inquiry and technological design and the usefulness of science in everyday life. The first part of this investigation looks at the conversations that occurred through e-mail and blog between student participants in their junior reflective scientist roles and virtual expert scientists. It addresses the following questions:

(1) Do the students *engage* in science and technology conversations with the virtual reflective scientists within the game play?

(2) What *themes* do these conversations address?

(3) Do the conversations *reveal* any of the students' understandings values and attitudes to science and technology and its relationship to society and the environment?

(4) Do the virtual reflective scientists *express* reflective scientist understandings values and attitudes?

(5) Do student participants *adopt* any reflective scientist views values and attitudes during conversations with reflective scientists?

Debriefing questions sent by e-mail asked student participants to examine their work in the Heat Game and use it as a context to answer metaphysical questions about science and technology and their relationship to society and the environment. The second part of this study compares the views, values and attitudes expressed by student participants in debriefing sessions and those expressed by participants on a questionnaire before the game. The research question addressed by this part of the study was:

(6) Did student-participants shift their profile of views, values and attitudes to more closely agree with the reflective scientist on the issues of the construction of science knowledge, the process of science, the relationship between science and technology, the interrelationship between science and technology society and the environment and/or the usefulness of science in everyday life?

In the next chapter the methods used to investigate these questions will be described and explained.

Chapter 3

Methods

Research Design and Rationale

To investigate the questions presented at the end of Chapter 2, the *Heat Game* was enacted with a group of grade 7 students in the Spring of 2007. This study is the very beginning of a larger design-based study involving the *Heat Game* that will follow the format laid out by Squire and Jan (2007). This larger study will involve cycles of game design, generation of hypotheses about what might be more effective, redesign and hypothesis refinement, where the appropriateness of game-design-changes comes from observing the educational outcomes developed by the students who test out the game in each cycle. As described in chapter 2, the *Heat Game* is a piece of education curriculum designed with different educational objectives but with a similar structure to *Mad City Mysteries.* Like *Mad City Mysteries* the *Heat Game* was built according to the principles of game-based learning theory (Gee 2007). The *Heat Game* was designed to encourage student participants to take on roles as junior reflective scientists with reflective scientist professional identities and perspectives. The *Heat Game* followed *Mad City Mysteries* design plan of teams of three students collaborating and competing with other teams. It followed *Mad City Mysteries* idea to situate the game space in an appropriate physical setting from the professional perspectives. Unlike *Mad City Mysteries* the *Heat Game* did not begin with already formed layers of narratives and tasks. Instead the *Heat Game* created narratives and science inquiry/technological design/information search and interpretation challenges through the virtual characters. These tasks were customized according to the directions taken by student-participants.

Student-Participants

The participants in the study were the full cohort of nine Grade 7 & 8 students, from a Montessori School in a city in Ontario, Canada, of 30,000 inhabitants. The participants were students in the class of the teacher-researcher conducting the study. The cohort comprised six grade 8 girls (two of whom experienced difficulties in a traditional classroom setting) and three grade 7 students, two boys and one girl. The two grade 8 students who had received psychometric assessment and were identified as needing individual education plans in the classroom. All students participated in the *Heat Game* to complete the Heat unit of the curriculum. Students were invited to participate in this study through a letter providing information about the study and asking for informed consent from students and parents. The format of the letter followed the guidelines given by the University Ethics Review Board (UERB) of Mount St Vincent University, and the UERB approved the study.

The study occupied six weeks during March and April 2007, (excluding March break). This provided about 15h of class time. Each individual session lasted 75 minutes. The study occupied the maximum time that could be allocated to this unit of curriculum in this school.

Throughout this study the participants will be referred to by their character names in the *Heat Game*: Team A: Drs. Peff-Puf, Huggatree and Leets; Team B: Drs. Noot, Justice and Hudson; Team C: Drs. Spacey, Daman and Acre.

Data Collection

In order to capture the developing views, values and attitudes of student participants, to science throughout the course of the project the researcher collected two kinds of data:

- e-mail and blog correspondence between role-playing student participants and virtual expert reflective scientists;

- student responses to statements about science, technology, society and the environment presented prior to and following participation.

Below, the two data sets are described along with the research questions that they were used to address.

E-mail correspondence and blog posts and comments were collected and organized into conversations called runs and examined to address the following questions: (1) Do the students *engage* in conversations about science with the virtual reflective scientists within the game play? (2) What *themes* do these conversations address? (3) Do the conversations *reveal* any of the students' understandings values and attitudes to science and technology and its relationship to society and the environment? (4) Do the virtual reflective scientists *express* reflective scientist understandings values and attitudes? (5) Do student participants *adopt* any reflective scientist views values and attitudes during the game play conversations with reflective scientists?

The questionnaire responses and additional information collected about views, values and attitudes of the student participants to science were used together to answer research question (6) Do student participants shift their views, values and attitudes to the reflective scientist position after the game?

The questionnaire instrument used before participation to collect student-participant views, values and attitudes was modified from Aikenhead and Ryan (1992) and Meichtry (1992). Aikenhead (Aikenhead and Ryan 1992) has done extensive work to discover the attitudes and understandings of Canadian students regarding science epistemology and the relationship between science, technology and society. To this end, he and his team, working in the early 1990's, interviewed thousands of Canadian students. Aikenhead and his group discovered that often students did not understand the language used in the questions they were asked. An example would be the word "tentative" in the statement "science knowledge is necessarily tentative" (Aikenhead and Ryan 1992). They created a new set of questions for students that used student language generated from the interviews they had done. From their work they created a new instrument for gaining knowledge of students' opinions called VOSTS (Views on Science Technology Society). VOSTS are structured as 'extreme' statements and Aikenhead and his group used these as provocative statements to get students thinking. Students then chose a response to the statement from a selection of responses generated in the interviews that Aikenhead had conducted. Because of the manner in which they were constructed VOSTS offer science epistemology questions in high school student language.

Grade 7 and 8 students often find it difficult to read a lot of information. On a trial run of using VOSTS it was discovered that the grade 7 and 8 students in this study found it difficult to read the possible alternative answers and keep them straight in their heads while selecting an answer. Looking through the literature a questionnaire modified especially for grade 7 and 8 students in the topic of science epistemology was discovered. Yvonne Meichtry (1992) modified it from a previous questionnaire for high school students for her study on teaching the nature of science and scientific knowledge to middle school children.

In order to create the questionnaire for this study, some questionnaire statements were used from the Meichtry study (1992) along with some VOSTS for the work of Aikenhead and Ryan (1992) that were shortened to make them easier for younger students to read. A statement used in this study modified from the VOST statement is given below as an example. The students were not asked to select a response. Instead they were asked to choose between agree, disagree, maybe or don't know.

> **Scientists and engineers can tell us only what *probably* might happen. They cannot tell what will happen for certain.**

The questionnaire for this study included 88 test statements aimed at discovering understandings, values and attitudes to science and technology and their relationship to society and the environment.

Before participation in the game, the statements on the questionnaire were read to the students. The students were asked to mark agree, disagree, maybe or don't know on the answer sheet. The questionnaire and the answer sheet can be seen in Appendix 3. Following examination of blog and e-mail correspondence a sub-set of statements from the initial questionnaire were selected to collect more in depth information on student participants' understandings values and attitudes to science after participation. Table 2 below shows the twenty-three questionnaire statements selected for use post participation. The particular questionnaire statements used were selected because they reflect the four themes that were evident in the blog and e-mail correspondence. Statements concerning a fifth theme were also selected: *the usefulness of science in everyday life*. After participation these 23 questionnaire statements were presented to the students in the context of the work they did in the *Heat Game.* This was done by creating a set of questions customized for each participant that connected the questionnaire statements to that student's experiences in the game (see appendix 2).

Table 2 List of questionnaire statements used to gather views, values and attitudes to science after participation

Topic: Constructing scientific knowledge

1. Generating scientific theories requires imagination.

2. Today's scientific theories may have to change if new evidence is discovered.

3. Scientific observations and interpretations can be different if scientists believe different theories.

4. Science knowledge may have to change if new evidence is discovered.

5. Scientists and engineers cannot tell us what will happen for certain.

Topic: Science Process

6. Scientists write reports in a very logical orderly way but they do the work in a much less logical and orderly way.

7. Scientific knowledge must be based on evidence that can be repeated over and over again.

8. Test results have to agree each time the test is done, before the results are accepted as scientific knowledge.

9. Scientists must report their work to other scientists for review before it is accepted as scientific knowledge.

10. When a research team makes a discovery, it is not alright for them to announce it to the press before other scientists have discussed it.

11. Scientists must check each other's work before it is published in science journals.

12. Students can add to scientific knowledge.

Topic: Science and Technology.

13. Science and Technology are closely related to each other because scientific research leads to new technology.

14. Engineers depend on scientific knowledge to build devices or machines that work..

Topic: Interrelationships between Science, Technology, Society and Environment

15. Science and technology cannot be relied upon to fix pollution problems in the future.

16. Scientists should not be held responsible for the harm that might result from their discoveries.

17. Scientist should be free to investigate what interests them.

18. The community should decide what research to fund.

19. Government agencies should decide what scientific research to fund.

20. Corporations should not decide what research to fund.

Topic: Science in Everyday Life

21. In everyday life, thinking like a scientist helps us solve practical problems.

22. Thinking like a scientist helps us figure things out and decide whether something (e.g. an advertisement) is true or not.

23. To understand scientists' predictions and warnings, we need to understand the science they are based on.

The student participants' final products from the *Heat Game* were not used as data to look for changes in views, values and attitude because these products were viewed as collaborative products created according to specific guidelines given by the teacher. Some examples of the final work of the students have been placed in the appendix 1.

Data Analysis

The Case Study

Following collection and organization of the e-mail and blog correspondence at the end of the game the teacher/researcher selected the correspondence of one team of student-participants for more in-depth examination. This group was chosen because they responded to all correspondence from the virtual experts and wrote most profusely in their correspondence, and their activities in the *Heat Game* involved all four themes of science discussed by participants in the game. These themes were: the construction of science knowledge, the process of science, the relationship between science and technology, and the interrelationship between science, technology, society and the environment. From this team of three, one student (Dr Spacey) was selected for the construction of a case study because she was the chief writer of correspondence. Dr Spacey corresponded mainly with the virtual expert Dr Boyle.

Quantitative methods

To analyze the questionnaire-statement response profiles of participants, they were compared to constructed standard reference profiles of a Traditional Common-Sense non-scientist, and of a Reflective Scientist.

These standard reference profiles consisted of expected responses of Traditional Common Sense Non-Scientists and of Reflective Scientists to the test-statements listed in Table 1. These profiles were based on the literature reviewed in chapter 2. The Reflective Scientist would agree and the Traditional common-sense non-scientist would disagree with all test statements as they have been written in Table 2 (see above).

Student responses to questionnaire statements, collected at the three different stages of the study, were scored according to whether they agreed with the Reflective Science or the Tradition Common-Sense profile.

The Sign Test: In comparing changes in the scores of responses to test-statements at two different stages of the assessment, there are two possibilities: either the number of students responding to each question as would the Reflective Scientist would increase, or it would not. The significance of any tendency for such positive movement in the group of participants across all test-statements can be assessed using the Sign Test: it compares the number of "successful tests" (cases where there is movement of the participant group towards the Reflective Scientist position) with the total number of tests (the total number of test-statements). The sign test was used to compare pre-test responses with those made immediately following participation; and to compare pre-test responses with those made five-months following participation.

The Chi-squared test: For each individual participant a statistical comparison can be made between the distribution of responses to the test-statements collected pre-participation (PP) and immediately post-participation (IPP) or pre-participation and five-months post-participation (FPP). If the *Heat Game* experience has been ineffective, then the distributions should be similar at the three stages (PP, IPP, and FPP) for all students, for all participants. Using the chi-squared test in pair-wise comparisons (PP vs. IPP or PP vs. FPP) it is possible to determine whether differences between distributions are significant or not, for each participant. To do this the number of agreements and disagreements with the reflective scientist are tabulated across all statements at the two stages being compared. The chi-squared test tells us whether the numbers observed at the second stage (either IPP or FPP) deviate significantly from those expected on the basis of the numbers observed at the first stage (PP).

Chapter 4

Results

In this chapter the data collected are examined to address the questions presented at the end of Chapter 2. Questions 1 and 2 are addressed using the blog and e-mail correspondence data for all student participants. Questions 3-5 are addressed using a case study constructed for one student participant, and question 6 is addressed using the questionnaire response data for all student participants in the study.

Response to Question 1: ***Do the students engage in science and technology conversations with the virtual reflective scientists within the game play?*** Two hundred and sixty-five e-mail or blog exchanges between participants and virtual experts were collected during the six weeks of the game. Two hundred and twenty seven of these involved science related talk. These exchanges were organized into 20 conversations called runs that occurred between student participants and virtual reflective scientists (a run being defined as the conversation about a particular piece of work and involving the same participants and virtual expert). Table 3 shows the runs, with their descriptive identifying names, the student participants, the virtual experts that were engaged in each run, and the number of exchanges involved in the run. Examination of Table 3 shows that while all student participants engaged in science and technology conversations or runs, some student participants engaged in more runs than others; for example Dr Spacey engaged in four runs while Dr Daman engaged in two. In addition some runs were longer than others as indicated by the difference in the number of exchanges involved in them; for example Great Bolts of Fire had 21 exchanges while Molo had 10.

Response to Question 2: ***What themes do these conversations address?*** The topics for conversation in runs reflected the activities that student participants were doing in the lab; for example the run *Great Bolts of Fire* concerns the experiment called "Great Bolts of Fire and the run Molo concerns the use of a phase change simulation using Molo software. Reading of the conversations between student participants and virtual experts in the runs revealed four general themes. The general themes of the conversations were identified as: 1. construction of scientific knowledge; **2.** scientific process; 3. relationship between science and technology; 4. the relationship between science and technology, and society and the environment. The numbers listed in the "Theme" column of Table 3 refer to these themes. Not all themes were represented equally reflecting the fact that student participants engaged in different activities in the game and therefore were talking about different aspects of science with the virtual characters. For example, *Great bolts of Fire* involved a science experiment conducted by Dr Spacey and Dr Acre, the results of which were applied to designing a house that was energy efficient to reduce global warming: this run involved conversations between the student participants and Dr Boyle that concerned *science process* (theme 2), *science related to technology* (theme 3) and *science and technology related to society and the environment* (theme 4).

