

A LOOK AT THE DEFINITION, PEDAGOGY, AND EVALUATION OF SCIENTIFIC
LITERACY WITHIN THE NATURAL SCIENCE DEPARTMENTS AT A
SOUTHWESTERN UNIVERSITY

by

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Chapter 1

Introduction and Theoretical Basis

There are a number of different arguments supporting the importance of being scientifically literate (Hazen & Trefil, 2009). The first comes from civics, which maintains that every citizen will be faced with public issues requiring some scientific background, and therefore every citizen should have some level of scientific literacy. Another argument comes from aesthetics and is closely allied with those made by liberal education in general, which is that the world operates according to a few general laws of nature. Every action a person takes during waking hours occurs because of these laws at work. There is intellectual and aesthetic satisfaction in seeing the unity between the colors of a rainbow and the behavior of the fundamental constituents of matter. The scientifically illiterate person is cut off from an enriching part of life, just as someone who cannot read. Finally, there is the argument of intellectual coherence. It is commonplace to note that scientific findings often play a crucial role in the intellectual climate of an era, such as Copernicus's discovery of the heliocentric universe playing an important role in sweeping away the old thinking of the Middle Ages and ushering in the Age of Enlightenment. What the Germans call the *zeitgeist*, which is the general intellectual tenor of the times, is influenced by the developments in science. Therefore, how can anyone hope to appreciate the deep underlying threads of intellectual life in his or her own time without understanding the science that goes with it (Hazen & Trefil, 2009)?

As science and technology continue to evolve on a global basis, it is essential for all students to be prepared for this rapidly changing environment. President Obama has included consistent themes of economic development, energy efficiency, environmental quality, health

maintenance, and the importance of scientific knowledge in national policy in his discussions of scientific issues and visions for science education (Obama, 2009). In science education, the President indicates that over the next decade, student achievement in the United States must move from the middle to the top on international assessments. This renews the earlier efforts in science education reform focused on achieving scientific literacy, notably Project 2061 sponsored by the American Association for the Advancement of Science (AAAS, 1989) and Scope, Sequence and Coordination launched by the National Science Teachers Association (1993). According to these initiatives, the scientifically literate person engages scientific knowledge and scientific ways of thinking for individual and societal purposes (AAAS, 1989).

Definition and Components of Scientific Literacy

The term, “scientific literacy,” has been used to express the broad and encompassing purpose of science education. The use of this term most likely began with James Bryant Conant in the 1940s (Holton, 1998), and was elaborated for educators in a 1958 article by Paul DeHart Hurd entitled “Scientific Literacy.” According to Hurd, scientific literacy describes an understanding of science and its application to social experience. In the 50 years since Hurd’s article, scientific literacy has been used extensively to describe the purpose, policies, programs and practices of science education. The historical perspective of scientific literacy, however, is not the reality of contemporary science education (Bybee, 2009). Academic researchers debate the real meaning of the term, classroom teachers claim their students are attaining scientific literacy, and the national and international assessments provide evidence that somewhere between the abstract purpose and concrete practice, the scientific community has

failed to achieve the goal, at least in the United States (Bybee, 2009). In fact, most school science programs emphasize content and methods that represent preparation for a professional career in science.

In contrast to preparing new scientists, the goal of scientific literacy, as it should be manifest in educational policies, programs, and practices, is to prepare students for life and work as citizens (Bybee, 2009). Hurd (1958) makes a clear connection between science and citizenship. Science has such a prominent role in society, Hurd argued, that economic, political, and personal decisions could not be made without some consideration of science and technology involvement (Hurd, 1958). Project 2061 poses the question of how today's education can prepare students to make sense of how the world works, to think critically and independently, and lead interesting, responsible and productive lives in a culture increasingly shaped by science and technology. Project 2061 defines scientific literacy broadly, emphasizing the connection among ideas in the natural and social sciences, mathematics, and technology (AAAS, 1989). Following soon after the publication of *Science for All Americans* (which presents a unified vision of scientific literacy that serves as a basis for discussions of the skills and knowledge that our nation's students should possess), the National Academy of Sciences joined the effort to ensure that all students achieve scientific literacy. The National Research Council posits that to keep pace in global markets, the United States needs to have an equally capable citizenry (NRC, 1996). *The National Science Education Standards* (NRC 1996), prepared by a wide range of individuals representing many constituents, were the result of NRC's position on science education. The definition of scientific literacy resulting from this work is broad and includes virtually all the objectives of science education that have been identified over the years. Holbrook and Rannikmae (2009) see the need for scientific literacy

to relate to an ability of functionality as a citizen within society (at home, work, and in the community), not purely at a knowledge level, but in making decisions and acting as a responsible citizen. Only the last, however, may be suggested as emphasizing socio-scientific decision making, where the focus not only regards changes to the natural world but also a way of thinking (Holbrook & Rannikmae, 2009).

Most recently, the Organization for Economic Co-operation Development (OECD), responded to members' demands, including the United States, for regular and reliable data to determine knowledge and skills of their students and to gauge the educational systems of the member countries. The OECD began working on the Programme for International Student Assessment (PISA) in the mid 1900s. PISA was officially launched in 1997, with the first survey taking place in 2000 (OECD, 2006).

Statement of the Problem

One might argue that the effectiveness of United States' science education has changed little since the 1987 commencement of Harvard University when the Harvard-Smithsonian Center for Astrophysics Media Department filmed the robed graduates as they were asked the following question: "Why is it hotter in the summer than in winter?" The results, displayed in their film, *A Private Universe*, found that only two of the twenty-three students queried could answer the question correctly. These results are not minor blemishes on a sea of otherwise faultless academic performances. Every university in the country has the same issue: all are turning out scientific illiterates, students incapable of understanding many of the important newspaper items published on the very day of their graduation. It is estimated that fewer than seven percent of adults in the United States classify as scientifically literate (Hazen & Trefil,

2009). Even among college graduates (22 percent) and those with graduate degrees (26 percent), the numbers who are scientifically literate by the standards of scholarly studies is not very high. Graduates in the United States as a whole simply have not been exposed to science sufficiently or in a way that communicates the knowledge they need to advance in the 21st century (Hazen & Trefil, 2009).

Science is organized around certain central concepts, certain pillars that support the entire structure. Since there are an infinite number of phenomena and only a few laws, the logical structure of science is analogous to a spider's web. Start anywhere on the web and work inward, and eventually one comes to the same core. Understanding this core knowledge, then, is what science is all about. In general, universities are structured to teach one science at a time. Thus, there is a fundamental mismatch between the kinds of knowledge educational institutions are equipped to impart and the kind of knowledge the citizen needs (Hazen & Trefil, 2009). To help students become scientifically literate, scientists must define what parts of their discipline are essential for the general citizen and then put that knowledge together in a coherent package.

When discussing the teaching and learning of scientific literacy, Lemke (2001) states that continuing to teach students science as autonomous disciplines inadequately prepares them for successful lives in the 21st century. He proposes that current teaching practices include historical origins of scientific concepts and economic impact on society (Lemke, 2001). Hodson (1982) posits that the goal of teaching and learning science involves enabling students to understand the natural world through grasping some of the classic and recent phenomena explained by scientists. How does the scientific community, specifically the

science disciplines of geology, astronomy/physics, biology and chemistry interpret scientific literacy and how is it taught in these disciplines?

Significance of Study

This research is different from any other that has been conducted in that it is specifically focused on scientific literacy within the Biology, Chemistry, Physics/Astronomy, and Geology departments at a southwestern university. This study is relevant as it provides specific insight into how university faculty within the aforementioned departments define, incorporate, and assess scientific literacy in their courses. This study contributes pertinent information regarding the integration of scientific literacy into college curricula and a comparison of the various natural sciences regarding the definition, incorporation and assessment of scientific literacy within those specified departments.

Research Questions

The questions that guided the research were:

1. How do faculty within the Biology, Chemistry, Physics/Astronomy, and Geology departments define scientific literacy and its components?
2. How do faculty provide the experiences to all students within their respective courses to provide scientific literacy and in what ways is this accomplished?
3. How do faculty assess student progress towards becoming scientifically literate citizens prior to completion of their science courses?

Purpose of Study

The purpose of this study was to determine how selected faculty within the natural sciences departments of the College of Science define ‘scientific literacy’, incorporate it into their teaching, and evaluate their students’ attainment of scientific literacy. The study specifically sought to determine how the faculty’s perception correlates with the College’s Mission Statement which indicates that the department “will facilitate students becoming and continuing to be mathematically and scientifically literate citizens.”

Chapter 2

Review of Literature

Scientific literacy is relevant to both the science community and the science education community. This chapter reviews the current research regarding the perception of scientific literacy within the science community, specifically geology, biology, chemistry, and physics/astronomy, as well as the science education community. Each community's perspectives of the definition of scientific literacy, the teaching and learning of scientific literacy and the evaluation process of scientific literacy are addressed.

Definition of Scientific Literacy

Science education community

According to Hazen and Trefil (2009), scientific literacy constitutes the knowledge a person needs to understand public issues. It is not the specialized content of experts, but more the general, less precise knowledge used in political discourse (Hazen & Trefil, 2009). For example, in the next few days anyone in the United States might pick up a newspaper and see a headline like “Major Advance in Stem Cells Reported” or “New Theory of Global Warming Proposed.” These issues directly affect a person's life and, as a citizen, one will need to form an opinion in order to take part in political discourse on these issues. Being able to understand these debates is becoming as important as the ability to read. Scientific literacy is a mix of facts, vocabulary, concepts, history, and philosophy. If one understands the news of the day as it relates to science or takes headlines, such as mentioned above, and puts them into meaningful context, then he/she is scientifically literate (Hazen & Trefil, 2009). Trefil posited

that when one understands the world it becomes less threatening and ultimately that is what science is all about (Trefil, 2007). This understanding of the world is scientific literacy.

Scientific literacy has a relatively long history and generally broad use in science education (Bybee & McCrae, 2011). Its meaning for schools in the United States generally includes an understanding of science and its application to the social experience (DeBoer, 2000). A variety of science educators have provided clarification of the term, particularly for school science programs. For example, Osborne (2007) posits that contemporary science curricula and practices are primarily “foundationalist” (p.174), a position that emphasizes educating future scientists versus educating future citizens. The perspective in the Programme for International Student Assessment (PISA) emphasizes educating future citizens (Bybee, 2009).

Science differs from all other intellectual activities so as to require a mode of thought that is out of keeping with one’s everyday experiences. However, knowing what science is about is prerequisite to such literacy. The population mass may never understand science in detail, but the hope would be that some understanding would be instilled about how science works and how scientists practice their discipline to serve the societal purposes of scientific literacy (Shamos, 1995).

The American Association for the Advancement of Science (AAAS), Project 2061’s *Science for All Americans*, was one response to including what students should know to be scientifically literate. This response included the following:

- being aware of some of the important ways in which mathematics, technology, and the sciences depend upon each other;
- being familiar with the natural world and respecting its unity;

- having the capacity for scientific ways of thinking;
- understanding some of the key concepts and principles of science;
- knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and weaknesses; and,
- being able to use scientific knowledge and ways of thinking for personal and social purposes (AAAS, 1993).

Following soon after the publication of *Science for All Americans*, the National Academy of Sciences (1996) joined the effort to ensure that all students achieve scientific literacy. Begun in 1992, the *National Science Education Standards* are part of the United States Government's approach to education reform – an approach that involves setting national goals and the standards for meeting them. The objective of the *National Standards* was for all students to achieve scientific literacy by mastering a set of content standards. There are five main assumptions comprising the identification of the content standards which are:

- everyone needs to use scientific information to make choices that arise every day;
- everyone needs to be able to engage intelligently in public discourse and debate about important issues that involve science and technology;
- everyone deserves to share in the excitement and fulfillment that can come from understanding and learning about the natural world;
- more and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems; and,

- to keep pace in global markets, the United States needs to have equally capable citizenry (National Research Council, 1996).

PISA 2006, an international standardized assessment measuring student domains in reading and mathematical and scientific literacy, situated its definition of scientific literacy within the four following competencies:

- scientific knowledge and the use of that knowledge to identify questions, to acquire new knowledge, to explain phenomenon, to draw evidence-based conclusions about science related issues;
- understanding the characteristic features of science as a form of human knowledge and inquiry;
- awareness of how science and technology shape our material, intellectual, and cultural environment; and,
- willingness to engage in science related issues, and with the ideas of science, as constructive, concerned, and reflective citizens (OECD, 2006).

As can be seen in the four categories, the authors of PISA 2006 did not perceive scientific literacy as a single discrete entity or typological classification, but rather as a continuum from less developed to more developed competencies that include proficiency levels, different domains of scientific knowledge, and attitudes toward science (Bybee, 2009).

It should be noted that no literature was found regarding any standardized assessment of scientific literacy at the collegiate level.

Science community

The beginning of a solution to the United States' problem with scientific literacy, both for those still in school and those whose formal education has been completed, lies in a simple statement: If you expect someone to know something, you have to tell him or her what it is (Hazen & Trefil, 2009). For example, if the government expects individuals to come to an intelligent decision on whether tax dollars should be spent on alternatives to fossil fuels, people have to be told, in order for them to understand, about the nature of energy in general and the potential benefits and risks associated with each specific energy source.

Scientific literacy within the science disciplines.

In general, all of the separate science spokespersons agree on the notion of scientific literacy. Resonating from each is the idea that the scientifically literate individual makes informed decisions regarding current scientific issues, both for personal and societal well-being, and possesses enough scientific knowledge to critically assess scientific material presented in the media.

Biology.

The American Institute of Biological Sciences states that it is dedicated to improving scientific literacy at all levels of formal and informal education. AIBS is working toward meeting this goal through a number of initiatives by recognizing teaching professionals, collaborating with other organizations, disseminating information, publishing teaching resources to improve biology education and encouraging students to pursue careers in biology (AIBS, 2011).

Although some academics believe that everyone should experience “real” science, with its mathematical rigor and complex vocabulary, others would disagree with this perspective

positing that this view is confusing two aspects of scientific knowledge. Surprisingly, some scientists are so focused in their area of expertise that they are just as likely to be ignorant of scientific matters outside their area of specialty as anyone else. As in many other endeavors, *doing* science is distinct from *using* science: scientific literacy concerns only the latter (Hazen, 2002). Brewer states that the definition of scientific literacy is looking at an article in a magazine or listening to a commentary on a newscast or television and having the ability to carry on a skeptical discussion. It is knowing enough about science to judge a story you are being told in a fair and accurate manner. Asking questions is basic to scientific literacy (Brewer, 2008).

Chemistry.

According to the American Chemical Society (Shakhashiri, 2010), chemistry is a fundamental science and guidance for a document called the *National Science Education Standards* (NSES) could not be written without a discussion of chemistry and all the other disciplines based on chemistry and chemistry principles. The goal of the standards is to ensure that all children and eventually all citizens are scientifically literate. The ACS states that of the basic sciences, chemistry fuels an industry that most directly translates to products people use and directly impacts their lives. Most importantly, chemistry fits neatly into the case made for scientific literacy in the introduction of the NSES. To paraphrase: (1) scientific literacy fosters personal fulfillment and excitement; (2) modern life requires a scientific way of thinking; and (3) scientifically engaged citizens help society address shared responsibility and fairly managed resources (Shakhashiri, 2010). Chemistry classes provide a learning platform for students to develop skills in technical writing and reading, data analysis, analytical thought, and working in teams—skills basic to daily life and successful employment. Even the

“cookbook” chemistry labs provide students experience to read, follow instructions and record observations. While central to laboratory reports, clear concise writing, supported by data, is also critical to any persuasive argument in business or law (Shakhashiri, 2010).

While physics, or any other science, could be substituted for chemistry in this statement, chemistry is unique in its ability to address how issues of science and technology affect people individually and globally (Carroll & Sherman, 2008). The 2008 president of the ACS states that scientific literacy enlightens and enables people to make informed choices, to be skeptical, reject shams, quackery and unproven conjectures. Scientific literacy is for everyone: chemists, artists, humanists, professionals, the general public, youth and adults alike. The level of scientific literacy in any society is a measure of what it values and its resolve to put these values into practice (Shakhashiri, 2010).

Physics/Astronomy.

The American Astronomical Society Mission and Vision Statement posits that the society will assist its members in developing their skills in the field of education and public outreach at all levels. The society promotes broad interest in astronomy, which enhances scientific literacy and leads many to careers in science and engineering (AAS, 2009).

According to Dr. George Nelson, former Education Officer of the AAS, the AAS supports the National Science Education Standards as they emphasize the importance of scientific methods and articulating well established scientific theories (Nelson, 2005).

The American Physical Society Mission Statement does not directly discuss scientific literacy but mentions that they strive to be the leading voice for physics and an authoritative source of physics information for the advancement of physics and the benefits of humanity. The mission statement also states that the society strives to collaborate with national scientific

societies for the advancement of science, science education and the science community. The Director of the Navy Nuclear Power School in Charleston, South Carolina, Warren Huelsnitz posits that the National Science Foundation surveys indicate that scientific literacy of the general public in the United States is low and not improving. He does not see that everyone needs to understand the string theory, but it would be nice if the general public understood the scientific process and could use logic and reasoning. People should understand that there is a difference in having a scientific basis for something and not having one. They should be able to use logic and reasoning to debate issues and make public policy decisions that affect their lives, rather than accepting the popular consensus without question (Huelsnitz, 2005).

Geology.

The Geologic Society of America states in their position statement that the knowledge of the earth sciences is essential to science literacy and to meeting the environmental and resource challenges of the 21st century. The GSA endorses the adoption of the National Science Foundation standards (NSES) by all public and private school systems and the incorporation of the study of the earth into all educational levels, kindergarten through twelfth grade. To ensure a scientifically literate society, one that maintains wise stewardship of Earth's precious resources, the Geological Society of America, in coordination with its member societies, also endorses the National Research Council's National Science Education Standards. Earth Science empowers individuals to think globally and act locally to make sound decisions about issues important to daily lives as citizens. People who understand how Earth systems work can make informed decisions about where to buy a home out of harm's way. They can debate and resolve issues surrounding clean water, urban planning and development, national security, global climate change, and the use and management of natural

resources. Essentially, when Earth Science education, from elementary through college is emphasized, everyone benefits (GSA, 2004).

Ultimately, while an agreement on a universal definition of scientific literacy differs, there seems to be two major camps, or points of view:

- (a) those that advocate a central role for the knowledge of science; and,
- (b) those that see scientific literacy in reference to societal benefits.

The first camp appears to be very prevalent in higher education today. It builds on the notion that there are “fundamental ideas” in science that are essential and that science content is a crucial component of scientific literacy.

The second camp encompasses the longer term view and sees scientific literacy as a requirement to adapting to the challenges of a rapidly changing world. This view sees scientific literacy in alignment with the development of life skills. It recognizes the need for reasoning skills in a social context, and above all, having little to do with science teaching solely focusing on an academic science background (Holbrook & Rannikmae, 2009).

Assumptions about Teaching and Learning of Scientific Literacy

Collectively speaking, the science education and scientific communities share in the assumption that a student-centered learning environment in which students relate better to content via contextual methods and a provision is made for collaboration with decision making and problem solving opportunities, will enhance student motivation to learn. The connection and application of subject matter to the real world is vital in enhancing scientific literacy.

Succinctly stated, John Dewey defended science as a legitimate intellectual study on the basis of the power it gave individuals to act independently. He said that whatever natural

science may be for the specialist, for educational purposes it is knowledge of the condition of human action (Dewey, 1916).

Science education community

When discussing the teaching and learning of scientific literacy, Lemke (2001) states that continuing to teach students science as autonomous disciplines inadequately prepares them for successful lives in the 21st century. He proposes that current teaching practices include historical origins of scientific concepts and economic impact on society. If authentic education is to take place, it needs to be taught in more humanistic ways, as human activity is socio-cultural in nature (Lemke, 2001). Hodson (1982) relates the goal of teaching and learning when he states that the object of science is to understand the phenomena of the natural world. In teaching science, the main objective is to bring students to a state of mind in which they understand some of the classic and recent phenomena that scientists have explained. The explanation enables one to understand the natural world in which they live (Hodson, 1982).

In most educational systems, science education is an integral part of the total education provision within a school. It may be argued that different subjects should cover different educational domains, or perhaps subdomains. For example, language arts would cover the development of communication skills, mathematics would teach logic, social science would teach cooperative learning or social values and science teaching would provide psychomotor and problem-solving skills. However, this assumption is not realistic because students typically select a variety of paths through the curriculum. By recognizing that science education is part of the educational provision within schools, the teaching of science subjects can be expected to promote the development of a range of skills and values, such as solving socio-scientific problems (Holbrook & Rannkmae, 2009).

One proposed method of teaching and learning scientific literacy, known as the Activity Theory, is through context-based situations and not through the identification of essential content. This view represents a major change in the focus of teaching science subjects, meaning that the content necessary for enhancing scientific literacy is taught within a cultural context. Teaching based on this model is less about post-positivism or the constructivist approach and more related to activity theory (Roth & Lee, 2004).

Activity theory revolves around three levels of activity:

1. Level of activity proper. This level can be interpreted as science-related practices to provide students with learning practices to problem solve, such as what society would envision as an area of need, such as making products from raw materials or resolving scientific issues that would affect society as a whole.
2. Level of action. This level stresses the division of labor and usually involves cooperative learning and group work. The goal is that each group member takes into consideration what is best for the entire group when presented with an issue or task at hand.
3. Level of operations. This level concerns the techniques and routines that could include plans and procedures for carrying out the actions related to the problem solving. For example, articles and reports have certain arrangements and speeches usually follow a prescribed agenda. Reflection can take the shape of planning a course of action or justifying what one is planning to do, not only for the individual, but with the cooperative decision making of the group regarding the task (Holbrook & Rannikmae, 2007).