Table 3 Run names, team participants, virtual expert advisors and category of science

Run Name	Team (A/B/C), participant	Virtual Expert	Number of exchanges	Theme
1) Great Bolts of Fire	C, Dr Spacey and Dr Acre	Dr. B	21	2, 3, 4
2) Molo	C, Dr Spacey and Dr Acre	Dr. B	10	1
3) Grob	C, Dr Spacey and Dr. Acre	Dr. B	10	1
4) Downsize C	C, Dr Spacey and Dr Acre	G.I.	15	3, 4
5) Green Roof	C, Dr Acre	Dr.C	10	4
6) HRV	C, Dr Daman	G.I.	24	2, 3, 4
7) Soil insulation	A, Dr Peff-Puff, Dr Huggatree, and Dr. Leets	Dr. B	41	2, 3, 4
8) Green Roof Drainage	A, Dr Huggatree and Dr. Peff-Puff	Dr. C.	10	4
9) Windows	A, Dr Leets and Dr. Peff-Puff	G.I.	17	4
10) Downsize A	A, Dr Peff-Puff	G.I.	11	3, 4
11) House A	A, Dr Peff-Puff		6	4.
12) IKEA	A, Dr Peff-Puff	Dr.L	7	4
13) Sedum Mats	A, Dr Huggatree	Dr. C	2	4.
14) Thermometer	A, Dr Peff-Puff, Dr Huggatree and Dr. Leets	Dr.B	6	2
15) Black and White	A, Dr Leets and Dr Peff-Puff	Dr.B	2	2
16) House B design	B, Dr Hudson and Dr Justice	G.I./J	33	4
17) Thermal Chimney	B, Dr Hudson	G.I.	3	4

18) Green Roof B	B, Dr Justice	Dr. C	23	3, 4
19) Passive solar	B, Dr Justice	Dr.C	2	4
20) Conductivity	B, Dr Noot	Dr. B	10	2, 3, 4
21) Plastic Lumber	B, Dr Noot	Dr. B	7	2, 3, 4

The Case Study

Questions 3 to 6 will be answered for one student participant using a case study. The case study is designed to give the reader a sense of the data. As explained in Chapter 3, Dr Spacey was chosen because she was the main correspondent for Team C. Team C engaged in four runs that ranged over all four themes of science (the construction of science knowledge, the process of science, the relationship between science and technology and the relationship between science, technology, society and the environment). The case study is divided into four sections. Each section describes Dr Spacey's work in a particular run. The four runs are called: *Great Bolts of Fire, Downsizing C, Molo* and *Grob* respectively. At the beginning of each section the run is briefly explained. Then Dr Spacey's work in that run is presented. Following the case study, questions 3-5 are addressed.

In the first run to be described Dr Spacey engaged in an experiment called *Great Bolts of Fire* to compare the amount of heat energy that could be transferred from two metal bolts of different masses that have been heated to the same temperature. Dr Spacey got the protocol from Dr Boyle the virtual expert physicist. The purpose of the experiment is to help students understand the difference between temperature and heat energy. Understanding this concept is relevant to the project that participants are working on because it is the reason why keeping a larger house at 20C uses more energy that keeping a smaller house at the same temperature. Understanding the concept is also a specific curriculum expectation for the Heat unit.

The experiment *Great Bolts of Fire* offers a context for Dr Spacey to engage in the process of doing science in the lab and having science conversations with Dr Boyle and other scientists, virtual and real.

The exchanges between Dr Spacey and Dr Boyle entitled *Great Bolts of Fire* occurred over a period of ten days. Dr Spacey spent five hours in the lab on four different days during this time period. Dr Spacey was the physicist for her team and she corresponded primarily with Dr Boyle, the virtual expert physicist. This conversation involved twenty-one exchanges, ten e-mails with Dr Boyle, three blog posts of Dr Spacey's work posted by Dr Boyle and seven comments on the blog posts. Dr Spacey entered the virtual world when she e-mailed Dr Boyle to thank him for sending their team experiments to try out.

> Thank you very much for giving me some ideas for experiments that I could use to determine the best ways to build an exceptionally good house. My team and I are going to try your experiments and send you the results we get.
> As a physicist what do you think is the most interesting thing about physics??
> Dr Spacey

Day 1 in the Lab: Dr Spacey chose a procedure for an experiment called *Great Bolts of Fire (Understanding the Difference between Temperature and Heat)*. She read the procedure and got the equipment together in the lab. She worked independently but asked Dr. Rees for any needed assistance. She tried the experiment and it didn't give her the results she expected.

Day 2 in the Lab: She discussed the experiment with Dr Rees and they collaborated to made adjustments to her procedure. Dr Spacey got her procedure working well. Working independently, Dr Spacey produced and sent the e-mail shown below.

The experiment that I did entitled Understanding The Difference between Temperature and Heat had a few flaws in it. I made a few adjustments and the results were a bit better. I used bolts that were extremely different sizes. I boiled the water in a kettle before I put it on the hot plate. I used test tubes and a smaller amount of water instead of having a larger volume of water like there was in the styrofoam cups. The experiment results are as follows for your experiment and my adjusted experiment.

Your Experiment

Original Water Temperature - 22 °C

Minute	**Tube 1 (large bolt) temperature**	**Tube 2 (small bolt) temperature**
1	24 °C	23 °C
2	24 °C	23 °C
3	24 °C	23 °C
4	24 °C	23 °C

My Adjusted Experiment

Original Water Temperature – 21 °C

Minute	**Tube 1 (large bolt) temperature**	**Tube 2 (small bolt) temperature**
1	29 °C	23 °C
2	29 °C	23 °C
3	29 °C	23 °C
4	29 °C	23 °C

Dr Boyle replied:

Thanks a million for putting in the time Heat Team C.
If I remember rightly your physicist is Dr Luna Spacey? I would like to know so that I can post these results on the blog with her name on it. I have a feeling other teams might be keen to read about it. **Also can you tell me the sizes of the bolts?** I notice that the first time you did the experiment the water didn't heat up much at all. **Could you tell me whether you used galvanized bolts and whether that made a difference? Also could you measure the volume of water you used in the styroform cup and in the test tubes?** As soon as I have that information I can post this experiment on the blog. It would be wonderful to get a photo to go with this. **Could you have someone take a digital photo and e-mail it to us**?
Hope to hear from you in the next day or so.
Dr B.

Dr Boyle's reply asks Dr Spacey some questions. These are practical pieces of information that would be needed if someone was to try repeating Dr Spacey procedure and get the same results. Dr Boyle went ahead and posted the results of Dr Spacey's experiment (shown above) on the blog and Dr Spacey received 2 comments on that blog post. These comments asked her further questions about her work. They were from other virtual characters. One asked Dr Spacey for more detailed information needed to repeat the procedure**.** One piece of information needed was the mass of the bolts. The other comment asked her to relate the experimental results to the real life problem that participants were working on: "To Design Energy Efficient Housing". Dr Spacey answered these comments in two further comments on the blog.

Day 3 in the Lab: Dr Spacey put together her experiment set-up again, took pictures with her digital camera which she keeps with her and made the measurements that Dr B had asked for.

Dr Boyle received the answers and posted them as a second blog post. You can see that Dr Spacey has given the size *as lengths measured in centimeters* rather than *as masses measured in grams*.

> The first time i did the experiment i accidentally used galvanized bolts which changed the results very much. i've made a chart to show the differences between experiment one(Ex1) and experiment two(Ex2)

Details	**Ex1**	**Ex2**
Bolt size	Large: 11cm Small: 5.5cm	Large: 8.5cm Small: 2cm
Bolt type	Galvanized	Non-Galvanized
Water volume	Cups: 150ml	Test tubes: 50ml

This post received a comment asking for the bolt measurements *as masses*. This is significant because it is the masses of the bolts that is so important.

Hi Dr Spacey,
I'm wondering about the bolts **what is their mass?** I am getting frustrated because when I try to repeat the experiment I don't get the same results! Now I thinking my bolts may be thinner. **The best way to know that we are heating up the same amount of matter is if the bolts have the same mass**. **Could you please weigh your bolts and post a comment to let me know their mass?**

A fellow scientist

Day 4 in the lab: Dr Spacey measured the mass of the bolts and sent this as a comment on the blog post. She completed a write up of her experiment with Dr Rees which is posted as a comment on the post of the pictures.

I have sent some pictures that i hope will be posted soon but until then i guess I'll just have to answer by describing things. **the mass of the non-galvanized bolts** (the ones you should be using) are as follows.
large bolt - 59g
small bolt - 6g

Dr Spacey e-mailed answers to Dr Boyle's questions and the pictures she had taken. Dr Boyle posted these on the blog and Dr Spacey's posts received more comments.


1. The 2 bolts of different sizes used in the experiment.
2. The bolts in the water bath to be boiled.
3. The bolts in the water bath viewed from above.
4. The large bolt in the testtube
5. The thermometer measuring temperature in the test tube (these 2 steps were repeated for the small bolt)

Results: the large bolt and the small bolt started at the same temperature. The large bolt had more heat energy and therefore it heated the water in the testtube to a higher temperature than the small bolt did.

Conclusion: The amount of heat energy in an object depends on more than just the temperature it is at, it also depends on the mass of the object.

Dr Spacey's answer to the comment asking about the relationship between this experiment and housing for sustainable living shows that she understands the connection

> This experiment is telling us that we want to build a smaller house for sustainable living. My reasoning for this is that with a smaller house you have a smaller amount of space (air and stuff) that needs heating during the year. Which means that it won't cost as much to heat a smaller house. With this information you could theoretically build the perfect house for the Johnson Family. They want a low cost for energy bills in their house. Heating takes up energy. With a smaller house you need less heat which means you need to use less energy.

When Dr Boyle answered Dr Spacey's question about physics this was her response

> I love physics. being able to change the world with one little discovery is mind-boggling. just the thought that everyone used to think that the world was flat and such silly things as that and that science and technology used physics to prove them wrong and show the people the truth. physics was as still is a very important thing in everyone's lives. and I'm glad to be a part of it.

The second run that Dr Spacey engaged in is called *Downsizing C*. A big part of the activity of Team C centered around creating a house design on SIMs and although the team discovered through *Great Bolts of Fire* that downsizing was a good idea, follow through was a bit of a problem. SIMs offers lots of wonderful options that are hard to resist. Dr Spacey worked with Dr Acre on the SIMs house. Dr Acre owned the SIMs game that the team used and she had a lot of input into house design. Team C created a wonderful house with a green roof using SIMs that they posted on the Blog (see next page). The run *Downsizing C* began with a comment on the post of this house picture on the Blog. It consisted of 15 exchanges and several were concerned with mathematical calculations, some of the correspondence is included here.

Wow! Your house is huge and when I mean huge, I mean HUGE.
Do you know how much heat is lost through the entire house? I am sorry that I am digging in on you, but I would like to let you know that I am thoroughly concerned about your house (I love the rest of this site too).
Thanks, now my guilty conscience is lifted.

Blog Comment from Dr Spacey

This experiment is telling us that we want to build a smaller house for sustainable living. My reasoning for this is that with a smaller house you have a smaller amount of space (air and stuff) that needs heating during the year. Which means that it won't cost as much to heat a smaller house. With this information you could theoretically build the perfect house for the Johnson Family. They want a low cost for energy bills in their house. Heating takes up energy. With a smaller house you need less heat which means you need to use less energy (small house 648 square feet).

The virtual characters responded and there was a flood of posts on the Blog such as this one.

We found this old newspaper clipping and really this is an old issue! We disbanded a couple of years ago in 2018 when average house size decreased to 1,000 square feet out of necessity. What's going on? Have we woken Sleeping Beauty? Are these House Designs for Real?
"The Citizens Against Living Large"

The content of the correspondence between Team C and the virtual characters was focused on figuring out the size of their house. There was a conversion factor between SIMs feet and regular human feet and teams differed in their ideas about what this conversion factor should be. At first the idea was that a SIMS square foot was the same as 16 human square feet but this meant that Team C's SIMs houses was colossal (about 5,000 square feet). Team C decided to downsize and created the smaller house of 648 square feet.

The *Molo* run concerned the use of computer simulation software from Molecular Workbench (Concord Consortium). Dr Boyle sent Dr Spacey and Dr Acre some work to try out. His reason for doing this was to provide the scientists with a source of help to explain their previous work on *Great Bolts of Fire* and *Downsizing C* in terms of the particle theory of matter. This explanation was required for their presentation to city council.

The *Molo* run started when Dr Boyle asked Team C to try out the Molo program. Dr Spacey and Dr Acre tried it out and sent their results to Dr Boyle to be posted on the blog. Dr Boyle responded asking the two Scientists for their opinion of the Molo program. Dr Spacey replied with the following:

> I think that the Molo program was a very fun way of learning. a way of learning that makes learning more fun. instead of listening to a teacher drone on for the hour in class they could learn with the Molo program. incorporating this program in your class would be a very good idea.

The aim of the *Grob* run was to provide a scenario where participants could see how a scientist's perspective and view of the world influences the theories that they build up to explain the world around them. It was hoped that the Grob run would give Dr Spacey and Dr Acre a new perspective on the nature of science knowledge. It was obvious from some of their responses to questionnaire statements before participation that they saw science knowledge as 'facts to be discovered' (this point will be discussed in the next section).

The *Grob* run started when a post appeared on the blog from Grob, an alien. The point of this was to encourage participants to think about different view points, and how the world might look different through the eyes of people coming from different perspectives. Scientists might look at the same thing but observe and interpret it differently because of their different perspectives. Different theories might be developed and this might lead to a different body of knowledge being created.

The *Grob* correspondence included seven blog posts, comments and e-mails. It was followed by post-game reflection on the issues.

> This is a transmission from another world, KERTRATS, you should receive it in your Earth Year 2020. We have intercepted your communications and interpreted your language. We have trouble understanding your concept of the individual. We, the Grob, are interconnected and integrated. We form a continuum. We form a continuous unit. What hurts one hurts everyone. Our whole planet forms a continuum: what hurts one part of the planet hurts everyone and everything. We are a system. The system is called Grob. We can act singly but we act for the whole. We are Grob. We wonder what it is that gave your people the view of the importance of individuals. When you act singly you act for the individual and forget about the whole. You forget the interconnectedness of your Grob. We notice how this view influences your observations and even your scientific theories. We intercepted a communication explaining your particle theory of matter. Only an individual centered society such as yours could produce a theory such as this. We in Kertrats know that matter is a continuous substance. When we exert pressure on one part all parts react. We intercepted your transmission in your Earth year 1920. We wonder if you still feel the same way about the importance of individuals.
> End of Transmission

A comment from Dr Boyle to Dr Spacey and Dr Acre on this blog post asked for help to defend the particle theory.