This approach to enhancing scientific literacy places the learner in the position of an apprentice. Therefore, addressing the needs is not driven by considerations of completing a curriculum plan or preparation for an examination, but rather relating to relevance in an educational sense. Roth and Lee (2004) likened the activity theory to a rope with fibers and threads. The rope represents the community of practice, or society, the persons involved are the thread; and, the various knowledge and skills held by the individuals are the fibers.

Feinstein (2011) posits that making science relevant should not be something that the teacher does in isolation, but rather as a pedagogical tool. This practice involves students starting with their own questions, firmly embedded within their own social context, and reaching into the social worlds of science in an attempt to connect scientific ideas with lived experiences. For example, students who learn about pesticide pollutants in their local watershed may learn some very specific lessons about toxicity and ground water, but as educators and theorists since John Dewey have recognized, the primary point of this exercise would be to teach the students that scientific knowledge and knowledge about science are both relevant and accessible. Whenever side-by-side comparisons of curricula featuring socially contextualized and decontextualized science are done, the findings indicate that students who learn science in meaningful social contexts do no worse on knowledge measures than their counterparts, who learned in a decontextualized manner, and often do significantly better on motivational and attitudinal measures. Combined with contemporary research on science in daily life, it is suggested that learning about science in a deeply personal context could make students more willing to plunge into unfamiliar, science-tinged waters in the future (Feinstein, 2011).

The Scientific Community

The scientific community provides assumptions for teaching and learning scientific literacy as well. For example, professors at North Dakota State University and La Moyné College in Syracuse suggest that a college course providing science history and nature of science topics could be useful in direct support of science content and problem solving skills by using examples from history, such as Boyle's Law. One method to convey science as a human endeavor is through the use of a biographical approach, which might include short, biographical statements included in textbooks, offering a starting point to a particular scientist. The life and work of the scientist is viewed more in depth through classical literature, teacher-led discussion, or student-oriented projects, class presentations, or collaborative efforts. It is worth emphasizing to students that the importance of empirical testing in science does not imply a single "scientific method," let alone a method that precludes imagination, creativity, passion or luck on unifying themes, particularly in the treatment of evidence, models and explanations. Although observations and experiments are what ultimately lead to acceptance in the scientific community, there are almost as many sources of scientific ideas, explanations, analogies, and questions as there are scientists (Rasmussen, Giunta & Tomchuk, 2003).

National Science Teachers Association. NSTA views the problem as the "I Love Lucy" syndrome in which Lucy and Ethel are in the candy factory making chocolates and finally realize they cannot keep up with the pace in which the conveyer belt is delivering the chocolate to them to be wrapped. They begin stuffing candy into their mouths, pockets and hats in a futile attempt to keep up. The same with science information: there is not a way to keep up nor is there any way to stop the machine. Therefore, in answer to this dilemma, three

possible solutions to teaching science are offered: focus on a few select topics, teach in context, and use cooperative/collaborative learning.

First, focusing on a few select topics means deciding what is most important and has good longevity, such as the major paradigms of science (as used by Thomas Kuhn in 1970). Paradigms are the most encompassing ideas that bind an entire scientific discipline together. For example, in geology, it might be plate tectonics, which explains much of what is known about volcanoes, earthquakes and the distribution of many fossil and living animals. By choosing to teach paradigms instead of a multitude of unconnected facts and principles, science educators promote real power and real access to scientific literacy.

Next is the idea of teaching in context, particularly with telling stories and using case studies. Within the book published by the NSTA, *Start with a Story: The Case Study Method of Teaching College Science*, the authors commend the national organizations' efforts to set up standards of scientific literacy as they treat scientific literacy as more than a mere collection of facts. Unfortunately, faculty, parents and textbook publishers are fixated more on the teaching of facts, principles and terms (Herreid, 2007). Cases engage students like few other devices in the classroom. People like stories and learning in the context of a story is easier and more likely to be retained, and simply more fun. The best case studies are those based on real events, especially those that involve unresolved issues, are current and involve public policy issues. Using case studies solves several science teaching concerns. Case studies show the process of science in action better than almost any other teaching experience. They expose the humanity of the scientific enterprise and students see how scientists "act just like people." With case studies, students see the need for basic science as well as applied science and this

offers the opportunity to explore the differences between tabloid science and original science reporting. It provides chances to explore the difference between science and pseudoscience.

Lastly, cooperative/collaborative learning in colleges and universities has gained attention recently. The data are overwhelming in favor of the cooperative mode over the lecture method. Johnson and Johnson (1989) have done over 600 studies in this capacity that are published. Students in cooperative environments retain more information, are more enthusiastic about their subject, and have more social skills and more tolerance for different opinions. Sheila Tobias (1990) writes in her book, *They're Not Dumb, They're Different* that this type of arrangement is more appealing to women and minorities because the traditional classroom can be alienating with its lectures and authoritarian tone. Ultimately, students must be prepared for science that has yet to be discovered, for the books that have yet to be written and for the ethical problems that are yet to be posed (Herreid, 2007).

Other science organizations. Brewer (2008) posits in a report to the American Institute of Biological Sciences that one of the most important skills we can teach students is how to ask questions, which is really at the root of scientific literacy. She is firmly rooted in the school of having people learn by doing and therefore is a proponent of the 5E Model (Brewer, 2008), which is an instructional design model, based on constructivist learning theories, that is effectively used in teaching science. This model is comprised of five sequences: engage, explore, explain, explore/extend, and evaluate. In addition to the 5E Model as a means of learning by doing, Brewer advocates getting outdoors and just stimulating students' curiosity about what they observe or as she puts it, "just dinking around." Even as scientists and researchers, misconceptions can occur when all the data are not present. People need to get out, practice with their hands, observe with their eyes, and hear with their

ears. After gathering the information, it is important to share with others, discuss the different perspectives from the data gathered and come to a consensus. Having students reflect on their own thinking and create portfolios is part of the learning process. Fundamentally, the connection between teaching and learning needs to be made, and that is what it is all about (Brewer, 2008)!

At the University of Florida (Yates, 1998), professors are suggesting that using the popular media, including magazines, journals, television, the internet and radio can provide students with alternatives to the textbook that highlight the impact of scientific knowledge on personal and social levels. General education courses can be enhanced through the use of written logs, student critiques and identifying biases that may be used to influence public opinion. Instructors should provide student-centered, inquiry labs as it is suggested that science is knowledge gained through experience (Yates, 1998).

Evaluation of Scientific Literacy

In the last decade, three measurement instruments for scientific literacy have become well known: Programme for International Student Assessment (PISA), Trends in International Mathematics and Science Study (TIMSS), and the National Assessment of Educational Progress (NAEP). Following are comparisons of the science knowledge and abilities delineated in the 2007 TIMSS (Molnar, Gordon, Jones, and Newton-Tabon, 2009) and 2009 NAEP (National Assessment Governing Board, 2008) with the knowledge and abilities that constitute scientific literacy as defined by PISA. While the language used to describe the essential knowledge and skills is different in the three frameworks, with few exceptions, the components are similar. Essential differences are in the assessments, the characteristics of the

items, and the testing time devoted to each component. Physical, Life, and Earth Sciences are science literacy components in all three assessments. PISA includes knowledge about technology and science as components of science literacy; neither TIMSS nor NAEP include these areas in their knowledge components (Champagne, 2009).

NAEP

The NAEP measures student science achievement nationally, state by state, and, most recently, across selected urban school districts. The framework provides guidance on the science content to be assessed, the types of assessment questions, and the administration of the assessment. For more than 35 years, the NAEP has gathered information on student achievement in selected academic subjects. Originally, assessments were age-based samples of 9-, 13-, and 17-year-old students. Beginning in 1983, the assessment also has included grade-based samples of students in grades 4, 8, and 12.

For more than 40 years, the NAEP has provided information integral to reporting on the condition and progress of education at grades 4, 8, and 12 for the nation and, more recently, for the states and for a set of large, urban school districts. Legislation concerning the NAEP states that its purpose is to provide, in a timely manner, a fair and accurate measurement of student academic achievement and reporting of trends in such achievement in reading, mathematics, and other subject matter. Because of its rigorous design and methodology, the reports are increasingly used for monitoring the state of education in the subjects that are assessed, as models for designing other large-scale assessments, and for secondary research purposes (National Assessment Governing Board, 2008).

The NAEP and its reports are a key measure in informing the nation on how well the goal of scientific literacy for all students is being met. The *Science Framework for the 2009*

National Assessment for Educational Progress sets forth recommendations for the design of a new science assessment. The first dimension of the framework includes science content and is defined by a series of statements that describe key facts, concepts, principles, laws and theories in three broad areas:

- Physical Science
- Life Science
- Earth and Space Sciences

The second dimension of the framework is defined by four science practices:

- Identifying Science Principles
- Using Science Principles
- Using Scientific Inquiry
- Using Technological Design

Some of the limitations of the NAEP that have been identified include:

- New types of assessment items require considerable time and cost for development, scoring and analysis;
- Safety and practical concerns limit access to certain physical materials and equipment during testing;
- NAEP does not report or monitor student achievement at the individual or school level;
- Limited time and resources prevent measurement of all important outcomes, limiting the definition of scientific inquiry and technological design; and,
- NAEP does not measure attitudes, beliefs, affect, or skills, such as creativity, collaboration and social responsibility (Fu, Raizen, & Shavelson, 2009).

The NAEP has typically reported subscale scores for content areas and not practices. Ultimately, it is up to the public and all those who have a stake in science education to consider the quality of the assessment itself, to press for assessment that is ever truer to the breadth and depth of what it means to achieve in science (Fu, Raizen, & Shavelson, 2009).

PISA

PISA benefits from its worldwide scope and its regularity. More than 70 countries and economies take part in PISA so far and the surveys, which are given every three years, allow them to track their progress in meeting key learning goals. PISA is the only international education survey to measure the knowledge and skills of 15-year-olds, an age at which students in most countries are nearing the end of their compulsory time in school. PISA is one of the largest scale international efforts to be launched to assess scientific literacy (OECD, 2006).

Every PISA survey tests reading, mathematical and scientific literacy in terms of general competencies, meaning how well students can apply the knowledge and skills they have learned in school to real life challenges. PISA does not assess how well a student has mastered a specific school's curriculum.

The PISA framework for assessing the scientific literacy includes four interrelated aspects:

- Knowledge or structure of knowledge that students need to acquire (e.g. familiarity with scientific concepts);
- Competencies that students need to apply (e.g. carry out a specific scientific process);

- Contexts in which students encounter specific scientific problems and relevant knowledge and skills are applied (e.g. making decision in personal life or understanding world affairs); and,
- Attitudes and disposition of students toward science (OECD, 2006).