> Dr Spacey and Dr Acre!
> Can you help us out defending the particle theory of matter to the GROB?
> Anyone else remember any experiments showing evidence for the particle theory of matter?
> What do you think of their view of us? Weird hey?
> The lunch room was like a conference centre today everyone was trying to defend the particle theory. Dermot was like the 'master of ceremonies'
> Some people were very interested in the Grob's continuum theory of matter
> As you know, all serious scientists accept the particle theory for many good reasons
> Help us out by posting comments that defend the particle theory
> Dr B

In previous work in science class we had done an experiment to defend the particle theory of matter so Dr Spacey and Dr Acre sent it to Dr Boyle.

Dr. Spacey and Dr. Acre said...

> The particle theory tells us that there are spaces between all particles of matter.
> This is the experiment that provides evidence for that.

Alcohol and Water Experiment.

1. Get pipette and test tube (10ml). with the pipette get 5ml of water with food colouring in it and put it in the test tube.
2. Turn the switch on the burette and slowly pour the rubbing alcohol(90% alcohol) into the test tube above the coloured water you should see the line separating the two different liquids. Fill the test tube completely
3. Put your thumb on the end of the test tube and shake it vigorously. you should feel a suction on your thumb.
4. Without taking your thumb off the top of the tube notice that a bubble appears inside the tube that was not there before. They is the space that the alcohol did take up but now doesn't because the alcohol particles fit between the water particles ans the whole lot together takes up less space than adding the alcohol space and the water space together.
This provides evidence that there is space between all particles because the two liquids mixed and the rubbing alcohol filled in the gaps between the water particles.

Dr Boyle responded:

Great,
Thanks for this,
This will really help because the Grob's continuous theory says matter has no particles and therefore no spaces. So how could the Grob be right?

Another participant commented on the Grob post with the following message:

Dr Peff-Puff said:

WHAT THE HECK IS A GROB???? there's a pic of it on the blog, that was posted a while ago and it looked like a slimy yellow slug thing!!! WHAT IS IT???

Dr Boyle's graduate student Peggy chipped in:

You know Dr Spacey,
Dr Boyle shared your message with me and I was thinking about what you were saying about theories from the past such as that the world was flat and how the discoveries from physics experiments helped people discover that the world is not flat. Results from experiments they did because of questions they asked helped them put together a new theory. At the time they couldn't go out into space and look down on the earth and see the shape of the earth. They had to formulate a new theory and design experiments to test it out by trying to disprove it. I have been thinking alot about this because of the GROB message. I don't know where the message came from its likely a hoax from someone like Dermot who likes to play jokes and who got his dates wrong and thought it was April 1st.
But even so it has awakened this debate over here that is still raging. Thank you for yours and Dr Acre's BLOG entry. I would be really interested in your opinions on the Grob's theory .
Peggy

Dr Spacey replied:

I think that the Grob's theory is somewhat logical while also illogical. They believe that when one person does something it affects the whole. Although this may be the case for one person affecting one or two other people, one person cannot affect hundreds of people with every action they do.

During reflection of the game Dr Spacey answered the following questions about Grob:

Q. GROB lives a very different life than us. In what way does GROB's life differ from ours?

R. GROB lives on a planet where they believe that what one person does effects the whole community. They live together and work together making sure that they are all equal no matter what.

Q. GROB has a very different point of view than us. In what ways did GROB's point of view differ from ours?

R. See previous question.

Q. What was it about GROB's point of view that affected the theory GROB developed about the nature of matter?

R. GROB's point of view was that the importance of individuals is meaningless. This affected GROB's theory because they say that matter is a continuous substance when really it isn't.

Q. If GROB and humans did the same experiment and they got the same results do you think they would interpret them in the same way?

R. Probably not.

Q. Why or why not?

R. Because we have different scientific beliefs.

Response to Question 3: *Do the conversations reveal any of the students' understandings values and attitudes to science and technology and its relationship to society and the environment?*

In the *Great Bolts of Fire* run, Dr Spacey's conversation with Dr Boyle does reveal some of her understandings of the science process. For example she says "The experiment results are as follows for your experiment and my adjusted experiment". In addition she presents the results of the experiment with pictures she has taken. She attaches a protocol and results and discussion.

Dr Spacey's conversation demonstrates her application of her science knowledge to the technological design problem of designing an energy efficient house.

> This experiment is telling us that we want to build a smaller house for sustainable living. My reasoning for this is that with a smaller house you have a smaller amount of space (air and stuff) that needs heating during the year.

Dr Spacey's conversation also indicates some of her views and attitudes to science such as her love of physics:

> I love physics. being able to change the world with one little discovery is mind-boggling. just the thought that everyone used to think that the world was flat and such silly things as that and that science and technology used physics to prove them wrong and show the people the truth. physics was as still is a very important thing in everyone's lives. and I'm glad to be a part of it.

The themes discussed in the run called *Downsizing* related science to technology in that downsizing can be seen as a device for designing a home that uses less energy. The topics discussed also related science and technology to society and to the environment since downsizing would save energy and reduce global warming which was the purpose of the game.

The Molo run and the Grob run together concern the construction of science knowledge. Conversations in these runs demonstrate Dr Spacey's understanding of science theories and how they depend on evidence.

> The particle theory tells us that there are spaces between all particles of matter.
> This is the experiment that provides evidence for that.

Dr Spacey's reflection on the Grob run indicated her understanding that scientists are influenced by their world view:

> GROB's point of view was that the importance of individuals is meaningless. This affected GROB's theory because they say that matter is a continuous substance when really it isn't.

This quote (above indicates that Dr Spacey did not believe that the GROB's viewpoint and the human viewpoint were equally valid.

Dr Spacey's responses indicate that she realized that Grob and Human science knowledge might be different because they looked at the world from different viewpoints.

> Q. If GROB and humans did the same experiment and they got the same results do you think they would interpret them in the same way?
>
> R. Probably not.
>
> Q. Why or why not?
>
> R. Because we have different scientific beliefs.

Response to Question 4*: Do the virtual reflective scientists express reflective scientist understandings values and attitudes?*

The virtual scientist does express the reflective scientist's understandings of science process. For example he asks Dr Spacey questions because he is trying to repeat what she has done. In order to do this he needs to know the size of the bolts. He needs precise information if he is to be able to repeat her experiment and obtain the same results. Reflective scientists believe that "Scientific knowledge must be based on evidence that can be repeated over and over again" (see Table 2). This attitude is evident in the following quote from a virtual reflective scientist: "I am getting frustrated because when I try to repeat the experiment I don't get the same results!"

The reflective scientist who asked Dr Spacey to explain how her *Great Bolts of Fire* experiment could improve her house design was linking science to technology in a reflective scientist manner. The reflective scientist believes that "science and technology are closely related to each other because scientific research leads to new technology".

When a virtual scientist expressed serious concern about the size of the first house in the run Downsizing C they were demonstrating the reflective scientist's view that science and technology can be used to help solve some environmental problems.

The virtual scientist expressed reflective scientist views when he asked for evidence to help defend the particle theory of matter.

> Can you help us out defending the particle theory of matter to the GROB?
> Anyone else remember any experiments showing evidence for the particle theory of matter?

However it was not until Dr Spacey reflected on her work that she considered topics such as "theory Ladenness". This topic was not discussed by virtual scientists.

Response to Question 5: ***Do student participants adopt any reflective scientist views, values and attitudes during conversations with reflective scientists?***

Although there are plenty of examples of Dr Spacey expressing reflective scientist understandings, values and attitudes to science (Question 3) and virtual scientists demonstrating reflective scientists understandings, values and attitudes (Question 4) it is difficult to show that Dr Spacey adopts those attitudes through the course of the game. It is difficult to know whether she had these reflective scientist views before participation. For example when Dr Spacey expresses her love of physics it is difficult to know whether she already had this passion before participating in the game. The conversations that occurred within the game play would only be able to demonstrate that a student participant adopted a reflective scientist stance if they changed their mind during a conversation. Another method that could be used to show that student participants came to adopt a reflective scientist stance is to use the questionnaire response data that was collected prior to and following participation. Table 4 below shows Dr Spacey's profile of understandings values and attitudes as they are reflected in her responses to questionnaire statements presented prior to and following participation. This profile is presented relative to the reflective scientist profile : "A" indicates agreement with the reflective scientist position.

Table 4. **Dr. Spacey's questionnaire response profile.**

Questionnaire Statement	Agreement with the reflective scientist	
	Before	After
Constructing scientific knowledge		
Generating scientific theories requires imagination.	A	A
Scientific theories may have to change if new evidence is discovered.	A	A
Scientific observations and interpretations can be different if scientists believe different theories.	A	A
Scientific knowledge may have to change if new evidence is discovered.		A
Scientists can tell us only what probably might happen.	A	A
Science process		
Scientists write reports in a very logical orderly way but they do the work in a much less orderly way.		A
Scientific knowledge must be based on evidence that can be repeated over and over again.	A	A
Test results have to agree each time the test is done, before the results are accepted as scientific knowledge.		A
Scientists must report their work to other scientists for review before it is accepted.		A
When a research team makes a discovery it is not alright for them to announce it to the press before other scientists have discovered it.		A
Scientists must check each others work before it is published in science journals.		A
Students can add to scientific knowledge.	A	A
Science and Technology		
Science and Technology are closely related to each other because scientific research leads to new technology.	A	A
Engineers depend on scientific knowledge to build devices or machines that work.	A	A
The Relationship between Science and Technology, and Environment and Society		
Science and technology cannot be relied upon to fix pollution problems in the future.		A
Scientists should be held responsible for the harm that might result from their discoveries		A

Scientists should be free to investigate what interests them.	A	A
The community should decide what research to fund.		A
Government agencies should decide what scientific research to fund.		A
Corporations should not decide what research to fund.	A	A
Science in Everyday Life		
In everyday life thinking like a scientist helps us solve practical problems.		A
Thinking like a scientist helps us figure things out and decide whether something (for example an advertisement) is true or not.		A
To understand scientists' predictions and warnings we need to understand the science they are based on.		A
TOTALS	11	23

Interpretation of the questionnaire data suggest that Dr Spacey did indeed shift her response profile to more closely agree with the reflective scientist after participation. This is particularly evident for the following themes; science process, the relationship between science and technology and science in everyday life. Dr Spacey's shift towards the reflective scientist position is also evident in her comments collected after participation.

For example in response to statements concerning the science process theme she wrote the following regarding her team's use of the scientific method:

> Our report at the end was organized but throughout the experiment we didn't have a whole lot of organization.

About repeatability she wrote:

> If experiments are testing the same thing then they should have the same results before they are considered to be true.

On the topic of peer review and checking each others experiments Dr Spacey wrote the following:

> I think it is important to check each others experiments because if only one scientist does the experiment then it may have something wrong with it and they would never know. Therefore, two scientists should look over the experiments.

> I think it (peer review) is a good idea because the experiment might have problems in the future if it isn't checked before it is published.

Examination of Dr Spacey's work in the *Heat Game* shows that she had direct experience related to these issues in the run *Great Bolts of Fire*. It therefore seems that although it is hard to find a change of attitude to the reflective profile expressed directly in Dr Spacey's run conversations, changes in attitude are evident in questionnaire response data and comments collected after participation. These changes in Dr Spacey's understandings, values and attitudes on the theme of science process can be directly related to her activities in the *Heat Game.*

To address question (6) questionnaire response data from all nine student participants was examined together.

Response to Question 6: ***Did student-participants shift their questionnaire statement profile of views, values and attitudes to agree with the reflective scientist on the issues of the construction of science knowledge, the process of science, the relationship between science and technology, the interrelationship between science and technology society and the environment and/or the usefulness of science in everyday life?***

The first question asked of the questionnaire data was whether all nine participants shifted their response profile to agree with the reflective scientist. The table below shows the number of questionnaire-statement responses in agreement with the reflective scientist profile for each participant before and following involvement and reflection in the *Heat Game.*

Table 5: Participant Questionnaire profiles: showing responses in agreement with the Reflective Scientist Profile: Before and Following Participation and Five Months Following Participation

Participant	Before	After	Five Months After
Dr Spacey	11	23*	N/A
Dr Daman	17	17	16
Dr Acre	8	21*	17*
Dr Noot	15	20	19
Dr Justice	14	17	15
Dr Hudson	11	17*	17*
Dr Peff Puff	14	20*	17
Dr Huggatree	10	20*	15
Dr Leets	14	20*	16

Table 5 shows shifts toward the reflective scientist profile for all participants except Dr Daman. A *chi squared* test was administered to determine the significance of the shifts. Six participants with significant shifts immediately following participation are indicated with an asterisk*.

Five-month post participation data indicated endurance of shifts. The shift remained significant for two participants, Drs Acre and Hudson.

The second part of this question asked whether student participants shifted their responses on all twenty-three questionnaire statements used. This section involves an examination of the number of participants who shifted their response to the reflective scientist profile for each questionnaire-statement. Table 6 shows the number of participants in agreement with the reflective scientist for each questionnaire-statement on each occasion that responses were collected: pre-participation, immediately post-participation, and five months post-participation.

Table 6: Responses to each Questionnaire Statement: Number of participants in agreement with the Reflective Scientist for each questionnaire statement. Note: Only eight students responded five months later.