Some of the limitations of this measurement tool that have been identified are:

- The limitations of validity and comparability of scores over time from earlier cycles of assessment need to be discussed in their assessment frameworks and reports.
- Knowledge about science was found largely in relation to the processes of science, rather than the nature of science as described in the framework (Lau, 2009).
- Accountability for PISA turns out to mean merely the posting of school level results. The National Center for Educational Statistics (NCES) frequently objects to many of the findings in PISA reports, but is often simply “politely” ignored.
- PISA itself admits to policymakers that it cannot reliably identify which parts of the education pipeline are working well and which need improvement.
- To get state level scores, about 1,500 students in the state need to be tested. This would be a cost of \$700,000 per state on average, which causes states to look elsewhere for less expensive, and possibly less comprehensive alternatives (Schneider, 2009).

TIMSS

TIMSS has been used around the world in order to develop better methods in teaching science and mathematics. TIMSS provides reliable and timely data on the mathematical and scientific achievement of the United States 4th and 8th graders compared to that of 60 other

countries that participate in this assessment (Molnar, et al., 2009). TIMSS is considered more grade and curriculum centered, and aligns broadly with mathematics and science curricula in the participating countries. Two levels are investigated for the science portion of TIMSS, which include the intended and the implemented curriculum. The intended curriculum is the science and math learning that society expects to take place within the students. The implemented curriculum is the content taught in class, how it is taught and who teaches it. The five domains in science include the following:

- Life Science
- Chemistry
- Physics
- Earth Science
- Environmental Science

The three cognitive domains for the science portion of the assessment are:

- Factual knowledge
- Conceptual understanding
- Reasoning and analysis

There is no perfect instrument to measure scientific literacy, and TIMSS also possesses some limitations with their instrument as with PISA and the NAEP. These limitations include:

- TIMSS produces cross-sectional data (single point in time) and therefore do not allow for longitudinal analysis (comparisons over time) at the student level, which is how researchers like to measure student achievement.

- TIMSS is a sample study; the average scores of the populations tested are only estimates of what the score would be for those assessed.
- Translation of the TIMSS to other languages related to poor scores for some students because vocabulary proved too difficult.
- Validity concerns exist since countries differ substantially in such factors as student selectivity, curriculum emphasis and the proportion of low income students taking the test.
- Formatting and technical issues have been found that can skew the comparative results that undercut the reliability of the TIMSS benchmark (Molnar, et al.).

Recommendation

One overall construct that could be said is missing from all three is that they are all considered large scale snapshots of achievement, and fall primarily within the scope of monitoring tools. This contrasts with state-level science assessments, which typically measures achievement of individual students and schools for accountability purposes (Fu, Raizen & Shavelson, 2009).

Ultimately, while the value of science literacy to the individual and to society and the contribution of the various components of science literacy are embraced, assessment is an intensive process, and some choices regarding the allocation of resources are part of the decision making process (Champagne, 2009).

Assessment tools for evaluating scientific literacy in the classroom could include laboratory-based inquiry experiments, critical readings of scientific articles in newspapers and other media and mini-projects (NSTA, 2006).

Laboratory activities offer important insights to students regarding the learning of science in general. For over a century, lab activities have been used to promote the enhancement of students' understanding of scientific concepts, scientific practical skills and problem-solving abilities, as well as interest and motivation. Learning by inquiry is an important component of the National Science Education Standards (NRC, 1996). The inquiry lab can serve as an important vehicle for the development of many science skills, including planning and designing an investigation, conducting and recording observations, manipulating equipment, measuring, collecting and analyzing data and designing an experiment for further investigation (NSTA, 2006).

Mini-projects involve groups of students aimed at an in-depth understanding of a given question or issue in a particular science discipline. The goal of the mini-project is the development of greater autonomy and independence by the learner. Students obtain information from multiple sources, such as the library, the internet or interviews. They design a research question and carry out the assignment in small groups, basing their inquiries on relevant issues. The projects incorporate a philosophy of science, technology and society (STS) (NSTA, 2006).

Critical readings of scientific articles in newspapers or other media can be another avenue for making subjects more relevant and up-to-date to assess scientific literacy because critical reading of information from the media is an important part of developing scientific literacy.

For some of the activities, rubrics can be designed for each component of the assignment and then students are fully aware of how they are being assessed.

Another viable method of assessment is that of the pre- and post-test. Throughout the course, students can be asked to develop explanations and then receive feedback on their work. At the end of the course, students critique earlier versions of their explanations. This allows students to appreciate how much they have learned and is an additional benefit to the instructor to perhaps see needed modification for future course instruction (NSTA, 2006).

Summary

In order to be properly prepared to enter a global society, students need to be scientifically literate, both for individual and societal good. Many college students in the United States are not adequately prepared in science to cope with life in the 21st century in the way that allows them to communicate the knowledge they need to make informed decisions on socio-scientific issues and global concerns. The science education and scientific community both agree that a student-centered learning environment that relates content through contextual methods and collaboration with decision making and problem solving opportunities will enhance student motivation to learn. This, in turn, creates an application to the real world which is vital to enhancing scientific literacy. It is therefore important to examine the processes and pedagogy at the collegiate level to understand how scientific literacy is integrated into the courses.

Chapter 3

Methodology

The researcher chose a qualitative approach for this study, which emphasized contextual and rich description, through interviews, observations, and archival data. The researcher utilized observations, interviews, and archival data to gain a better understanding of how faculty within the College of Science, specifically from the Geology, Chemistry, Physics/Astronomy and Biology Departments define, incorporate and evaluate scientific literacy within their courses. Qualitative research is a field of inquiry that crosscuts disciplines and subject matter, and is a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that makes the world visible (Denzin & Lincoln, 2005). By employing the tools of the qualitative method when investigating scientific literacy, the researcher was afforded the opportunity to delve into the world of diverse perspectives regarding this cutting edge of science education.

Research Design

Participants

Faculty members who participated were selected from each of the natural science departments which were Geology, Physics/Astronomy, Chemistry and Biology. One faculty member per department was selected to participate, and their participation was completely voluntary. Due to scheduling limitations, selection of faculty was determined by those who taught classes within a time convenient to the researcher. The results included those participants teaching classes either late spring or summer. The researcher conducted a “Class

Search” through the university website to locate faculty within the aforementioned science departments that met these criteria, which included three professors and one instructor.

All participants in this study were men, ranging in age from 43 to 67. Each professor always taught at the collegiate level and taught for a minimum of 15 years each. All participants indicated that their interest in pursuing a career in science began at an early age, either through exposure to a school experience, such as a field trip to an outdoor venue or parental interaction such as reading science related literature, such as dinosaurs or astronomy.

Professor Cesium, a professor in the Chemistry Department, has taught all levels of curriculum from introductory classes to graduate classes, including topics courses in chemistry. His interest in chemistry originated from an early curiosity of science and detective work, for which he said chemistry was a good match. He thought biology was too descriptive and physics was fascinating but relied too much on a mathematical framework and less on a conceptual one. Therefore, chemistry was a happy medium. He did some volunteer work in K-12 and has an appreciation for those teachers in elementary and secondary classrooms.

Professor Madrone, a biology professor, indicated that his initial interest in science stemmed from a field trip his elementary class took to a farm. He told the story about how it was raining that day and the smells of the farm intrigued him; however, the epiphany was when he saw a “Jack in the Pulpit” plant and it fascinated him so much that he wanted to learn more about it and parlayed this curiosity for plants into a lifelong career studying them.

Professor Stargazer is an instructor in the Physics/Astronomy Department. He said that an individual must know physics before he/she can understand astronomy. As a child, his parents had books about astronomy readily available, which developed his interest, so he decided this was something he would like to do when he became an adult. He earned a Ph.D.

so he could teach at the collegiate level, and is on several science teaching committees to make science more interdisciplinary.

Professor Celtic is a professor in the Geology Department. At a very young age, he stated that he would ask his mother to read to him from the encyclopedia. On one occasion, she read about dinosaurs and he made the pronouncement that he wanted to study dinosaurs for the rest of his life. He was knowledgeable enough about geology prior to entering college that, as a freshman, he would go to the graduate lounge and carry on discussions about geology and paleontology with the graduate students, and it was not until the end of the year that it was discovered he was not a graduate student himself.

Data Sources

Faculty selected for this study participated in an initial interview, and three classroom/or lab observations. Each interview and observation lasted no more than one hour. The researcher conducted four follow-up interviews, one in person and three via email. A digital recorder was used for all interviews with the exception of the initial interview with Professor Madrone. He preferred not to be recorded at that time, so the researcher wrote the data in a journal during the interview. The researcher engaged in member-checking by sharing a draft of the final report with each participant to ensure accurate representation of them and their ideas.

Interview prompts included the following questions:

Background

- How did you become interested in [geology, biology, physics & astronomy, or chemistry]?

- Have you always taught the subject you now teach? If not, why did you decide to change?
- Have you always taught at the collegiate level? If not, when did you begin teaching at the collegiate level?
- What brought you to this particular university and when did this occur?

Individual definition of scientific literacy

- How would you define scientific literacy?
- How would you describe how you develop this in your students?
- How would you describe what scientific literacy looks like in your classes and labs?
- How are the undergraduate courses different from the upper level courses in the way you incorporate scientific literacy?

Following the first interview and subsequent to observations, the researcher asked each professor if they were familiar with the College of Science Mission Statement.

The researcher used classroom and/or lab observations, which included off-site observations, and an observation journal to record data, including participant and guest speaker instructional practices, as well as those observed while on field trips. Classes observed during the summer counted for two observations as an equivalency to a normal academic semester. The Research Design Criteria (refer to Appendix A) indicates specific information regarding data collection. As a result of data collected during the summer semesters, time constraints for both the researcher and the participants may have resulted in possible time lapses between interviews and observations.

This research study also used archival data, such as syllabi, assessments made available, study guides, and any other materials provided by the participants for the researcher's availability. Additional data included specific readings located on course websites, access to specific websites related to the course, such as "Astronomy Picture of the Day" or "Google Mars", and any lab manual pages corresponding to labs observed.

Preparing Data for Analysis

Following completion of data collection, the researcher began the data analysis. First, the observations were taken from the written journal and put into a WordDoc format. Interviews were transcribed by the researcher and also placed into a WordDoc. The data were placed into data units in order for later categorization. Examples of data units are:

1. Professor Celtic concluded the class by telling students about putting the lectures into a continuum and not to use the information in isolation. He stated that this type of test requires "that type of thinking" to assimilate several lectures. He indicated to students that they needed to know how to put it altogether and referred to the mineral continuum.

2. Professor Madrone told the story of a Polish couple who cooked and ate mushrooms and also gave them to their cat to eat. After consuming the mushrooms, the cat began writhing and moving in such a way that indicated it was in pain. After observing their cat in such a state, the couple went to the hospital thinking the mushrooms they had eaten, and given to their cat, must be poisonous. They had their stomachs pumped and were sent back home. Upon arrival to their home, they expected to see their cat dead—instead, they found her with kittens. He told the students to know what it was they were eating.

Data Analysis

The researcher initially took the data units for all data collected, pasted them onto separate file cards, created data piles, and then placed each unit into piles that seemed similar. Following the first round of categorization, the researcher waited a couple of days, returned to the piles, reshuffled them and again placed each unit into piles of similar categories. Some data units were switched to another category in which the “fit” seemed better and others were combined. During this process, emerging themes occurred and those became a new category as well. Labels were created for these piles and stored in a safe location, within a decorated photo box for organization. Once the categories were established and labeled, the researcher began to go through each data pile and read the data included to ensure that each data unit belonged with the grouping specified. The researcher conferred with a colleague during the course of arriving at more stable categories. Several broad categories were established, with inclusions and exclusions for each grouping. An outline was then formulated with each professor as a major heading, and subcategories under that heading which included each of the categories determined from the data collection.

Data Reporting

To report the data collected, this research used collective case study to analyze each participants’ definition, incorporation, and evaluation of scientific literacy into his classes. The study was presented in a descriptive format that allowed for the rich description and context for the data gathered.

Chapter 4

Results

This chapter presents the main themes emerging from the analysis of the data. The themes are storytelling, real world connections, technology, and collaboration. Within the context of these major themes, the ways the professors define, incorporate ideas of, and evaluate learning of scientific literacy are discussed.

Storytelling

Storytelling is a quintessentially social activity. It requires not only readers or listeners, but other storytellers. Stories are both the raw material and the cultural product of memory. Their telling creates a sense of immediacy (even when they are about very old events and actions) and creates a universal feeling of taking part. At the same time, stories impart highly particular information: descriptions of individual actions, emotions, and outcomes that may be idiosyncratic or unique. It is precisely this uniqueness that often makes for a most compelling story. Stories are the mark of the human and to be human is to be endlessly entwined in complex relationships of difference that don't settle comfortably into neat, prefabricated categories (Scott, 2011).

According to Herreid (2007) not only are stories captivating, they make it easier to learn and recall facts, figures and equations. Moreover, stories tell the problems humanity has faced and still face, the values cherished, the barriers surmounted, whether personal or societal. They help tie people with the umbilical cord of DNA to their heritage—to those who have gone before and those who struggle in today's world in ways that otherwise would not be

known. Stories put learning into context, whereas lectures often do not. Stories put the life back into teaching, and people love stories (Herreid, 2007).

Definition

Each professor introduced the idea that stories were a way of helping students assimilate content details into contextual meaning. Telling stories conveyed content knowledge in a way that enhanced student understanding of the material taught. Delivering scientific knowledge through telling stories helped students remember better because the content was transferred in a manner that included necessary information for students to know, but not so detailed-driven that it became burdensome. For example, Professor Madrone embraced a definition of scientific literacy when he stated that storytelling was better than just giving students facts and numbers, and that stories, with some details, created a learning experience and covered necessary content. This definition corresponds to the National Research Council's (1996) definition which states that everyone deserves to share in the excitement and fulfillment that can come from understanding and learning about the natural world. He gave an example of a story he told students when talking about forested ecosystems, which revolved around a particular pine tree that is the oldest living organism up to 1000 feet in elevation. Rather than simply giving isolated facts about the tree, he told the story from personal experience. He incorporated a holistic scenario by telling about hiking up to the area where the tree thrived and how tranquil the surroundings were as if to guide the students along the same path that he took so they could share the experience as well. Within the story, he provided information about the organism and the ecosystem, not merely details.

Another example of scientific literacy through storytelling came from an interview with Professor Celtic when he said, "Stories are important, not just the bits and pieces, but the

meshing together. All the pieces work, they mesh and we get a nice story and it is still the best way to present it to people” [Interview #1, 7/5/11]. Professor Celtic showed a definition of scientific literacy when he related the example of taking a geology course which entailed learning about rocks and minerals and a wide variety of bits and pieces of historical information, which he referred to as the “language of the Earth.” He stated that understanding the language is a prerequisite to storytelling and that “during millions of years of evolution, the narratives of village elders and relatives passed down through the generations” [Interview #1, 7/5/11]. The definition purported by Professor Celtic is similar to what Herreid mentioned when he stated that stories are a way to connect to the past and hold onto the memories of who we were and are. He further posits that by simply telling just the facts, the life has been sucked out of science (Herreid, 2007).

Although the participants showed evidence of the idea of scientific literacy through the theme of storytelling, their own definitions of scientific literacy could be touted as more of an undercurrent. For example, Professor Madrone stated that his definition of scientific literacy is “knowing your field well and what is in your field. It is the literature in general for your field” [Interview #1, 3/18/11]. Although he states literature in general, which does not coincide directly with his statements about storytelling, this perception of literature was supported to mean more than simply scientific articles as evidenced by a class handout he provided students during a class observation that clearly had the literature in story format [Observation #2, 7/13/11]. Also, a field trip to a local botanical institution included a visit to their library that housed a plethora of literature, which provided not only scientific information about botany, but historical stories and incredible literary pieces dating hundreds of years ago with accounts of economic uses of plants through the ages [Observation #3, 7/25/11]. Professor Madrone

sees storytelling as an important way to get science knowledge across to students, the idea that an individual is to know the literature in general for his/her field would indicate that either reading the material, or having it read is a way of promoting his definition of scientific literacy.

Professor Celtic talked about the language and how stories are important, not just the bits and pieces. When asked about his own definition of scientific literacy, he stated that an important question he asked when talking about scientific literacy was, “Do students know the difference between just believing something and knowing that something you believe could be falsified” [Interview #1, 7/5/11]? He continued to say that he thought the attainment of scientific literacy had a lot to do with culture, which he said is an extrinsic motivator. In other words, storytelling in different cultures is how knowledge was passed down from generation to generation and this knowledge within the culture translates to a belief system. Therefore, as a result of the generational storytelling, sometimes these individuals find it difficult to change their own beliefs or even understand why scientists change their beliefs when evidence is provided to falsify it. Succinctly articulated in his book, *The Nature of Science*, Aiken included a John Ferguson quote which states, “Ninety-nine percent of a man’s story is the story of his science” (Aiken, 1991). Although Professor Celtic’s definition does not directly parallel the idea of scientific literacy within storytelling, one could posit that storytelling is a highly cultural activity. And through storytelling one could attain the knowledge and understanding necessary to differentiate between what is simply just a belief and what could be falsified.

Glimpses of a definition of scientific literacy within storytelling could be seen with Professor Cesium when he indicated that “people are wired a little differently and scientific

literacy involved planting a seed; an evolution of sorts” [Interview #1, 6/2/11], a statement that he made indicated he was aware of using narrative in his classes. He mentioned that he tried to convey the importance of scientific literacy, which was a topic that was brought up in an initial lecture then reinforced throughout the semester with various topics. He referred to an example of acid rain or batteries, which begins with the chemistry and underlying science of associated with batteries, but as the semester progresses, he would show how this pertained to renewable and nuclear energy. By attaining this knowledge, he then charged students with a responsibility as a responsible member of society to correct, or convey, accurate information on these scientific issues, which would be the fruition of planting the seed. Professor Cesium’s definition was quite tentative when related to storytelling; however s when he said, “I believe that it is essential to provide a wee bit of historical evolution of a given concept lest the students think that the complexity of the solution to that topic appeared magically at once” [Interview #2, 9/12/11].

Additionally, Professor Stargazer gave a definition of scientific literacy as having a familiarity with some of the big topics in science. If a student is mathematically literate and intellectually curious enough, they would have the tools so when a topic comes up, they can educate themselves about it. He is the only participant to indicate that another type of literacy is necessary as a prerequisite to scientific literacy. He stated, “they [students] have to understand what numbers and statistics mean and how much different a million is from a billion” [Interview #1, 6/2/11]. Otherwise, we would have to go through and say that this and that is important to know, but if a student is mathematically literate and curious enough they are well equipped” [Interview #1, 6/2/11]. His own definition does not speak directly to storytelling; however, the indirect indication would be that it does fit with storytelling. In

order to achieve the familiarity with the big topics, storytelling could be an option, which was evidenced through his teaching.

Incorporation

The inclusion of storytelling as a component to perpetuate the idea of scientific literacy was evidenced by each professor, although the degree by which the participants incorporated storytelling differed. One participant did not indicate storytelling as a component, but during observations by the researcher, this component consistently resonated throughout his teaching. Whether directly or indirectly implied, it was evident that all professors viewed storytelling as an integral part of science teaching that allowed students to grasp a better understanding of scientific knowledge in a conceptual manner.

For example, in an interview statement, Professor Celtic related the following regarding storytelling integration into science:

Narratives are wonderful things and people are used to hearing narratives. For millions of years, in our own evolution, we hear the narratives of village elders or relatives and that is the way that knowledge is passed down. Whether it is absolute, or metaphorical, or allegorical, or whatever, that is the way our brain is set up and the way it does best and that is why fables tend to work well. If someone is Biblically centered, like the way Jesus taught, was always metaphors and allegories. Not direct, but examples. The stories are not pulled out of the air, but supported by real information. That is how you let the average Joe and Joette know is by stories [Interview #1, 7/5/11].

He also incorporated storytelling through the use of the handouts he passed out during class and made available to students online. For example, during one observation, he referred to the handout with accompanying pictures about conglomerates and muds and indicated that the kind of rock and its features can tell a story about the past. Another example from this handout showed a map of a national park within the southwest known for its mountainous terrain, and how paleosoils told the story of soils and sluggish material because it had to do with shale and mudstone [Observation handout #2, 5/12/11].

Professor Madrone demonstrated the incorporation of scientific literacy through storytelling with anecdotal accounts from his own experiences. During an interview, he talked about the importance of storytelling because students remember things better that way. He states, “Some people cannot tell stories. Another thing is that I have so many unique experiences that I have a library of information that I could use. Other people do not” [Interview, 2, 7/26/11]. His responses indicated that he believed storytelling is better than just giving facts and numbers to students to convey scientific knowledge and retention, even to the point of using nursery rhymes, such as the “Red Queen Rhyme.” He related the following example of one that he tells students in relation to species’ survival:

Organisms will have to survive or they go extinct. They have to constantly change or adapt and that relates to the Red Queen Hypothesis, which is from *Alice in Wonderland*, who says that it takes all the running you can do to stay in one place. That is like evolution, it takes all the evolving you can do to be competitive [Interview 2, 7/26/11].

Evidence of Professor Madrone’s incorporation of storytelling could also be found in the class handouts he provided to students. For example, in relating content information about the prairies, he used the handout material which had both pictures and the story to transfer the information to students. The story included the American Bison, Native Americans, and the building of the railroad through the prairies and how these all affected the vegetation, as well as the existence of the bison [Class Handout #2, 7/13/11]. By incorporating this story, he provided not only important content facts, but a contextual framework in which it fit.