Questionnaire Statement	Number of participants in agreement with the reflective scientist		
Topic: Constructing scientific knowledge	Before	After	5 mo. later
1. Generating scientific theories requires imagination.	6	9	8
2. Today's scientific theories may have to change if new evidence is discovered.	6	9	8
3. Scientific observations and interpretations can be different if scientists believe different theories.	6	9	8
4. Scientific knowledge may have to change if new evidence is discovered	7	8	6
5. Scientists and engineers cannot tell us what will happen for certain.	8	8	8
Topic: Science Process			
6. Scientists write reports in a very logical orderly way but they do the work in a much less logical and orderly way.	2	6	1
7. Scientific knowledge must be based on evidence that can be repeated over and over again.	8	6	8
8. Test results have to agree each time the test is done, before the results are accepted as scientific knowledge.	4	4	6
9. Scientists must report their work to other scientists for review before it is accepted.	5	6	6
10. When a research team makes a discovery it is not alright for them to announce it to the press before other	3	7	8

scientists have discovered it.			
11. Scientists must check each other's work before it is published in science journals.	3	7	5
12. Students can add to scientific knowledge.	9	9	8
Topic: Science and Technology			
13. Science and Technology are closely related to each other because scientific research leads to new technology.	7	9	8
14. Engineers depend on scientific knowledge to build devices or machines that work.	4	8	8
Topic: Science, Technology, Society and Environment.			
15. Science and technology cannot be relied upon to fix pollution problems in the future.	1	8	6
16. Scientists should not be held responsible for the harm that might result from their discoveries (but they should have to think about the impact of their work	1	7	7
17. Scientists should be free to follow their interests.	6	8	NA
18. The community should decide what research to fund.	7	3	5
19. Government agencies should decide what scientific research to fund.	1	8	0
20. Corporations should not decide what research to fund.	8	9	6
Topic: Science in everyday life			
21. In everyday life thinking like a scientist helps us solve practical problems.	4	9	6
22. Thinking like a scientist helps us figure things out and decide whether something (for example an advertisement) is true or not.	4	8	7
23. To understand scientists' predictions and warnings we need to understand the science they are based on.	1	9	6

Immediately post-participation, the number of students who agreed with the Reflective Scientist stance increased for twenty of the twenty-three questionnaire-statements. All students already agreed with the reflective scientist response for one of the three questionnaire-statements that did not show an increase. A sign test was performed to determine whether twenty out of twenty-one represented a statistically significant deviation from what might occur by chance. This deviation is highly significant ($P = 0.0001$). Five months following participation, fourteen out of a possible twenty questionnaire-statements showed an increase (due to an error, one test-statement was not asked). A sign test demonstrated that this deviation is significant at the $P = 0.05$ probability level.

Teams of participants took their projects to design energy efficient housing in different directions therefore they learned about different aspects of science in the *Heat Game.* Their different experiences and the different aspects of science that they engaged in can be seen by looking at Table 3. This table shows the runs that different participants engaged in and the themes of science that were involved. It is evident from this table that not all participants engaged in activities relating to all themes of science in this study. Therefore it cannot be expected that all participants would shift to the reflective scientist position on all questionnaire-statements concerning all themes. The sign test was a useful test to use to compare questionnaire-statement responses collected pre-participation and post-participation (either immediate or after five-months) because it helps to determine whether the combined shift across all questionnaire-statements to the reflective profile is significant regardless of the magnitude of the shift. The results show that the shift was significant immediate post-participation and five months post-participation. The next section looks at the shift in responses for each of the themes of science: Construction of Science Knowledge, Science Process, Science related to Technology, Science, technology, society and the environment, and science in everyday life.

A surprising result from this study is the observation that many students already agreed with the five questionnaire-statements on the *construction of scientific knowledge* before participation. One possible explanation for the observation that most students already agreed with the Reflective Scientist on these five statements might be prior learning about this topic in class with the same instructor. Another is that questionnaire statements might be insufficiently refined to provide the discrimination necessary to resolve alternative understandings on this topic. Evidence for the latter explanation comes from responses to different statements that were used on the pre-participation questionnaire but not used for post participation interviews.

Students responded to many statements before participation (88 statements were used) that were not selected for use following participation. There were several statements about the construction of science knowledge that used the term 'science facts' instead of 'science knowledge' and students responded differently to these questionnaire statements. These can be seen in the table below.

Additional questionnaire statements about the construction of scientific knowledge asked before participation	Reflective Scientist position	Number of students who agreed with the reflective scientist
When we do science we discover the facts/truth about the world we live in.	**F**	**0**
When we do science we only improve our understanding of the world we live in: we cannot discover the facts/truth	**T**	**2**
Scientific knowledge is a collection of facts about the world.	**F**	**1**
Scientific knowledge is not a collection of facts; it is a collection of interpretations of observations	**T**	**3**

Before participation, most student participants disagreed with the Reflective Scientist on the statements concerning the nature of science *facts*. After participation related but different statements on the same theme were used presented. There were two alternative statements; the first based on the Traditional Common Sense view of science (TCS) and the other the Reflective Scientist (RS) view and student participants were asked to choose between them. Table 7 shows the statements and the response of the student-participants.

Statement about the construction of scientific knowledge used in de-briefing	Which do you think is right?		Number of students	
	TCS	RS	TCS	RS
Some people say that scientific knowledge is true beyond a doubt, it is a collection of facts about the world. Others say that scientific knowledge is our best understanding of the world at the present moment and it may have to change in the future	True beyond doubt, collection of facts	Best understanding		9

After participation all students agreed that scientific knowledge is our best understanding of things rather than being a series of *facts* that are true beyond a doubt. This is evident from Dr Daman's explanation for his answer during de-briefing.

> Because it could very well change at any time anywhere in any way (Dr Daman).

However students continued to refer to science 'facts' and the 'discovery of science facts' even after they had agreed that science was really a collection of best understandings. An example of this comes from Drs Justice and Hudson's debriefing:

> Knowledge can always become greater because every day we are discovering new facts about the world (Drs Justice and Hudson).

These observations suggests that although students' understandings, values and attitudes about the nature of science knowledge have moved towards the Reflective

Scientist position they are not firmly established there: while students are convinced that science knowledge can change, they still see science facts as fixed items that can be discovered.

The results for the *science process* theme were more mixed, perhaps because of participants' different experiences in the *Heat Game.* Interesting to note is the observation that while all students agreed with the Reflective Scientist about the 'messiness' of science immediately post-participation, they did not agree five months later. This may be explained by the fact that immediately post-participation, test statements were presented in the context of the work the participants did in the game. This would likely have made the 'messiness of science' test-statement (#6) easier to understand.

There were two questionnaire statements on the topic of science process that elicited shifts in responses towards the Traditional Common Sense profile rather than the Reflective Scientist stance (questionnaire-statements # 7 and # 8). These concerned the reliance of scientific knowledge on evidence that can be repeated. A possible explanation for this result is confusion between the terms 'experiment' and 'protocol' or 'procedure' in science (see chapter 5 for a discussion of this result). After five months all participants agreed with the Reflective Scientist on statement #7. This suggests that all participants understand that science relies on evidence. Two participants did not agree with statement

#8. They were two of the same participants who disagreed with the reflective scientists on this statement immediately post-participation.

All participants had ample opportunity in the *Heat Game* to relate *science and technology* through the application of their results of science experiments to devices and design ideas for energy efficient housing. All students could explain the work they did in the *Heat Game* in terms of application of science to technological development. The only participant who disagreed with the reflective scientist on a questionnaire-statement on this topic was Dr Daman. Dr Daman used the science process to test a device rather than as a first step in the development of the device which might explain this result. Five months later all participants agreed with both statements.

There are two different sub-themes in the *science, technology, society and environment* section. The first has to do with the usefulness of science and technology for solving pollution problems. Before participation only one student agreed with the questionnaire statement that science cannot be relied upon to solve pollution problems in the future. Immediately post-participation all but one participant had shifted their response to agree with the reflective scientist position that science and technology cannot be relied upon to solve these problems. Five months later six out of eight still agreed with this position. Dr Justice and Dr Hudson expressed their reason in the following statement:

> The reason we feel this way is because we the people are the ones responsible for pollution and we are the ones who have to cut down. In the future there may be devices that might help but we don't see that time coming along any time soon.

All participants were focused on issues relating to these statements for the duration of the *Heat Game*. This can be seen by looking at themes discussed in the runs in Table 3. It is therefore expected that all participants should agree with the Reflective Scientist on these questionnaire-statements after participation.

The second theme for this section concerned responsibility and control for developments in science and technology. Most students shifted to agree with the reflective scientist position that scientists should not be held responsible for the impact of their discoveries because there is no way of knowing what that impact might be. However, immediately post-participation everyone agreed that scientists and engineers should have to think about the impact and stop their work if they discover it has negative results.

Dr Peff-Puff, Leets and Huggatree put it this way:

> Some projects are much worse for the environment and not necessarily needed. If the scientists and engineers had to think about if it was going to have a negative effect on the environment, they would have to think about if they actually needed it and if they didn't the project may be terminated.

All students agreed that there should be controls on science and technology and immediately post-participation they mostly agreed with the reflective scientist that scientists should be free to investigate what interests them but government should decide what to fund based on what is good for the people. They felt that if the community decided that might be too complicated.

Dr Peff-Puff, Leets and Huggatree felt this way about it:

> There would have to be enough of an opinion (in number of people) to pass on what goes and what doesn't.

It is interesting to note that five-months post participation students' had shifted their position on the question of who should decide what research to fund. No-one agreed that government should decide what research to fund. Students responded with the answer "maybe" to this test-statement, and "maybe" *is* perhaps the appropriate response to this statement for a Reflective Scientist too.

All students except one shifted to agreement with the reflective scientist position on all three of the questionnaire statements related to the *science in everyday life* theme. Only Dr Daman felt that science thinking might not be helpful when deciding whether or not to believe something like an advertisement.

Dr Peff-Puff, Leets and Huggatree responded in the following words:

> Knowing science helps us figure out (in an advertisement) if the person is lying through their teeth at the power of a certain product.

Everyone shifted their responses to agree with the reflective scientist about the need to understand science in order to interpret scientists' predictions and warnings. Dr Noot expressed it this way:

> You can't always believe what people tell you, you never know when they are lying, thinking like a scientist can help you; you can look for the evidence.

Five months post-participation two students answered maybe to these three questionnaire-statements. Participants' shift to the Reflective Scientist response on the final questionnaire-statement concerning the need for science understanding when interpreting scientists' predictions and warnings, is particularly important for this study. Dr Spacey's explanation shows that, like the Reflective Scientist, she came to realize the need to understand the science to help prevent the crises that scientists warn us about.

> Using scientific knowledge we may be able to understand what's going on and be able to help prevent it from becoming a major crisis (Dr Spacey).

The results presented in this chapter demonstrate that

(1) Student participants did engage in science and technology conversations with the virtual reflective scientists within the game play. Some students engaged in more conversations than others and conversations varied in length.

(2) Within these conversations four main themes are addressed: the construction of science knowledge, science process, the relationship between science and technology, the interrelationship between science and technology and the wider world of society and the environment. The particular theme discussed depended on the work that the student participants are engaged in during their investigations. Certain themes were discussed more often that others.

(3) These conversations were effective for revealing understandings, values and attitudes to science and technology and their relation to society and the environment.

(4) The virtual characters did express reflective scientist understandings, values and attitudes.

(5) The e-mail and blog conversation showed participants developing reflective scientists views, values and attitudes but it was difficult to know for certain whether participants had these views before participation

(6) Response profiles generated using questionnaire data demonstrated changes towards a reflective scientist's stance for all student participants. Student participants differed on the theme of their shift depending on the particular work they were engaged in during the game play (construction of science knowledge, the process of science, the relationship between science and technology, the

interrelationship between science and technology society and the environment and/or the usefulness of science in everyday life).

These results will be discussed in the next chapter.

Chapter 5

Discussion of Results

> *Well just because we're students doesn't mean we can't make discoveries. I mean, we're young but we're not unintelligent. We could be doing an experiment that we thought up and discover something new. Then we could send it to a professional scientist who would do the experiment again and then publish it and give us our credit for thinking it up. So theoretically we could be contributing to much more scientific knowledge then you think we are (Dr Spacey).*

The data presented in the previous chapter suggests that all students shifted their profile of understandings values and attitudes towards the Reflective Scientist stance after participation in the *Heat Game*. They came to see themselves as capable young investigators (see quote above from Dr Spacey). This chapter will discuss these results in the context of some of the literature reviewed in chapter 2. It is divided into three sections. The first section will look at the understandings, values and attitudes that participants adopted as they moved toward a Reflective Scientist's stance. The second section will discuss possible explanations of what it is about engagement with the *Heat Game* that helped students adopt this stance toward science. The final section of the chapter will speculate on the usefulness of the augmented reality game approach for increasing scientific literacy and encouraging interest in science and technology courses and careers.

Adopting the Reflective Scientist Stance

The views, values and attitudes incorporated into the Reflective Scientist stance concern the following themes: the social construction of scientific knowledge, the science process, the relationship between science and technology, the relationship between science technology, society and the environment, and the use of science thinking in everyday life. Results presented in Chapter 4 show examples of student participants adopting some of the reflective scientist's views, values and attitudes to science within each of these themes after playing the *Heat Game*. For the purposes of this discussion the themes will be grouped into two main areas: the process of science and the construction of scientific knowledge; the interrelationship between science, technology, society and the environment. The aim of this section of the discussion is to relate the results of this study to the literature on understandings, values and attitudes to science reviewed in Chapter 2.

The process of science and the construction of scientific knowledge

Traditionally science is often taught transmission-style to intermediate level students as a series of science 'facts'. Since students have little or no understanding of the nature of the science *process* and how it is used to construct science knowledge, it is impossible for them to interpret the *meaning* of the science knowledge that is delivered to them by teachers or through the media. They do not know what questions they should ask about the information such as: How do we know that? What studies were done? What kind of evidence is there? (Arons 1983). One of the aims of the Heat Game was to help students understand something of the *nature* of science – how it reaches its understanding of things – so that they would be better able to interpret science knowledge.

Over the last fifty years there has been much disagreement about the nature of the science process and how it is used to construct knowledge (Medawar 1982, Popper 1963, Kuhn 1962, Latour 2004, Woolgar 1988). A field of study called 'Science Studies' initiated by philosophers, historians and sociologists of science has developed that offers new perspectives on the internal workings of science and the construction of science knowledge (Woolgar 1988). Research in Science Studies work has challenged the natural scientists' view about what it is they do (see Dawkins 2003 for the scientists' perspective). There is still much disagreement between the two sides.

Students who go on to become practicing natural scientists hear little or nothing about the field of Science Studies in their university training while students who go into Science Studies often learn to criticize natural science without appreciating its usefulness as a method for addressing questions about the natural world. The Reflective Scientist stance promoted in the *Heat Game* incorporates views, values and attitudes from both sides. Like Dawkins (2003), the Reflective Scientist believes in the usefulness and beauty of science as a process for constructing understanding of the natural world. At the same time, like Woolgar (1988), she/he is aware of the limitations of the process.

The *Heat Game* provided student-participants with a simulation of an authentic science setting within which they could work on real inquiry-based science to create their own science knowledge. In addition the *Heat Game* provided a simulation of a virtual community of authentic scientists with whom student-participants could interact. In this section of the thesis the learning that happened through *doing* inquiry-based science will be discussed, followed by consideration of the learning that occurred through *communicating* within the virtual science community.

Participants had the opportunity to address science questions pertaining to the Heat unit of the Grade Seven Ontario Curriculum. They were free to conduct experiments and they were given protocols to use as starting points. Through their work in the *Heat Game* participants like Dr Spacey (see Case Study Chapter 4) experienced the ‘messiness’ of science. Participants discovered that protocols don’t always ‘work’ and that order is often imposed on messy experiments after they are completed, when scientists write their reports. McComas (2004) makes the point that students often mistakenly believe that scientists follow the Scientific Method as if it is written in stone. Following engagement in the *Heat Game* most students came to understand that the scientific method is more of a rough guide than a rigid protocol (see Chapter 4; Table 6).

Through practice, participants learned that scientists use their imagination to make predictions, interpret results and think of ways to apply them to practical matters like designing energy-efficient housing. Post-participation, the students all agreed that scientists need to use their imagination in many aspects of their work (see responses to questionnaire statement 1, Chapter 4, Table 6). In his 2005 paper McComas includes imagination as one of the most important tools for scientists that educators need to demonstrate and share.

Although results indicate that, in general, students increased their understanding of the science process as defined by the Reflective Scientist stance there were some seemingly anomalous results that require further consideration. When students were asked whether test results (results of experiments) must agree each time the test is done before results can be accepted as scientific knowledge, several students answered “No” (see Chapter 4; case study). Careful reading of the reasons they gave for this answer, and examination of their work in the game, suggests that these students might be confusing the terms *experiment* and *protocol*. Some students worked within the heat game to modify a *protocol* so that it could be used to detect differences that might result from an *experiment*. Students often referred to *protocols* as *experiments*. An example of this can be seen in Dr Spacey’s correspondence with Dr Boyle (see Chapter 4; case study). Dr Spacey says, “Your experiment had some flaws in it” when what she means is, “your protocol had some flaws in it”. This confusion of terms could explain the students’ responses to the questionnaire statement about test results. Their experience in the game led them to understand that protocols can and should be modified so that they are useful for detecting differences but they may have come to believe that experiments can be modified until the researcher obtains the result they *want*. If this is the case it indicates the importance of defining and using terminology precisely.

When science knowledge is delivered to students in elementary school and high school, they are usually told that science facts were discovered by individual scientists (McComas 2004). Often students have no way of knowing that, rather than working in isolation, scientists interact within a community of other scientists with whom they discuss, review, repeat and critique science work before it is accepted and incorporated into science knowledge (Driver et al 1996). One of the most exciting discoveries about the *Heat Game* is its success at modeling how scientists communicate with each other within the science community. The *Heat Game* did this by creating a community of virtual scientists with whom participants communicate by e-mail and blog. An example of the manner in which this communication occurred comes from Dr Spacey's work in the game (see Chapter 4, case study). At all levels of the science process, Dr Spacey was in communication with Dr Boyle and other scientists. In Dr Spacey's answer to the question: "Can students contribute to scientific knowledge?" she demonstrated her clear understanding of the way scientists work together in their community (see epigraph to this chapter). Most students who participated in the game demonstrated their understanding of the part that peer review, cross-checking and critiquing play in the science community (see Chapter 4, Table 6).

Participants were not required to conduct and communicate their own experiments in the *Heat Game*. They were given the option to study reports of scientists' work from the literature. Student-scientists Dr Hudson and Dr Justice took this route when they focused on a report on heat transfer through green roofs. These students did not have the opportunity to learn about the science process to the same extent as other students like Dr Spacey. Dr Hudson and Dr Justice did not come to agree with the reflective scientist view about the importance of peer review and cross-checking before publication. So although this study of the *Heat Game* involves a very small number of participants, this result supports the inference that although *talking* about science is very important for increasing students understanding, it is not enough. Researchers in science education who advocate for inquiry-based science in classrooms often make this point (Millar 1989, Roth and Roychoudhury, 1993). In future trials of the game it will be imperative to ensure that all students engage in conducting their own experiments.

Professional scientists themselves often do not reflect very much upon the *nature* of the scientific enterprise or of science knowledge itself since they are focused on actually *using* science (Medawar 1982). An appreciation of the *nature* of science really only comes from focusing on it explicitly, by talking *about* science and the manner in which science knowledge is produced (Driver 1996, Gee 2007). This focus on the nature of science is typically the domain of philosophers and social scientists (Popper 1963, Kuhn 1962, Latour 2004, Woolgar 1981). An important element of the learning system created around the *Heat Game* is its provision of an opportunity for students to engage in conversations *about* the work they did as scientists in the game. It was this opportunity for reflection that allowed them to see the science enterprise from the outside.

In their survey of young people images of science, Driver et al (1996) report that placing complicated questions about the nature of science into a real context aided students' understanding. The e-mail questions that student-participants answered after the *Heat Game* asked them to focus on complex issues like: the important role that creativity and imagination play in science, the tentative nature of scientific knowledge, and the lack of certainty in science. In these conversations the issues were related to the actual work students had done in the *Heat Game* making them easier to understand. Results show that, after participation, all but one student agreed with the Reflective Scientist on the questionnaire statements concerning these issues. However, students continued to refer to science *facts* being *discovered* by scientists (see Chapter 4, p 67), so it is clear that more work needs to be done.

Driver et al (1996) discuss the use they made of stories to probe students' understandings of the nature of science theories. For this study, in order to discuss the relationship between the scientists' accepted theories and their interpretations of observations, a story was created on the blog around a character called Grob from the planet Kertrats. In the *Heat Game,* Grob posted on the blog challenging the particle theory of matter. Grob had a completely different view of the cosmos than humans do. Grob believed that individuals are all connected and related and that what affected one Grob affected the whole. For this reason Grob interpreted matter as a continuous substance rather than as made of particles, like atoms and molecules, with spaces between. In post participation conversations about the story of Grob students were asked whether Grob and human scientists might interpret their observations differently. All students in the conversations believed that they would. When asked whether this might lead to scientific knowledge being different on Earth and on Kertrats, Dr Spacey's opinion was that it would, because Humans and Grob have different scientific beliefs (see Chapter 4, case study). It is exciting to consider how the game approach allows the introduction of characters and stories through which complex ideas such as the social construction of scientific theories can be addressed. Future versions of the *Heat Game* could incorporate more stories.

The interrelationship between science, technology, society and environment

It will take more than science and technology to stop global warming, though it can help (Drs Peff-Puff, Huggatree and Leets). We feel this way because it is human activity that causes global warming (gas companies). We, the people, are the ones responsible for pollution and we are the ones who have to cut down (Drs Hudson and Justice).

In this time of environmental crisis, science and technology education has the responsibility to help students develop an understanding of the complex relationships between our life style choices, the technological processes we use to sustain them, and the impact they have on the biosphere (Hodson 2003). Scientific literacy needs to encompass this understanding (Elsop 2005). The Reflective Scientist stance that students came to adopt through participation in the *Heat Game* incorporates understanding of these connections.

The *Heat Game* was designed to build awareness of connections between life style choices, technology and environmental impact through the virtual world scenario created for the game, and through the mission of the participant and virtual scientists working within that world. By setting the scenario of the *Heat Game* in a future where the impact of global warming is more pronounced and reduction of energy use is an imperative, it was possible to allow participants to experience the reality of this situation for a team of scientists working to design housing for sustainable living in that future time. Participants became deeply engaged by the game and developed a new awareness of the connection between our housing choices, the energy needed to sustain those choices, the technology used to produce this energy, and the environmental cost of our energy production methods. This is evident in the final presentations that they gave to city council (see appendix 1), and in the comments they made when questioned after participation (see Chapter 4).

An example of this developing awareness occurred when participants first designed their houses using SIMS. Participants struggled with their desire to make their houses energy efficient but at the same time appealing in their eyes and received cultural norms. They wanted to add all the modern conveniences for the Johnson family who would be living in the house. This struggle is evident in the following quote from Dr Hudson. She is writing to the Johnson family who will live in the house that her team is designing.

> Dear Ida Johnson,
>
> We are pleased to hear that you are happy with the progress we have made. Of course we will be happy to post some interior pictures on the blog, (your farmstyle kitchen is quite impressive) we are in the process of furnishing the house. No, we have not yet been able to get the cost of the house, we are dealing with the amount of money we have to spend, but when we find an estimated price we will let you know. We are definitely working towards making this house as energy efficient as possible (Dr Hudson, engineer, Team B).

Dr Hudson's struggle reflects a modern-day dilemma for many inhabitants of western countries who want large luxurious homes with all the trimmings even when they are aware of the direct and environmental costs of this lifestyle choice (Monbiot 2006). In the *Heat Game,* all participants like Dr Spacey became aware that smaller houses were required if they were going to reduce energy use and help stop global warming (see Chapter 4, case study). In their speeches to city council at the end of the game (see Appendix 1), all participants in the *Heat Game* showed that they had developed an understanding that we have the ability to make choices to invent and use technology that minimizes energy use for housing (e.g. passive solar construction, green roofs and heat recovery ventilation systems). Hodson (2003) makes the point that we should help students understand that we are capable of this kind of ‘technological choice’.

In post participation conversations *about* science and its interrelationships with society, students were asked for their opinions about the responsibility of scientists and engineers to research and develop science and technology that is good for society and the environment. Although students believed that scientists should have to think about these issues and should not develop discoveries and devices that they know might be bad for people and the environment, most of them did not believe that scientists should be held responsible for their discoveries (see Chapter 4, Table 6, p64-65). As the student participant Dr Daman explained, scientists can sometimes discover something accidentally when they have set out to research something else altogether. Driver et al (1996) discovered that the students in their study did not understand the manner in which society influences decisions about what scientists investigate. In conversations about control and funding of scientific research and development of technology students who had participated in the *Heat Game* mostly agreed that it was government rather than corporations that should decide what research to fund, because they are most likely to think about what is good for people (see Chapter 4, Table 6). It would be interesting to extend the *Heat Game* to include modeling of the research application process, the complexities of obtaining funding and the power of corporations to influence what research gets done.

After participation in the *Heat Game* most students came to agree that thinking like a scientist is useful in everyday life (see Chapter 4,Table 6) Most important for this study, they came to see that science thinking is necessary to help us understand scientists' predictions and warnings. They believed that this understanding can help us to make sensible choices that minimize further harm.

It is important that students recognize that although we can use technology wisely to create devices that allow us to live more sustainable lives, technological fixes cannot be relied upon to solve all our pollution problems. Research on student attitudes has shown that students often believe that science and technology can be relied upon alone to solve pollution problems such as global warming in the future (Aikenhead and Ryan 1992). In the *Heat Game,* even though participants worked to develop devices and methods that reduced energy use in housing, they did not believe that science and technology could solve all our pollution problems. Examination of participant questionnaire statement response profiles indicates, that after participation in the *Heat Game,* all students agreed with the Reflective Scientist stance that we cannot rely upon science and technology to solve our pollution problems in the future (see Chapter 4, Table 6). This is evident in the following quotes taken from conversations during which participants reflected on their work in the game.

> It will take more than science and technology to stop global warming, though it can help (Team A)

> We feel this way because it is human activity that causes global warming (gas companies)… we the people are the ones responsible for pollution and we are the ones who have to cut down (Team B)

Hodson (2003) stresses the point that although it is important to incorporate into science and technology education the recognition that environmental problems are social problems, ("problems of people, their lifestyles and their relations with the natural world”), values cannot and should not be imposed upon students; they need to be fostered from within (Hodson 2003). This is what is so exciting about the game approach. Through their actions in the *Heat Game*, students found their way to changing their values and attitudes because they came to see the world from a new perspective; that of the reflective scientist.

How Students Adopt the Reflective Scientist Stance

> *I love physics. Being able to change the world with one little discovery is mind-boggling. Just the thought that everyone used to think that the world was flat and such silly things as that and that science and technology used physics to prove them wrong and show the people the truth. Physics was and still is a very important thing in everyone’s lives. And I’m glad to be a part of it (Dr Spacey).*

In order to adopt the Reflective Scientist stance students needed to do two things: Do authentic science and converse with reflective scientists in a science world that focuses on a real-life problem; and reflect upon what happened in the game from the outside, from a more philosophical perspective. These dimensions are enlarged upon below.

The *Heat Game* was designed to allow “the participant to experience expertise: to feel like an expert”, (Gee 2007). In their e-mail correspondence with non-player virtual people, students did adopt some of the characteristics of the professionals they were emulating when they reported the results of their experiments and applied their new knowledge to their house designs (see Chapter 4, case study). In his book *How computer games help children learn,* Shaffer (2006) suggests that one of the reasons why young people enjoy playing the epistemic learning games that his group in Wisconsin has designed is because they provide an opportunity for them to make things happen.

> Epistemic games thus fulfill young people’s basic need to make things happen in a positive and constructive way. These games are fun because they let players think and act like professionals

> who care about doing things that matter not just to themselves, but to others in the world (Shaffer 2006, p132)

The young people who participated in the *Heat Game* said that they really enjoyed playing the role of scientists because they could make things happen, as Dr Daman put it:

> It made you really believe you could do things (Dr Daman; student-participant).

In order to understand how the *Heat Game* worked to help bring participants toward a reflective scientist's way of thinking, parallels may be drawn between the *Heat Game* and what James Gee says about the game *Full Metal Warrior*.

In his description of the game *Full Metal Warrior* Gee makes the point that the players must ("think, act and value like a professional soldier") to be successful at playing the game (Gee 2007). The game offers affordances, or opportunities for success, to players who have taken on the professional soldier profile of understandings, values and attitudes. These affordances are built into the game.

> The soldiers know how to operate in a hostile, highly populated environment. The player comes to learn that or fails at the game (p. 74 Gee 2007)

In the *Heat Game,* although success may not be quite as exciting as it is in *Full Metal Warrior,* affordances, or opportunities for success, are offered to participants (in their virtual character form) who take on the profile of understandings, values and attitudes of the professional scientist. An example can be seen in the case study of Dr Spacey's work in the game. Dr Spacey succeeds when she publishes a science article (*Great Bolts of*

Fire) on the on-line journal (the blog), or when she responds to queries or criticism from other scientists or the public (blog comments) or when her work is cited by another team (on their final presentations).