Another example came from Professor Stargazer. Not only did he tell stories from a historical account, but he infused an entrepreneurial connotation. He told a story to the class about the randomness of the stock market and related in an interview the reasoning behind this strategy. He said:

I tell this story to the class to show them that as a scientist you always want to ask questions and you always want to know why this happened. You are not just satisfied with the explanation of *how* it happened but you want to know *why* it happened [Interview 1, 6/2/11].

It was evident, either directly through interviews or indirectly through observations, that the participants incorporated scientific literacy through storytelling as a means for conveying information in an understandable, contextual manner to promote student awareness of science. For example, Professor Stargazer stated that he wanted to reinforce to his students how to think like a scientist so he accomplished this through storytelling. He used an experiment that he related to students about randomness and coin flipping as an example. The experiment begins with 128 students flipping a coin and the people who end up with tails leave the room. This continues until eventually there are eight students left who still flip the coin and seven come up with heads. He posed the question to the class, “Would it be fair to say that these people are exceptional coin flippers?” The answer was no and he then pointed out that he relates this to the business world so students saw the connection between his narrative and the real world of commerce. He said that it’s about the way the whole world works, not just astronomy [Interview #1, 6/2/11].

In addition, during a lecture class, Professor Celtic commented: “Geologists want to tell stories of how the past is used to reconstruct how things got to be the way they are today” [Observation #3, 5/12/11]. There was no observable confirmation that the incorporation of storytelling led students to becoming more scientifically literate; however, from examples provided from the participants’ use of storytelling, the evidence suggests that the professors provided a learning environment which encouraged the promotion of scientific literacy.

Evaluation

None of the participants made a direct reference as to the idea of evaluating scientific literacy through storytelling; however, it was evidenced during interviews and archival material. For example, Professor Madrone's own definition of evaluating scientific literacy involved students possessing conceptual knowledge of the subject by showing that they have read the literature and are able to articulate the general understanding of what articles they have read. One example of an evaluation tool was evidenced when he said, "I require a reference list to indicate where they have gotten their material from. The connection between scientific literacy and literature is important" [Interview #1, 3/18/11]. Because one of his teaching methods was using storytelling to convey information in both a factual and contextual manner, the evaluation piece became a similar process for students who would then research scientific material in various forms of literature seeking out the accuracy of information. Hence, his statement of a reference list becomes the tool to check their understanding of viable and reliable literature. This aligns with the NSTA's statement that one of the ways in which scientific literacy can be evaluated is through critical readings of scientific articles in newspapers and other media (NSTA, 2006). Another example came from one of his exams for the course in which he had some questions that related to specific storytelling events from the class. Although the questions were not worded exactly the same as he presented it in class, the information that students needed to provide was in direct alliance with the stories that he told in class. Some of these questions were open-ended and included content such as the formation of coal, oil and gas leading up to a detailed account of specific shale found in Colorado and the importance of this shale [Test #1, Summer 2011].

Another example came from Professor Stargazer when he stated that his evaluation of scientific literacy was “to have a conversation with them [students] on a new topic where they would have to synthesize new information” [Interview #1, 6/2/11]. He also mentioned evaluating scientific literacy through short quizzes or giving students an oral exam. An example of this could be found in his study guide in which tells the story of the recognizable constellations Hercules and Scorpius and then he asks the students to find out specific information about them. He actually refers them to a website on mythology to help them [Study Guide #3, Summer 2011]. This is a good indication that he is using storytelling as a means of evaluation. Professor Celtic mentioned that a research paper is certainly one way that he evaluates scientific literacy. He stated that he tells his students that there may be more than one view on a topic such as the literature they have not cited where people have disagreed with whatever the topic might be and that is important [Interview #1, 7/5/11].

Professor Cesium stated that he had never tried to actually evaluate scientific literacy per se, but the goal would be for a student to perhaps share in a public forum the science knowledge that he/she has gained [Interview #1, 6/2/11].

The actual definitions of the participants project a parallel of scientific literacy evaluation related to storytelling. Through various mechanisms of evaluating their students, storytelling plays a factor because in order for students to relate scientific information to others, whether written or orally, the information had to be shared with them first, which as indicated, was through storytelling.

Real World Connections

According to Trefil and O'Brien Trefil (2009), questions such as how current science issues affect one's daily life and how one considers the roles he/she might play in changing how a science-connected problem is resolved over the coming decades are those that should provide the foundation of young people's scientific literacy and related social responsibility. Those who are scientifically literate are better able to cope with the demands of everyday life in an increasingly technology-dominated society, better positioned to evaluate and respond appropriately to supposed "scientific evidence" used by advertising agencies and politicians and better equipped to make important decisions that affect health, security and economic well-being (Hodson, 2002).

Definition

The participants' definition of scientific literacy became evident during the interview as they talked about real world connections. Professor Stargazer showed his definition when he stated, "Actual scientific literacy is having a familiarity with some of the big topics in science" [Interview #1, 6/2/11]. Both Professor Stargazer and Professor Cesium offered a definition that linked real world connections to commerce and entrepreneurship. For example, Professor Cesium stated, "A lot of job opportunities are with start up companies. Not that I think these students will start up their own company but more than likely statistically, they will begin with a start up company" [Interview #1, 6/2/11]. Professor Stargazer also made reference to the work world when he said, "Some science majors, particularly physics and astronomy majors get hired to be stock market analysts because of their mathematical abilities" [Interview #1, 6/2/11].

Professor Madrone rendered his definition of real world connections in a more nonverbal manner by immersing students into real life situations, such as a field trip to a local botanical institute, nature walks, and bringing in guest speakers from the outside. As an example, he mentioned taking his students on a nature walk around the campus to identify plant and tree species, but the summer class did not participate in this activity because of the extremely hot days; however, during a class observation at a local botanical institution, students were exposed to actual plant specimens [Observation #3, 7/25/11].

Professor Celtic embodied his definition by saying that he thought if someone is scientifically literate they read scientific articles in magazines or newspapers or watched news shows like NBC where they talked about science issues, whether it involved biology, geology, chemistry, or paleontology. One interesting caveat to his definition was his concern that students were exposed to science teachers early on who suffocated their motivation to learn science because of rote memorization of terms which did not encourage students to want to learn science. He expressed the following:

I liken it [science teaching] to a painting—just the sketches and no colors that fleshed out those students less afraid of science, not necessarily a scientist, but stayed abreast of things. For example, if the topic were climate change, it is one thing not to know anything at all, but another to recognize a line of propaganda [Interview #1, 7/5/11].

Two of the four participants, Professor Cesium and Professor Stargazer indicated that their own definition of a scientifically literate person was something that included maturity and an evolutionary process. In other words, the real world connections they spoke of above would enhance their definitions since they both talk about real world connections in relation to employment following college. Because Professor Celtic's own definition included scientific literacy as an extrinsic and cultural assimilation, his account of real world connections would

coincide with his definition as the motivation he referred to in order to learn science is extrinsic and cultural. However, he does go on to say that scientific literacy is an awareness of things [current science issues] and there should be an avenue for people in general to have an application in science, such as local societies in which people from all walks of life can meet and talk about those concerns [Interview #1, 7/5/11]. Professor Madrone, in his definition said that he thought scientific literacy was neither intrinsic nor extrinsic, but had a neutral quality. However, extrinsic tools were evidenced through the use of field trips, outside speakers, and incorporating experiences with real specimens.

Incorporation

A recurring idea within the reform documents is ‘connections to everyday life’. Simply stated, the rationale for incorporating real world connections into science instruction is to move students towards scientific literacy. Scientific literacy requires more than knowledge of science content. Incorporating real world connections give students opportunities to apply scientific content both to their personal lives and to societal issues. Additionally, making these real world connections improves attitudes toward science and science careers (Yager & Alcaay, 2007). It also improves process skills, creative thinking, and the ability to apply information and processes to new situations, and the understanding of the nature and history of science (Yager & Alcaay, 2007).

Incorporation of scientific literacy through real world connections by each participant was evidenced either through direct observation, interviews, and archival data. For example, Professor Madrone incorporated real world connections when he invited a guest speaker from a local botanical institution to talk with his class about the identification of poisonous plants. The speaker talked to the class about the history of poisonous plants then connected the history

of how the poison was used to their everyday lives in ways such as how to identify a poisonous plant in their surroundings. He offered specimens of actual plants that students could view with reference material from the Center for Disease Control for future purposes if necessary [Observation #1, 10/28/10]. According to the American Institute of Biological Sciences, collaborating with other organizations to improve biology education is one way to improve scientific literacy at all levels of both formal and informal education (AIBS, 2011). Another example came from a trip to a local botanical institution in which students could view and touch actual plant specimens. Material from this organization was offered to students which indicated further workshops on exploring local watersheds and connecting with nature [Botanical Organization Flyer, 7/25/11]. Professor Madrone did not specifically state that he perceived collaborating with other organizations as helping develop scientific literacy.

Professor Stargazer connected to the real world during a lecture observed by the researcher. As he talked about nuclear containment, he referred to Chernobyl and Hiroshima. He posited the scenario to the class that all the containment chambers were exposed to the air and there was no more shielding. He led up to the posing question regarding an ethical dilemma associated to this situation. He asked,

Should the public be told about the impending doom and then if it does not happen, a widespread panic has been caused; or, just wait and see if something is going to happen and if nothing does, there is no harm done. But, if it does, people will wonder why no advance warning was given [Observation #1, 7/11/11]?

Another example from Professor Stargazer occurred during an interview in which he posited:

....every time a big idea comes through the refereed journals, it is going to come through *Scientific American*, so the article is going to get written up in layman's terms and I keep track of it that way and if a big idea or something that interests me, I will look into it further [Interview #1, 6/2/11].

He continues, I talk a lot of topics in my class and I can tell what my students are interested in by what they ask questions about and what they talk to me outside of class about. If the topic was a march through the planets, when we got to Earth I would stop and mention global warming and the hands would always shoot up in the air and I would spend maybe half the lecture on it [Interview #1, 6/2/11].

Incorporation of scientific literacy through real life connections through careers was manifested with two of the four participants. For example, Professor Stargazer stated:

Science majors, particularly physics and astronomy majors get hired to be stock market analysts. The reason why is if you are an investment banker looking at 1000 people you can potentially hire for 10 spots and 999 of them have taken business calculus and they hated it and did not understand it, but I had taken 5 semesters of math and understood it very well, then that person stands out and is probably going to get the job because they are a different thinker. Then I would say think of how a scientist looks at the stock market [Interview #1, 6/2/11].

Professor Cesium also referred to a connection between science and entrepreneurship. This philosophy is embedded in one of the courses that he teaches which affords students the opportunity to choose an interdisciplinary topic related to chemistry, research it and then do a presentation. According to the syllabus, several guest speakers from the business world are invited to the class to give students real world advice and information related to entrepreneurship [Course syllabus, 9/6/11].

Professor Cesium also cited the importance of extending the concept of scientific literacy and real world connections in his labs. During an observation in one of the labs, the topic was silicone polymers. While explaining the properties of the polymer, he made connections several times to substances that one might find in the real world that is a silicone polymer, such as the child's toy called Silly Putty [Observation #3, 9/6/11]. To further solidify the concept of the lab, in the lab manual pages for this class, there is one assignment that asks students to research and find representative examples of silicones that are used for various applications [Lab Manual, pp. 176-180, 8/31/11].

Evaluation

Each participant manifested a concept for the evaluation of scientific literacy through the use of real world connections. There was some delineation between the knowledge that science majors should possess as opposed to non-majors. Science majors, according to participants, should be held accountable for more specific knowledge of their field, whether that was geology, chemistry, biology or otherwise. As Professor Madrone affirmed, “I expect the students who were science majors to have grasped the ‘why’ of the science concepts and processes and the non-majors needed to understand only the ‘what’” [Interview #1, 3/18/11]. More specifically, he relates that the scientific literacy with majors who are entering the science field would be expected to have a more intricate knowledge than those who are not, but still need a general working knowledge of science. For example, he states, “non-majors need to know general desert plants and their adaptations, but majors would need to know how they have adapted and evolved to that point” [Interview #2, 7/26/11]. Additionally, Professor Celtic posited that at the graduate level, “scientific literacy evolved into a specific science, which meant reading references and staying abreast of current issues” [Interview #1, 7/5/11].

Each participant showed an idea of the evaluation of scientific literacy by allowing students to choose a topic of interest within their specified content area and subsequently researching that topic and producing a research paper, with references. One professor chose the topics for the students, but the concept of scientific literacy evaluation through real world connections still occurred. The papers had to be on a current issue topic or perhaps one that analyzed how misconceptions ended up in television shows, such as the inaccuracies regarding dinosaur facts on some programs [Interview #1, 7/5/11]. He also provided example exams for students in which questions covered the real life connections that he talked about in class. For

example, there were questions about the Hawaiian Islands and their geologic significance and other questions referencing actual locations and not simply factual, content based questions [Exam Example #3, Summer 2011].

According to the PISA framework for assessing scientific literacy, contexts in which students encounter specific scientific problems and relevant knowledge and skills are applied (e.g. making decisions in personal life or understanding world affairs).

Professor Stargazer also displayed another dimension to evaluation when he stated:

In an ideal world, at the end of the semester he would simply converse with them [students] about a completely new topic and allow a couple of hours in preparation to think about what they were going to say. The topic would not be one that showed up during the semester in class, but they would find out information on and report back to him [Interview #1, 6/2/11].

He also provided students with archives from previous classes regarding topics in preparation for upcoming exams. These various topics would include renewable energy, global warming, and readings about philosophy and the scientific method as it relates to real world situations. For example, how for each dollar spent on the space program, which has given us Velcro, integrated circuits, revolutionary medical technology, fifteen dollars are returned into the economy in terms of revolutionary products [Astronomy Handout, Summer 2011].

Another example came from Professor Cesium when he talked about the idea of scientific literacy evaluation in a future sense:

To me, the ultimate would be if, in 5 or 10 years, a student is at a PTA meeting or a city council meeting and had the opportunity to share that knowledge in a public forum with their fellow citizens then that's it. That is the dream and the goal [Interview #1, 6/2/11].

Technology

Technology has been a powerful force in the development of civilization, which has forged a link with science. Because of greater technological advances, it is especially important for students to understand its connection with science. Like the scientific disciplines, the boundaries between science and technology are often blurred, so a clear distinction is not the point. Rather, students should understand how technology draws on science and contributes to it (AAAS, 1989).

Definition

According to Miller (2002), a 21st century society requires a populace knowledgeable about scientific and technological issues for the democratic process to function properly. The internet is a promising resource for the promotion of scientific literacy. It is a versatile tool that can be used in the classroom and as a life long learning resource. It can be used as a valuable research tool, as it is important to provide easy-to-find, interesting, high quality scientific material in order to promote scientific literacy (Miller, 2002).

The participants did not indicate an idea for the definition of scientific literacy within the scope of technology. Technology held an important role for each professor, predominately for the execution of assignments and online classes, which dovetailed into the incorporation of scientific literacy, but not as a definition.

Incorporation

According to the National Science Education Standards (NRC, 1996), activities involving technology should make appropriate connections to student experiences and promote student-centered, inquiry-based learning. Since the internet has become an increasingly important research tool, it is important to provide easy to find, interesting, high-

quality scientific material in order to best promote scientific literacy. The internet, and other distance learning technology, can provide the capacity to bring together large audiences that would not otherwise easily communicate with each other. It can strengthen the bonds between formal education and outside institutional resources such as museums, and aid in forming the bonds of a community of learning.

All participants showed incorporation of scientific literacy through technology use for student learning. For example, the researcher did one observation in the library for Professor Cesium because he wanted students trained on how to use reliable websites for gathering information for their research project on current science issues relating to chemistry. During the class, the librarian told students they could find more current articles about science on the Web of Science website. He then drew a Venn diagram by using a drawing tool on the computer to indicate that the database can take related records and see what they have in common. He gave students step-by-step instructions so that everyone would be on the same webpage [Observation #1, 8/30/11].

Subsequent to this observation, the researcher observed Professor Cesium guiding students through a tutorial on setting up a Power Point presentation. During the discussion he shows the students a slide, done by military personnel, that has an immense amount of arrows and writing and is very small print and uses this as an example of how not to present information on a slide for their presentation [Observation #3, 9/6/11].

Another example of the incorporation of scientific literacy could be seen with Professor Madrone. He indicated that with his online classes, he required students to do a research report from a list of topics that he specified; however, the students could choose from that list, referencing articles that were of a scholarly nature. The actual assignment was not accessible

to the researcher; however, he gives a similar assignment in his regular classes in which students are assigned a topic, such as malaria and the treatment of it, which is a botanical treatment and then they would get specific references for it. There was no actual assignment for the researcher to examine but it is referenced on the syllabus as an assignment [Course Syllabus, Fall 2010].

Professor Stargazer and Professor Celtic both showed how they incorporated scientific literacy by providing students with websites related to their discipline so students could obtain real-time information, such as Google Mars [Celtic Observation #1, 5/12/11] and references to astronomical sites so not only did students receive content information, but also had visuals of the concepts taught [Stargazer Observation #1, 7/11/11]. By using these resources, it helps to stimulate students' interest in science knowledge, which, in turn, promotes scientific literacy. In the syllabus for Professor Stargazer's class was also a myriad of resource websites for students to use when either studying for an exam, or enhancing their concept knowledge of a topic. For example, in Study Guide #3, one of the tasks is for students to visit a website on the planets and then describe what is thought to be the main source of Jupiter's inner heat, with subsequent questions relating to the same website [Study Guide #3, Summer 2011].

Another example involved Professor Cesium. He taught scientific literacy when he discussed online exercises that textbook publishers were initiating. He commented:

So there is more structure now with these online exercises and what they are doing is not simply indicating the portion of the problem that the student got wrong, but actually telling the students what they were probably thinking by answering the question the way that they did [Interview #1, 6/2/11].

This type of exercise aligns with the ACS definition, according to Shakhshiri (2010) that chemistry classes provide a learning platform for students to develop skills in analytical thought, which is deemed basic to daily life and successful employment. Professor Cesium

also incorporated technology during the training session he provided students regarding how they should present their “Generic Scientific Talk.” He provided them with a handout specifically outlining how to assemble a successful PowerPoint presentation [Class Handout Observation #3, 9/6/11] and also took them to the library [Observation #1, 8/30/11]. The librarian assisting the class walked them through a series of best known science websites to peruse for articles related to their topic, which the professor allowed them to choose. Each student was provided with a list of resources for this assignment [Chemistry Resources Handout, 8/30/11] so they could accomplish their research and then with the training that Professor Cesium provided with the technology, present it in a professional manner.

Evaluation

The idea of evaluating scientific literacy within the theme of technology was indicated by all participants through student research projects. For example, Professor Celtic stated that in an upper level course he allowed students to choose a topic from a list of broad topics and he expected them to use scientific articles and literature, but he did not want websites used, only articles and then the pdf version. He stated that this forces students to use the library and also he requests a Xerox copy of the first page of the articles they referenced [Interview #1, 7/5/11]. Both Professor Cesium and Professor Celtic enlisted the aid of the library to guide students on how to look for good resources online for research reports. Another example involved Professor Madrone who mentioned that he had his online classes do a research project online. Professor Stargazer did not specifically address the inclusion of a research project for his students, but he did comment that to evaluate scientific literacy, in a perfect world, he would have students research a new topic, give them a couple of hours to gather information, then return and he would give them an oral exam [Interview #1, 6/2/11].

Professor Cesium indicated an additional caveat of scientific literacy evaluation when he commented about using technology in his classes, “One of the university goals is for students to learn how to think, and if I have taught you how to think, then I have achieved a huge, major goal” [Interview #1, 6/2/11].

Collaboration

The underlying premise for collaborative learning is founded in constructivist theory. According to Vygotsky’s Zone of Proximal Development, problem solving skills can be placed into three categories: (1) some can be performed independently; (2) others cannot be performed even with help; and (3) between these two extremes are skills that can be performed with the help of others, which are the skills in the ZPD. His belief is that learning is fundamentally a socially mediated activity (Cleborne, Johnson & Willis, 1997). Learning consists of active participation by the student versus passive acceptance of information presented by an expert lecturer or by authoritative text. Learning comes through transactions and dialogue among students and between faculty and students, in a social setting. Students learn to understand and appreciate different perspectives through a dialogue with their peers, as well as dialogue with their teacher (Johnson, Johnson, & Smith, 1991). This type of learning is grounded in the belief that learning is most effective when students are actively involved in sharing ideas and work cooperatively to complete academic tasks. Collaborative learning has been used as both an instructional method and as a learning tool at various levels of education (Zakaria & Iksan, 2007). Collaborative learning can be used for any type of assignment that can be given to students in lecture classes, laboratories, or project-based courses (Mabrouk, 2007).

Advances in technology and changes in the organizational infrastructure of many corporations put an increased emphasis on teamwork within the workforce. Workers need to be able to think creatively, solve problems, and make decisions as a team (Totten, Sills, Digby, & Russ, 1991). The development and enhancement of critical-thinking skills through collaborative learning is one of hallmarks of a scientifically literate person, which is a person that can think critically and scientifically, especially about public policy, including national, religious, ethnic and economic issues (Hobson, 1996).

Definition

According to Holbrook and Rannikmae (2007) scientific literacy emphasizes a socio-scientific decision making component and includes ways of thinking which include the following:

- Ability to think scientifically;
- Ability to use scientific knowledge in problem solving;
- Ability to think critically about science and to deal with scientific enterprise;
and,
- Knowledge needed for intelligent participation in science-based issues.