Full Metal Warrior is good at teaching "….some of the values, attitudes, practices, strategies, and skills of a professional officer commanding a squad…." (Gee 2007, p 74) not only because it is designed with the appropriate affordances that encourage the adoption of a professional soldier profile but also because the player takes on the role of a virtual character that already has some of the expertise built in. The virtual character can already do some of the "soldier stuff" necessary to take advantage of the affordances to succeed and overcome the trials that the player and his virtual character must overcome together. When the virtual player superimposes her or his own desires and goals and beginning expertise onto what the virtual character can already do, they share expertise. Together the player/virtual character duo tackle the hurdles and take the opportunities that lead to success. In the game scenario, the player, through the action she/he takes as the virtual character, shifts her/his profile to that of the professional officer, she/he takes on the characteristics of the authentic professional (Gee 2007).

For the *Heat Game* to be effective at teaching some of the understandings, values and attitudes of a reflective scientist, not only does it have to have the affordances built in, it also must provide an opportunity for the player to become a double with a virtual character with expertise. In the *Heat Game* the player creates her/his own virtual character, for example Dr Spacey, Team Physicist. The expertise comes from her parallel virtual expert Dr Boyle, Expert Physicist. Dr Spacey and Dr Boyle work together to conduct experiments, modify experimental procedures, publish papers and defend the particle theory. They are both driven to apply their knowledge to the technological problems of designing energy efficient housing and they are both motivated by the fact that global warming has reached a stage of serious crisis in the year 2020 (see Chapter 4, case study).

Dr Spacey achieved success in the *Heat Game* because of her imaginative interactions with Dr Boyle. Participants or participant teams could not play the *Heat Game* without this interaction with a virtual expert. They needed to contact a virtual expert to get started in the game and to post on the blog. The need for shared skill-sets is built into the game so that the player has an opportunity to develop a profile like that of the reflective scientist professional. It is interesting to note that Dr Daman who engaged in only one run through the game (Chapter 4, Table 3, p46) did not shift his understandings, values and attitudes to the reflective scientist point of view (Chapter 4, Table 6 p66).

The *Heat Game* encouraged participants to shift their profile to that of a reflective scientist because the game had the selective pressure for these values and attitudes built in. The virtual expert reflective scientists provided the know-how or understandings necessary to achieve the goals of the game. The *Heat Game* offered affordances to players who bonded with a virtual expert and took on the profile of an reflective scientist to play the game. The player and the expert worked together and shared expertise. The player came to take on the understandings, values and attitudes of the expert scientist who sees science as useful and believes we can make good choices for technological development that respect the rights of everyone and do not adversely impact on the environment.

Scientists do not necessarily reflect upon what it is they do (Medawar 1982). In order for the *Heat Game* to be a learning system for a Reflective Scientist an opportunity for reflection needed to be included. The post-participation questions, by placing complex metaphysical themes into the context of the game play, provided a critical bridge between concrete learning in the *Heat Game* and these abstract philosophical questions concerning the nature of science knowledge and science as a social enterprise. These questions encouraged student participants to examine their activities in the game and reflect upon what they had done. Gee (2007) has made the point repeatedly that there are two levels of knowing a domain, from the inside and from the outside. Driver (1996) explains that when science itself is the focus of inquiry the language used is different. When conducting an experiment scientists will *talk science* about objects and about observations that were made in the real world. When talking *about science knowledge* philosophers and social scientists (and some scientists) will be focusing on issues like the nature of theories, theory laden-ness and the manner in which science functions as a social institution. For the *Heat Game* to be successful as a place for learning science literacy that encompasses all that the Reflective Scientist stance stands for (professional science knowledge, science studies reflection and social and environmental conscience) it is crucial that participants have an opportunity to look at their work within the game from the outside.

The Usefulness of the Game Approach

A recent international report from the organization for economic co-operation and development (OEDC 2006) lists concerns about negative environmental and societal consequences as one of the underlying causes for the decline in relative numbers of students registering in science and technology courses in high school and third level education. Students need to realize that it is possible to use science and technology wisely and control technological development (Hodson 2003). They need to know that negative societal impacts are not an inevitable result. The *Heat Game* helped participants come to this realization because they developed technology that reduced energy use and helped reduce global warming.

Decline in enrolment in science courses leads to declining levels of scientific literacy among the general population. In order to interpret scientists' predictions and warnings we need to be able to understand the science they are based on. Without scientific literacy citizens are more likely to accept asserted truths wherever they come from, expert or charlatan, scientist or politician, rather than ask questions such as "How do we know? "Why should we believe it" and "What is the evidence for it" (Arons 1983). In the *Heat Game* student participants like Dr Spacey practiced making decisions based on the results of science knowledge from their own experiments. Student participants came to understand the connection between science claims and the work that scientists actually do. It is hoped that by understanding this connection they will be in a better position to ask appropriate questions of the science knowledge claims they hear through the media; that they will be in a better position to weigh up evidence, come to their own conclusions and make their own decisions.

This work with the *Heat Game* demonstrates the usefulness of the augmented reality game approach for allowing students to try on the complex combination of understandings values and attitudes that belong to the Reflective Scientist. Hopefully, through doing so, students have developed a deeper respect for the usefulness of science and technology for building understanding of the natural world and for helping us to develop a more sustainable society.

Chapter 6

Conclusions

In providing an opportunity for scientific literacy learning, as defined by the Reflective Scientist stance, the *Heat Game* and concomitant debriefing does the following:

1) Allows participants to:
    - Conduct practical, inquiry-based, science work and design-based technology work that addresses real-world problems;
    - Engage in the kind of conversations with expert reflective scientists that promote the development of reflective scientist understandings values and attitudes about environmental stewardship and the process of science including the importance of communication in the science world.
    - Reflect upon the nature and construction of science knowledge and the science enterprise in debriefing sessions that use concrete examples from their science investigations and conversations within the game.
2) Allows the teacher to:
    - Facilitate rather than impart science learning by role-playing a senior colleague within the science world;
    - Model science practice both through experience in the laboratory and through science conversations.
    - Focus primarily on designing and operating the game as an exciting learning environment.

This preliminary trial of the game reveals:

- the importance of making sure that all participants conduct inquiry based science and technological design activities,
- that the virtual characters must use terminology precisely and accurately,
- the importance of incorporating a reflective component where student participants can reflect upon their work in the game.

Bibiography

Arons, A. (1983) "Achieving wider scientific literacy." Daedalus, 112: 91-122

Aikenhead (1990) "Scientific/technological literacy, critical reasoning, and classroom-practice." In S.P. Norris & L.Ml Phillips (eds.), Foundations`in literacy policy in Canada. Calgary, AB: Detselig.

Aikenhead, G., and A. Ryan. (1992) "The Development of a New Instrument: Views on Science-Technology –Society (VOSTS)." Science Education 67.5: 477-94.

Dawkins, R. (2003) A Devil's Chaplin,. Mariner Books

Driver, R., Leach, J., Millar, R., and P. Scott (1996) Young People's Images of Science . Buckingham: Open University Press,

Elshop, L (2005) "Scientific Literacy to Avoid a 'Progress Trap'' Memorial University Site 8 February 2008 <http://www.mun.ca/educ/faculty/mwatch/fall05/elshof.htm>

Ehrlich, R. (2007) "Science will never explain everything-that is why it is so useful". Skeptic 13,.2 : 17- 19

Gee, J.P. (2003) "Postmodernism and Literacies", in Critical Literacy: Politics, Praxis and the Postmodern. Lankshear C. and P. McLaren eds. New York: State University of New York Press

Gee, J. P. (1996) "Discourses and Literacies", in Social Linguistics and Literacies: Ideology and Discourses. London: Routledge/Taylor Francis, 124-148.

Gee, J. P. (2004) Situated language and learning: A Critique of Traditional Schooling, London: Routledge.

Gee, J. P. (2007) Good Video Games and Good Learning. Collected Essays on Video Games, Learning and Literacy. New York: Peter Lang

Greenberg, D. (2001) Science, money and Politics Chicago: Chicago University Press

Hacking, I. (1983) Representing and Intervening, Cambridge University Press.

Hansen, N.R. (1958) Patterns of Discovery: An Inquiry into the Conceptual Foundations of Science, Cambridge University Press

Haraway, D. (1989) Primate Visions: Gender, Race, and Nature in the World of Modern Science, Routledge

Hodson, D. (2003) "Time for action: Science education for an alternative future." International Journal of Science Education, 25.6: 645-670.

Hodson, D. (2005) "What is scientific literacy and why do we need it? Memorial University Site 8 February 2008
< http:// www.mun.ca/educ/faculty/mwatch/fall05/hodson.htm>

Hofstein, Aand Lunetta, V. 1982 "The role of the laboratory in science teaching: Neglected aspects of research" Review of Educational Research, 52.2: 201-217

Hoffstein, A and Lunetta, V. 2004 "The laboratory in science education: Foundations for the twenty-first century" Science Education 88.1: 28-54

Kuhn, T (1962) Structure of Scientific Revolutions, Chicago: University of Chicago Press

Lankshear, C. and M. Knobel (2004) A Handbook for Teacher Research, Berkshire:Open University Press.

Lankshear, C. and M. Knobel (2006) A New Literacies Sampler , New York: Peter Lang.

Latour, B. and S. Woolgar (1979) Laboratory Life: The Construction of Scientific Facts, Beverly Hills: Sage Publications

Medawar, P. (1982) "Hypothesis and Imagination" in Pluto's Republic, Oxford University Press

Meichtry, Y. (1992) "Influencing student understanding of the nature of science", Journal of Research in Science Teaching, 29: 389-407.

McComas, W.F. (1996), "15 Myths of Science: Lessons of misconceptions and misunderstandings from a science educator", Skeptic, 5. 2 : 88-95

McComas, W. F. (2004) "Keys to Teaching the Nature of Science", The Science Teacher; 71,. 9 24-27

McComas W. F. (2005) "Teaching the Nature of Science: What illustrations and examples exist in popular books on the subject" presented paper: IHPST conference, Leeds (UK)

Millar, J. (1989) Doing Science: Images of science in Science Education, London: Farmer Press

Monbiot, G., (2006) Heat: How to stop the planet from burning, Doubleday.

National Commission on Excellence in Education (1983) A Nation at Risk <http://www.ed.gov/pubs/NatAtRisk/index.html>

OEDC Global Science Forum (2006) " Evolution of student interest in science and technology studies policy report" OECD Site <http://www.oecd.org/dataoecd/16/30/36645825.pdf>

Olson, R. (1990) Science deified and science defied: The historical significance of science in western culture, Vol. 2 University of California Press

Ontario Curriculum for Science and Technology 2007 Ontario Ministry of Education Web Site
<http://www.edu.gov.on.ca/eng/curriculum/elementary/scientec18currb.pdf>

Penzias and Wilson (1965) "A Measurement of Excess Antenna Temperature at 4080 Mc/s" The Astrophysical Journal 142: 419

Popper, K. (1963) Conjectures and Refutations: The Growth of Scientific Knowledge. London; Routledge

Press, F. (1982) "The Fate of School Science" Science 216: 1055

Ralston Saul, J. (1993) Voltaire's Bastards, The dictatorship of reason in the west, Penguin

Rocard Report. Science Education Now: A Renewed Pedagogy for the Future of Europe. 2007. European Commission Official Publications Site. 8 February 2008 <http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf>

Roth and Roychoudhury (1993) "The Development of Science Process Skills in Authentic Contexts" Journal of Research in Science Teaching 30.2: 127-152

Roth (1995) Authentic School Science: Knowing and Learning in Open-Inquiry Science Laboratories , Dordrecht, the Netherlands: Kluwer Academic Publishers

Roth (2005) Talking Science: Language and Learning in Science Classrooms, Nanham MD: Rowman and Littlefield

Science and Technology, Grade 7 Textbook, (2000) Addison Wesley, Longman

Science Teachers Association of Ontario (2006) "Position Paper on the Nature of Science" STAO Site 8 February 2008 <http://www.stao.org/resources/position-statements/Nature%20of%20science.pdf>

Shaffer, D. W. (2006) How computer games help children learn, New York: Palgrave Macmillan

Squire, K.D. & Jan Mingfong (2007) "Mad City Mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers", Journal of Science Education and Technology, 16.1: 5-29

Tallis, R. (2007) "Right, what have scientists ever done for us? Well…," TimesOnline (U.K.) site <http://www.timesonline.co.uk/tol/comment/columnists/guest_contributors/article1449416.ece>

Woolgar, S. 1988 Science: the very idea, London: Ellis Horwood. Ltd

Appendix 1

Final Products from the Students' Investigations

In May 2007 the three teams of students in the *Heat Game* study produced Powerpoint presentations for a mock city council consisting of two engineers, an employee from our city Hydro company (electricity supply), our school principal and two environmental activists from our community. They also presented short speeches for our real city council. Slides from the Powerpoint presentations that demonstrate their house designs have been reproduced here along with the speeches they prepared for city council. Although in their speech each team focused on one or two devices for reducing energy use in their houses, their house designs incorporate many more.

In the speeches it can be seen that student participants clearly recognized the link between science experiments, technological design to reduce energy use,

> During our research we got the idea to downsize our house from an experiment we did. It showed that the amount of heat energy needed to heat a substance to a particular temperature depends on the mass of the substance. We realized that the amount of heat energy needed to bring the air in a house to a particular temperature depends on the mass of air contained in the house. In other words, the bigger the house the more energy needed to heat or cool it. Our house for a three person family has just 648 square feet of space to be heated in winter or cooled in summer We believe that downsizing is the single most important thing we can do to reduce energy use for heating or cooling a house. Reducing energy use would reduce greenhouse gas emissions and help stop global warming (Team B)

Using a variety of assessment methods, designed in consultation with other teachers, final products were evaluated at a 4+ level indicating achievement far exceeding curriculum expectations for all teams.

On the following pages, pictures of the three houses designed by the three teams participating in the *Heat Game* are provided along with the speeches they wrote for city council.

Speeches for city council:

> Good evening Mayor and city council, ladies and gentlemen,
> My name is Carol Rees and I am a teacher at Montessori School. In our grade 7/8 class we have been learning about global warming and climate change. We have discovered that Canadians are among the top users of energy and the top emitters of greenhouse gases on the planet.
> We have embarked on projects to come up with ways to reduce energy consumption in homes and buildings. We have focused on reducing energy use for heating and cooling homes and buildings since this constitutes at least half of the total energy used. It is our hope that by sharing our discoveries with you tonight we might be able to help create a better future for us all. You will hear 3 short speeches from 3 teams of students.
> Team A

> Hello and good evening city council, we have chosen to talk to you about Project Passive Solar. Project Passive Solar involves making the most of free energy from the sun and the insulating power of the earth to keep our house warm in winter. This will reduce energy use and energy costs and it will cut down on production of greenhouse gases and help stop climate change.

In our design the house is oriented so that large windows face south while the north side of the house is built into an earth bank or hill. First we will talk about the landscaping that provides the shelter on the north side of the house then we will talk about the windows on the south side of the house.

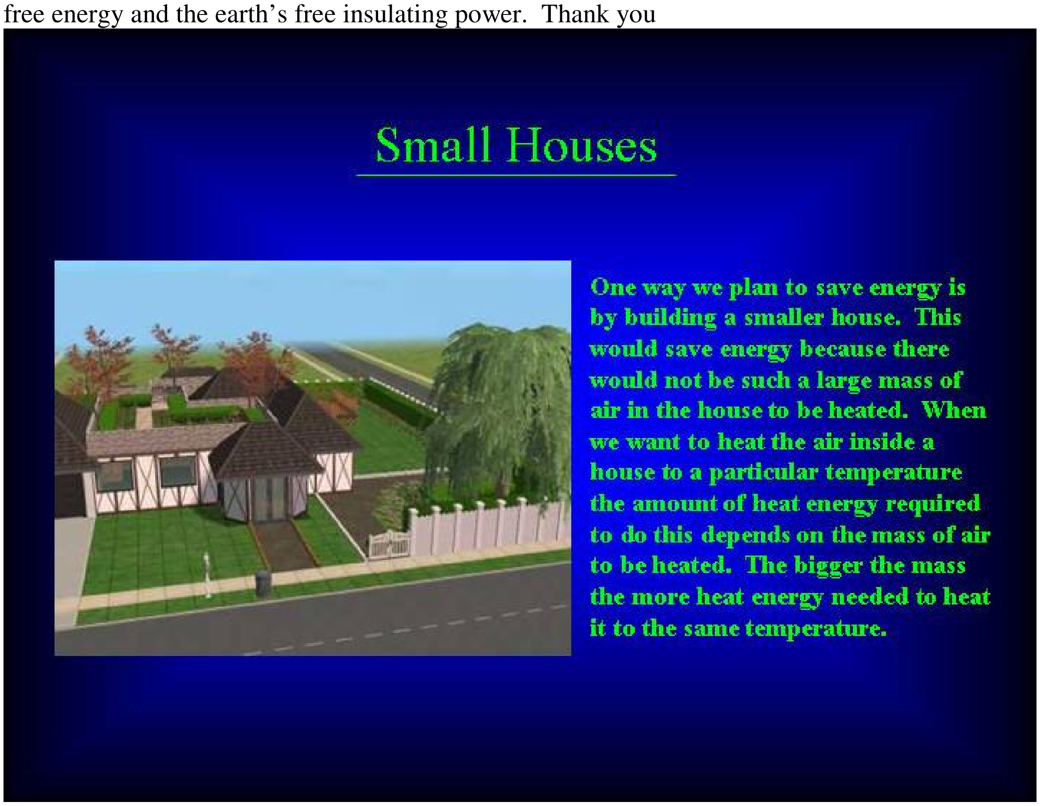
During our research for Project Passive Solar we read about houses that are built into earth banks to take advantage of the insulating power of the earth. We decided to test out this idea. We designed an experiment to test the insulating power of soil and discovered that soil was a better insulator than a commercially available insulator called cellulose.

Because of the results of our experiment we decided to make use of this idea. For our house we will choose a lot that already has a hill or earth bank. If necessary we will build an earth bank on the lot.

An unprotected home looses much more heat on a cold, windy day than on an equally cold, still day. The bank and the well-located trees and shrubs that we will plant around our house will intercept the wind and cut heat loss. Infiltration or air leakage can account for as much as one-third of heat loss in some buildings. Cold, outside air flows in through cracks around windows and doors and even through pores in the walls. This produces drafts that may cause you to compensate by raising the thermostat to unreasonable levels just to maintain a modicum of comfort. Both windbreaks like the bank, and foundation plantings cut down on the penetrating power of the wind. As well as our landscaping we will of course do our best to seal cracks and reduce air leakage.

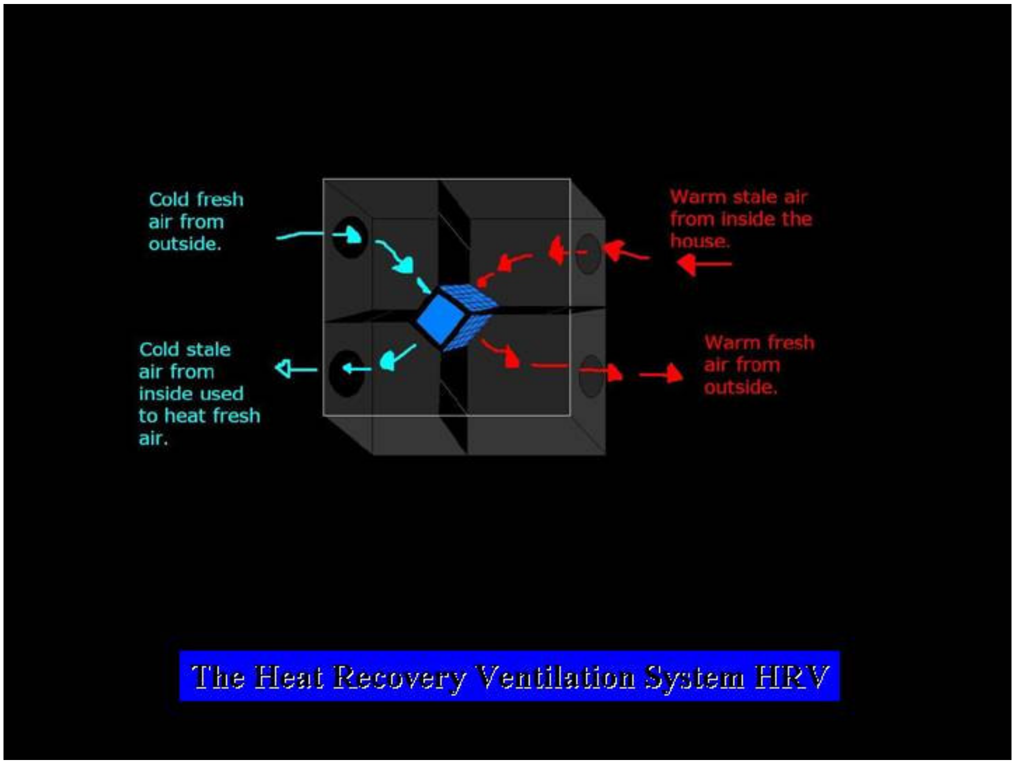
If we want to use passive solar heating in our houses we have to choose the right windows. We want high solar gain in winter so that we get the radiant energy from the sun to help us heat the house. We also want to reduce as much as possible the transfer of heat back out through the window by the processes of radiation, conduction and convection. We have chosen low-e triple glazed argon filled windows. Argon gas cuts down on the transfer of heat out of the house by conduction and convection while low-e coating cuts down on the re-radiation of heat out of the house through the windows. In summer we would need to cover the windows with drapes or blinds so that the house does not get too hot.

We recommend the passive solar design for houses of the future. It makes sense to use the sun's free energy and the earth's free insulating power. Thank you



Team C We will be talking to you about two methods we used in our house design to reduce energy use: downsizing to a smaller house and the heat recovery ventilation system.
During our research we got the idea to downsize our house from an experiment we did. It showed that the amount of heat energy needed to heat a substance to a particular temperature depends on the mass of the substance. We realized that the amount of heat energy needed to bring the air in a house to a particular temperature depends on the mass of air contained in the house. In other words, the bigger the house the more energy needed to heat or cool it. Our house for a three person family has just 648 square feet of space to be heated in winter or cooled in summer. It is cozy and comfortable. Our house is a single story home which makes it easier to maintain a balanced temperature. We have additional unheated space that includes a garage, porch and patio. During the summer the family has more space to use. We believe that downsizing is the single most important thing we can do to reduce energy use for heating or cooling a house. Reducing energy use would reduce greenhouse gas emissions and help stop global warming.

The second method we would like to describe is the heat recovery ventilation system. Ventilation is important for your home. It is a way to keep your house safe from dangerous chemicals like carbon monoxide, or toxins from smokers, gas leaks or just household products like hairspray. In modern homes the architectural structure and design is so airtight that even small amounts of chemicals can have a large impact. Normal ventilation systems extract hot air from the house and bring in cold fresh air. The heat recovery ventilation system heats the cold fresh air using heat energy from the warm outgoing air. To do this it uses a heat exchange system of aluminum passage ways that are in close contact with each other. When the air in the warm passage ways touches the walls it transfers heat through the aluminum from the hot to the cold passage ways. The heat recovery ventilation system can result in up to 85% of heat staying in the house while allowing appropriate ventilation. In winter in Canada the HRV must have a defrost damper. With a defrost damper if the HRV gets frost inside, the damper shuts down the HRV for a few minutes while the ice melts, then the HRV starts running again. This keeps the HRV in good condition. The HRV system is generally placed in the basement or attic and is connected to the supply air-return vents in the house's main ducting. The unit costs between $700-2000 depending on the size of the house. We highly recommend the heat recovery ventilation system to city council. It is a simple relatively inexpensive method to reduce energy use for heating buildings. Using HRVs would cut down on greenhouse gas emissions and help stop global warming.



F.A.M House #1

Energy efficient appliances…

-Green roof

-Green house roof

- Solar Panels

-plastic lumber

-Thermal Chimney

-Passive Solar

Square footage: 1470sf

Team B
Our team has chosen the green roof as the most important device for reducing the amount of energy used to heat and cool buildings. We have chosen this particular device because the green roof has been well investigated and it is becoming very popular in various countries.
A green roof is basically a layer of vegetation that grows on a layer of soil on your roof. Beneath the vegetation and the soil there are various other layers. There is a drainage layer to take water away from the roof and a waterproof roof membrane to stop water getting into the building. There is also a root barrier layer that protects the roof membrane from the roots of plants.
The cost of installing a green roof depends on the type of green roof used. There are two types of green roof extensive and intensive. An extensive roof involves simple plants, shallow soil and it is less effective at cutting down on energy transfer however it is cheaper to install. It costs $8-20 dollars per square foot. An intensive green roof involves a variety of different plants that are more visible and have more colour and beauty and this green roof has a deeper soil layer. The cost of installing this type of roof is $15-25 dollars per square foot.
There have been a lot of scientific investigations done to determine the effectiveness of green roofs at cutting down on energy transfer. I would like to tell you about experiments that have been done in Ottawa by Dr Karen Liu working for the National Research Council of Canada.
In her experiments Dr Liu has measured the amount of heat transferred through an extensive green roof and compared that with the amount transferred through a regular roof for each month of the year. During the spring and summer the green roof reduced the amount of heat transferred substantially. The green roof was very helpful for keeping the building cool in summer. She reported that “the average daily energy demand for space conditioning was reduced by 75%”. She found that during the winter when the green roof was frozen and roofs in Ottawa were covered with snow, the green roof did not make as much difference.
Having done this research on green roofs we have discovered that they can cut down on energy use in buildings and therefore reduce greenhouse gas emissions and help stop global warming. As energy costs increase in the future we believe that green roofs will be very useful at cutting costs, especially for cooling in summer. We recommend that city council investigate using a green roof on a municipal building to cut energy use. We appreciate that you have allowed us to come and give our speech today.

Appendix 2

Dr Spacey

This is one last thing I am hoping you can do related to the science projects. It will allow me to know what you have learned from playing the game HEAT and designing housing for sustainable living. You will not be judged by your responses to these questions. You do not have to study to answer them. What I am hoping to discover is what you know without studying. If there is too much writing to do please let me know and I can ask you the questions instead. Then I will write down the answers. Your work will be used to help me and others learn more about how best to teach science.

If you have trouble with the questions as in not understanding them please let me know. If this takes you too long please stop and let me know. This is not meant to be a test and it should not be hard so let me know if it is!

Please answer these questions on the document on the computer (you don't need to print this out). Then please e-mail the whole document (questions and answers) back to me.

The scientific process

When you look at your great bolts of fire experiment on testing the amount of heat energy in two metal bolts with different masses what would you say is the question that you wanted to answer using this experiment?

Did you have an idea of what you thought the answer might be?

When you set up your experiment in what ways were the bolts treated the same (try to think of everything)?

Were there any ways that were they treated differently (try to think of everything)?

In what way did the bolts differ from each other?

What conclusion did you draw from doing the experiment?
.

How sure do you feel about your conclusion?

If you wanted to feel even surer what would you do (try to think of everything)?

Is it important to make experiments 'fair tests'?

Why do you think?

People say that the scientific method is:

1. Asking a Question (question)

2. Guessing the answer (hypothesis)
3. Collecting evidence to test if your guess or hunch is right or wrong (results)
4. Making a conclusion (conclusion)

Did your great bolts of fire experiment follow the scientific method?

Explain your answer.

When scientists write up the results of their experiments, they use the format of: question, hypothesis, results and conclusion.

Did your report on the blog have any of those parts?

If so which ones?
.

Did you organize your experiment in that way or did you notice the parts of the experiment after you had done it?

Would you agree of disagree with this statement:

"Sometimes scientists write reports in a very logical orderly way but they do the work in a much less orderly way"

Why or why not?

When Dr Boyle wanted to repeat your experiment exactly what did he need to know?

Why is it important that he can repeat your experiment?

Would you agree or disagree with this statement:

Scientific knowledge (information developed by doing science) must be based on evidence (for example the results of experiments) that can be repeated over and over again.

Why do you think this is important?

Would you agree or disagree with this statement:

"Test results have to agree each time the test is done, before the results can be accepted as scientific knowledge?"

Why or why not?When you did your great bolts of fire experiment it didn't work the first time. You followed the protocol but you did not see a difference between the temperature of the water after the large and small bolts were transferred into the cups.

What did you do when you discovered that the experiment 'didn't work'?

Do you think this would happen often to scientists when they are trying to set up experiments or repeat experiments that others have done?

What attributes would scientists have to have to help them deal with this issue?

If you were writing a protocol for other scientists to follow what would you do to help get around this problem?

Science and technology/ interdependency

Once you had completed your experiment and come to your conclusions what did you do that made practical use of the knowledge that you got from doing your experiment?

In what way did your house design depend on your scientific knowledge that you got from doing your experiment?

Would you agree of disagree with this statement?

People say that technology is the application of scientific knowledge to a practical problem.

In your work what would be classified as the practical problem and what would be classified as scientific knowledge? What would the technology be?

In a debate if one side claimed "Engineers depend on scientific knowledge to build devices or machines that work" and the other side claimed "Engineers could build devices or machines that work without scientific knowledge" which side would you vote for?

Why?

Creative thinking and imagination

When you thought of your idea of how to apply what you found in your great bolts of fire experiment to your house design by downsizing, this was not something you had originally planned. You made a connection between what you discovered and how you could use the information.

You were using your creative thinking skills and imagination to come up with this insightful connection!

Scientists and engineers use their creative thinking skills and imagination when they are generating scientific theories, making connections and thinking of inventions and applications of their ideas. Would you agree or disagree with that statement?

Why or why not?

Scientific process
When you sent your results to Dr Boyle to publish on the blog he asked for the details of the experiment so that he could repeat it himself. Why do you think this was important to him?

Do you agree or disagree with this statement:

"The results of experiments that test the same thing have to agree (be the same) each time the test is done, before the results are accepted as scientific knowledge."

Why do you think this is important?

Would you think that in general it is good for scientists to check each other's work?

Would you agree or disagree with this statement?

Scientists must report their work to other scientists for review before it is accepted.

Why do you think?

When a research team makes a discovery, do you think it would be okay for the research team to announce their discovery to the press before other scientists have discussed it?

Why or why not?

Scientists check each others work before it is published in science journals.
Would you agree or disagree with this statement?

Why or why not?

What discovery did you make with your great bolts of fire experiment?

Did you add to scientific knowledge (information developed by doing science)?

Do you think that students can add to scientific knowledge (information developed by doing science)?

Why or why not?
Understanding that science theories are constructs

When you explained what was happening in your experiment and application to your house in terms of the particle theory of matter, you had to imagine what was happening to particles that you could not see. You were accepting that the particle theory was correct.

You received a request from Dr Boyle to defend the particle theory because it was being challenged by an alien called GROB.

You gave evidence from an experiment you had done in the past that supported the particle theory but not GROB's continuum theory of matter.

Do you think that sometimes today's scientific theories might have to change if new evidence is discovered that today's theories cannot explain?

Why or why not?

GROB lives a very different life than us. In what way does GROB's life differ from ours?

GROB has a very different point of view than us. In what ways did GROB's point of view differ from ours?

What was it about GROB's point of view that affected the theory GROB developed about the nature of matter?

If GROB and humans did the same experiment and they got the same results do you think they would interpret them in the same way?

Why or why not?

Would you agree or disagree with the statement that: Scientists interpret their results differently if they believe different theories.

Why or why not?

Scientist build up scientific knowledge by collecting interpretations of observations (or results of experiments) about the world; creating theories to explain these observations; thinking of ways to test out these theories to generate more observations.

If Kertrats and Earth were identical planets but GROB and HUMANS have very different lives, points of view, and theories do you think scientific knowledge would be different on Kertrats (GROB world) and on Earth (HUMAN world)?

Some people say that scientific knowledge is true beyond a doubt, it is a collection of facts about the world. Others say that scientific knowledge is our best understanding of the world at the present moment with our present way of thinking. Which do you think is right?

Why?

Science and technology interconnectedness

Once you had completed your experiment and come to your conclusions what did you do that made practical use of the knowledge that you got from doing your experiment?

In what way did your house design depend on your scientific knowledge that you got from doing your experiment?

Would you agree or disagree with this statement?
Technology is the application of scientific knowledge to a practical problem.

In your work what would be classified as the practical problem and what would be classified as scientific knowledge? What would the technology be?

In a debate if one side claimed "Engineers depend on scientific knowledge to build devices or machines that work" and the other side claimed "Engineers could build devices or machines that work without scientific knowledge" which side would you vote for?

Why?
Science and technology/ environment and society

In our work we were aiming to design housing that would conserve energy, reduce greenhouse gas emissions and help stop global warming.

If you overheard an argument where one side was saying "science and technology can solve global warming" and the other side was saying "science and technology cannot necessarily fix the problem of global warming" which might you agree with?

Why?

When we presented our projects to city council we made some recommendations to them about what people including city council could do to build houses and buildings that used less energy and therefore help stop global warming.

Do you think this was a good idea?

Why or why not?

What did you think of their response?

What would you like to see happen about this?

Do you think that science and technology can help solve pollution problems?

Why or why not?

When team A were doing their work they said one good thing about soil was that as well as being a good insulator it did not harm the environment. Do you think that scientists and engineers should have to think about whether the work they are doing will be good or bad for the environment?

Why or why not?

When you were doing your work you were concerned that the products such as furniture in the house were made by companies that did not allow child labour and that made sure that workers were generally treated fairly. Do you think that manufacturing companies should have to think about whether the products they sell have been made in a way that is good for the environment and for people?

Why or why not?

Your ideas for methods and devices to help save energy were not bad for the environment but sometimes scientific discoveries or a new piece of technology might be bad for the environment and/or people. If we wanted to control this, what do you think we should do? Please check the answers you think are right 1, 2, 3, 4?

1. The scientists and engineers should be held responsible, they should not develop something that might be dangerous and they should test it out and if it is dangerous get rid of it.

2. The scientists and engineers should be free to discover and invent anything but the government should stop them developing it if it turns out to be bad for the environment or people.

3. The whole community should be in control of whether scientists and engineers develop and invent something. They should be allowed to stop inventions that are bad for the environment or people.

4. Companies who make money from the discovery or invention should be allowed to develop it to make money even if it is bad for the environment or people.

Scientific thinking and practical everyday life

When you conducted your great bolts of fire experiment you were thinking like a scientist. Then you applied your knowledge to the practical problem of building a house that did not use so much energy.
Some people say that in everyday life thinking like a scientist helps us solve practical problems. Would you agree or disagree?

Please write about an example of a time in everyday life when you were thinking like a scientist to solve a practical problem?

Some people say that thinking like a scientist helps us figure things out and decide whether something (for example an advertisement) is true or not. This is because thinking like a scientist means asking what evidence there is to support the claim of the advertisement. Do you agree or disagree with this?

Why or why not?

When we hear predictions and warnings such as about global warming do you think that thinking like a scientist might help us understand them better and decide whether they are serious or not?

Why or why not?

Do you think scientists can tell us what will happen for sure or only what probably might happen?

Why do you think this?

Appendix 3

Scientific Literacy Questionnaire

For the research study

The Heat Game An Augmented Reality Game for Scientific Literacy

By Carol Rees 2007

modified from Meichtry (1992) and Aikenhead and Ryan (1992).

Aikenhead, G., and A. Ryan (1992) The Development of a New Instrument: Views on Science-Technology –Society (VOSTS), Science Education 67.5, 477-49.

Meichtry, Y. (1992) Influencing student understanding of the nature of science, Journal of Research in Science Teaching, 29, 389-407.

Instructions to students

Please listen to the question and answer True, False, Maybe or Don't know on the answer sheet provided

1. **When we do science we discover the facts/truth about the world we live in (e.g. about atoms and molecules).**
2. **Scientific models (e.g. the model of atoms moving in the molecular workbench software) are created from scientific theories; they are not copies of reality.**
3. **Today's scientific theories (e. g. the particle theory of matter) may have to change if new evidence is discovered.**
4. **The scientific method is questioning (asking a question), hypothesizing (predicting the answer), collecting data (observations or experimental results) and concluding.**
5. **Generating scientific theories (e.g. the particle theory) does not require imagination.**
6. **Scientific knowledge (information developed by doing science e.g. about atoms and molecules) cannot be judged as morally good or bad, but the ways people use scientific knowledge can.**
7. **Test results (e.g. that a particular chemical dissolves) have to agree (be the same) each time the test is done, before the results are accepted as scientific knowledge.**
8. **Scientific knowledge (information developed by doing science e.g. about atoms and molecules) is not a collection of facts; it is a collection of interpretations of observations (things scientists see or results of experiments).**
9. **Scientific knowledge (information developed by doing science) must be based on evidence (e.g. results of experiments) that can be repeated over and over again.**
10. **Scientific knowledge (information developed by doing science) may have to change if new evidence (things scientists see or results of experiments) is discovered.**
11. **Students cannot add to scientific knowledge (information developed by doing science).**
12. **Scientific ideas develop from *hypotheses* (predictions) to *theories,* and finally, if they are good enough, to being scientific *laws.***
13. **Technology (designing and building machines, like computers or weapons) is the application of scientific knowledge (information developed by doing science) to a practical problem.**
14. **Scientific knowledge (information developed by doing science) is a collection of facts about the world.**
15. **If scientists find that people working with asbestos have twice as much chance of getting lung cancer as the average person, this must mean that asbestos causes lung cancer.**

16. **All developments in technology (e.g. machines like computers or weapons) have come directly from scientific knowledge (information developed by doing science).**
17. **Scientific observations (things scientists see or results of experiments) can be different if the scientists believe different theories.**
18. **Scientists will ask different questions depending on who they are, their gender (male or female) or their culture.**
19. **Scientists and engineers can tell us only what *probably* might happen.**
20. **With the same background knowledge, two scientists can develop the same theory independently of each other.**
21. **Scientists create theories to explain their observations (what they see or results of their experiments) of the world around them.**
22. **Scientific models (e.g. the model of atoms moving in the molecular workbench software) are exact copies of reality.**
23. **Scientists must check each others work before it is published in science journals.**
24. **Scientific knowledge (information developed by doing science) is sometimes morally good and sometimes morally bad.**
25. **Scientists write reports in a very logical orderly way but they do the work in a much less logical way.**
26. **Engineers could build machines without scientific knowledge (information developed by doing science).**
27. **Scientific theories (e. g. the particle theory of matter) never change.**
28. **Scientists work in a very logical and orderly way.**
29. **Scientists are not influenced by personal or social factors in their work; they are objective.**
30. **Scientists will interpret their observations differently depending on their who they are, their gender (male or female) or their culture.**
31. **Scientific knowledge (information developed by doing science) never changes; it is true beyond a doubt.**
32. **When we do science we only improve our understanding of the world we live in; we cannot discover the facts/truth.**
33. **Scientists only believe a theory (e.g. the particle theory of matter) to be true because of the evidence (things scientists see or results of experiments).**
34. **Science and technology are closely related to each other because scientific research leads to new technology.**
35. **The results of experiments that test the same thing do not have to agree in order for scientific knowledge (information developed by doing science) to be accepted.**
36. **Scientists cannot be truly objective; they are always influenced by personal and social factors.**
37. **Science and technology (developing machines) can help people make some moral decisions.**
38. **Scientists will ask the same questions about the world regardless of who they are, their gender (male or female) or their culture because all scientists are trained in the same way.**

39. Scientists and engineers cannot tell what will happen for certain.
40. Students can add to scientific knowledge (information developed by doing science).
41. Few developments in technology (developing machines like computers or weapons) have come directly from scientific knowledge (information developed by doing science).
42. Scientists will interpret their observations in the same way regardless of their who they are, their gender (male or female) or their culture because scientists are trained in the same way.
43. Generating scientific theories (e.g. the particle theory of matter) requires imagination.
44. Scientific theories (e.g. the particle theory of matter) are based upon repeated observations (things scientists see or results of experiments).
45. Sometimes scientists are influenced by their scientist friends when deciding whether to believe a new theory.
46. When a research team makes a discovery, it is all right for them to announce it to the press before other scientists have discussed it.
47. Engineers depend on scientific knowledge (information developed by doing science) to build machines that work.
48. Scientists must report their work to other scientists for review before it is accepted.
49. It is acting responsibly to produce products for rich countries in poor countries where labour costs are low.
50. Corporations produce goods as cheaply as possible.
51. Science and technology cannot necessarily fix pollution problems in the future.
52. Science and technology can offer a great deal of help in solving pollution problems.
53. Government agencies should give scientists research money to explore the curious unknowns of nature and the universe.
54. To understand scientists' predictions and warnings we need to understand the science they are based on.
55. Scientists should be free to investigate what is of interest to them.
56. Most scientists are concerned with the effects (both helpful and harmful) that might result from their discoveries.
57. The community should decide what scientific research to fund.
58. Heavy industry has greatly polluted North America. Therefore, it is a responsible decision to move heavy industry to underdeveloped countries where pollution is not so widespread.
59. Government agencies should decide what scientific research to fund.
60. Scientists should not be held responsible for the harm that might result from their discoveries.
61. It is not the responsibility of scientists to report their discoveries to the public in a way that they can understand.
62. Science and technology are neutral but they can be used for good or bad.

63. It is not acting responsibly to produce products for rich countries in poor countries that have low pollution standards.
64. Science and technology cannot help people decide if something is bad for the environment.
65. Corporations should decide what research to fund.
66. In everyday life, thinking like a scientist helps us solve practical problems.
67. Science and technology can be relied upon to fix pollution problems in the future.
68. The community should tell scientists what to investigate.
69. It is acting responsibly to produce products for rich countries in poor countries that have low pollution standards.
70. Science and technology are bad for the environment.
71. There seems to be two kinds of people, those who are born able to understand the sciences and those who are born able to understand the arts.
72. Scientists should be held responsible for the harm that might result from their discoveries.
73. Thinking like a scientist helps us figure things out and decide if something (for example, an advertisement) is true or not.
74. Science and technology are not bad for the environment but the use we make of science and technology can be bad for the environment.
75. Government agencies should tell scientists what to investigate.
76. It is not acting responsibly to produce products for rich countries in poor countries where labour costs are low.
77. We can understand scientists' predictions and warnings without understanding science.
78. In everyday life scientific thinking is of no value.
79. The whole community should decide on pollution standards.
80. Big corporations do not produce goods as cheaply as possible.
81. When a new technology is developed the decision to use it should depend only on how well it works.
82. Whether we believe something is true or not has nothing to do with science.
83. The decision to use a new technology should depend on whether the advantages to society outweigh the disadvantages to society.
84. Science and technology can help people decide if something is bad for the environment.
85. Scientists should be held responsible for reporting their discoveries to the public in a way that they can understand.
86. The decision to use a new technology should depend on the profit that can be made from it by the company that develops it.
87. Most scientists don't think about the effects (both helpful and harmful) that might result from their discoveries.
88. Everyone is born with the same potential to understand science; whether they understand it or not depends on their education.