(Holbrook & Rannikmae, 2007).

Two of the four participants displayed an idea of a definition of scientific literacy relating to knowledge needed for intelligent participation in science based issues. The other two participants alluded to a definition that maintained a more general ability to discuss scientific issues in a collaborative setting with their peers and societal settings. For example, Professor Celtic showed his concept of scientific literacy when he stated that student collaboration is critical to the holistic learning process and without it only sequential learning

occurs [Interview #1, 7/5/11]. Additionally, Professor Stargazer also displayed his idea of a definition when he tells his students repeatedly during an observation that he wants them to see how scientists think through the examples that he gives them during class. For example, he talked about looking at history from 100 years ago when scientists thought that the Sun was like a lump of coal that someone lit, which was falsified, and 100 years from now scientists will be saying that about present day scientific findings [Observation #3, 7/14/11]. In other words, scientists work together and as Professor Stargazer posited, "...in science we need to prove theories wrong, so that is why I am talking about the wrong theories first" [Observation #3, 7/14/11]. He also made a reference to thinking like a scientist when talking about the stock market, and how scientists would look to see if the stock market could be random. He mentioned an experiment performed with local businessmen and the way in which scientists would think about the stock market, involving collaboration from several professional groups.

Professor Madrone communicated his idea of a definition when he made this statement, "Students need to know something about the subject in order to carry on an intelligible conversation with their classmates" [Interview #1, 3/18/11]. Professor Cesium's presented an example relating to the idea of socio-scientific decision making when he made this reference: "...to share that knowledge in a public forum with their fellow citizens..." [Interview #1, 6/2/11].

Incorporation

According to Hodson (2002), student capabilities through collaboration include the following:

- Gain context-needed science knowledge/concepts important for interacting with socio-socio-scientific issues within society;

- Develop interactive society skills associated with collaborative team work, tolerance of others and a willingness to work;
- Acquire communicative skills related to oral, written and symbolic/graphical formats so as to develop the capacity to express scientific ideas in meaningful social contexts; and,
- Undertake scientific problem solving to (better) understand the science background related to socio-scientific issues in society (Hodson, 2002).

The display of the conception of scientific literacy through collaboration resonated with all of the participants, either manifesting as student/professor and/or student/student interaction. For example, Professor Cesium posited when talking about interaction with students:

I believe when students ask ‘why’ I do certain things that I want to give them a perspective they cannot get from lecture notes. My job is to interface between lecture notes and the distillation of how I guide the students’ thinking and add extra insights; an extra example, a different point of view [Interview #1, 6/2/11].

During an interview, Professor Celtic talked about collaboration with students when he notices that a student has done poorly on an exam he will ask to see their notes in an attempt to see where the problem might be in their learning. He also stated that he collaborates with students on their research reports by editing the first copy of their document [Interview #1, 7/5/11]. By assisting students in this manner, he is helping them with what Hodson postulates that student collaboration is a process to acquire communicative skills related to oral, written and symbolic/graphical formats so as to develop the capacity to express scientific ideas in meaningful social contexts. Through this collaboration, students will then learn how to undertake problem solving related to socio-scientific issues in society (Hodson, 2002). Within

this type of collaboration, it is noted that students are also becoming more aware of their own way of thinking.

The researcher found evidence of scientific literacy being promoted through interactions between students and the professor. An example of this occurred during an observation of Professor Madrone as he talked with students about prairie grasses. Following along on the class handout for the slide presentation he was using in class, the topic of tall grass prairie arose. The handout [Observation #2 Handout, 7/13/11] showed a picture of a farmer in the early 19th century using a rudimentary plow and another picture of a modern day plow. Professor Madrone stopped and with the help of some of the agriculture students in the class, he wanted other students to have a better understanding of how this piece of equipment affected the prairie, so he inquired the following of the agriculture students:

It could not be farmed. But a steel plow could conquer it [big blue stem grass]. Have any of you ranch management students already talked about this in your class? Who invented the first plow?" This encouraged a response from a student who said it was John Deere [Observation #2, 7/13/11].

Professor Celtic showed his interpretation of incorporation of scientific literacy through collaboration in the following example:

I say that is one of the best ways of studying. Actually, a real danger is what I call sequential learning. You take your notes and study in isolation, and begin to say, "I know that, I know that." Well, that takes things out of context, out of order, and all of a sudden things start to break down. So, one of the best things I tell them is to get 2 or 3 friends, or 3 or 4 friends, and let one get the book out and the rest close the books and ask questions that are spread out for the week. Then you start to think of things in a less sequential manner. That is critical, When I see a student who has done poorly and uses the sequential learning, that is probably what did them in [Interview #1, 7/5/11].

Professor Madrone talked about the incorporation of scientific literacy through collaboration when he indicated that he allowed students to collaborate when creating an online research report [Interview #2, 7/26/11].

Evaluation

The idea of evaluating scientific literacy through collaboration was manifested by each participant in varying ways. Two participants suggested that scientific literacy is not immediately visible during the semester, but might present itself during the course of the student's life outside of their classes. For example, Professor Cesium stated:

“...in my mind I am trying to plant a seed in one mind and that seed grows and propagates, right? Oh, I guess if you saw a student taking another role on campus or some volunteer organization that helps to promote learning that is a clear manifestation” [Interview #1, 6/2/11].

Professor Celtic additionally showed his idea of scientific literacy when he talked about members of a geological society that held members in varying occupations from perhaps accountants to carpenters. These individuals are citizens who have enough scientific knowledge to produce published papers, yet may not have the technical knowledge as a scientist would have. He commented that “so this society has had about half professional and half non-professional members since it first started” [Interview #1, 7/5/11]. Within the syllabus for his course is a “Suggested Study Hints” in which states that it always helps to study with friends because one may think you know the material but the best way to find out is to have a friend quiz you without an open textbook or notes [Course Syllabus, May 2011]. Although this is not a direct tool of evaluation it does suggest that collaboration is helpful and agrees with Hodson's view on collaboration and scientific literacy in which students gain context-needed science knowledge/concepts important for interacting with socio-socio-scientific issues within society (Hodson, 2002).

Professor Madrone's idea of evaluating scientific literacy through collaboration was evident when he said, “they [students] are able to discuss environmental issues” [Interview #1, 3/18/11].

Summary

Overall, the data indicate evidence of participants possessing ideas of the definition, incorporation and evaluation of scientific literacy within the main themes of storytelling, real world connections, technology, and collaboration. But, the data indicate variability in how the participants do actually or metaphorically define, incorporate and evaluate scientific literacy within the themes. It could be inferred that, despite the mission statement's inclusion of "promoting and encouraging scientific literacy", the participants embed this philosophy within their teaching and learning separate from the statement. It was decided in the initial research that the researcher would not inquire as to the participants' knowledge of the mission statement until data were collected in order to obtain data that would be an indication of how the participants viewed scientific literacy. The main focus of this study was to see how the participants did define, incorporate and evaluate scientific literacy. Following data collection, the researcher then inquired of each participant as to their awareness of the mission statement. One participant did not respond to the question. One participant said that he knew the university had a mission statement but was not aware that the college of science had one. Two participants stated they had some familiarity with it having read it on occasion. None of the participants expressed any emotion when the mission statement was brought up such as surprise or concern. Nor did they indicate that in any way would they change the way in which they taught their classes. As a result of the responses by the participants, any further questions regarding the mission statement were not discussed.

Chapter 5

Discussion

Although several definitions of scientific literacy exist, the definition put forth by the National Research Council, comprised of a wide range of individuals representing many constituents, succinctly states scientific literacy as an inclusion of the following components:

1. everyone needs to use scientific information to make choices that arise every day;
2. everyone needs to be able to engage intelligently in public discourse and debate about important issues that involve science and technology;
3. everyone deserves to share in the excitement and fulfillment that can come from understanding and learning about the natural world;
4. more and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems; and,
5. to keep pace in global markets, the United States needs to have equally capable citizenry (National Research Council, 1996).

These components have been used as a benchmark for the definition of scientific literacy when looking at the participants' own definition, incorporation and evaluation of scientific literacy as it applies to the themes of storytelling, real world connections, technology, and collaboration.

Definition of Scientific Literacy

The results of this study suggest all participants showed components of the NRC definition of scientific literacy as revealed through the themes of storytelling, real world connections and collaboration. There was no indication of a definition of scientific literacy through the theme of technology.

The results suggest that three out of the five components of the NRC definition of scientific literacy were evident through storytelling. Although the delivery of stories differed between participants, storytelling was used to convey content information to students in a manner that enhanced assimilation of the content material. Professors indicated that storytelling took the details that students needed to know and meshed them together in a format that presented a unification of the content material. This supports Bickmore and Grandy (2007) who found that some researchers feel that science is the modern art of creating stories that explain observations of the natural world.

Using the NRC definition, the participants in this study aligned with the definition of scientific literacy through the need to use scientific information to make choices that arise everyday. Their stories included characters who applied scientific information, such as various plants that could be harmful, and determined the difference between edible and non-edible vegetation. Their understanding of scientific literacy also includes sharing in the excitement and fulfillment that can come from understanding and learning about the natural world. This was shown through personal experiences by the participant relating the stories in a way that allowed students to become a part of the natural world in which the story was being told as if they were actually a part of the scenario. Another definition component that was evident was that of the requirement of thinking creatively, reasoning, making decisions, and solving

problems because more and more jobs demand advanced skills. Two of the participants referenced entrepreneurship and commerce when they told stories about science concepts and how scientific literacy related to the business world. There was no direct evidence of a connection to the definition relating to the need to be able to engage intelligently in public discourse and debate about important issues that involve science and technology as it related to storytelling. However, the definitions that were found through storytelling would indirectly align with the component of the NRC definition of keeping pace in global markets and the need for the United States to have equally capable citizenry. Stories tell the problems humanity has faced and still face, the values cherished, the barriers surmounted, whether personal or societal (Herreid, 2007). Subsequently, the practice and incorporation of storytelling can assist with the learning of scientific information and the ability to understand socio-scientific issues which promote capable citizenry and keeping place in global markets.

Results suggest that within the theme of real world connections, participants defined scientific literacy in two of the five components set forth in the NRC definition. For example, two of the four participants referred to connections to the world of commerce and entrepreneurship, which aligns with the component of demanding advanced job skills requiring making decisions, thinking creatively and solving problems. One participant indicated that he thought scientific literacy was an extrinsic and cultural assimilation, which corresponds to the NRC definition which states that the intrinsic components of excitement and fulfillment come from learning about the natural world, which can take place extrinsically. He further suggested that early science teaching had an affect of a student's attitude toward science in college. However, another participant defined scientific literacy within real world connections as neither intrinsic nor extrinsic, but had a neutral quality. Although he indicated

this definition, he did show through his teaching, guest speakers and field trips the implementation of real world connections as a means to help students grasp scientific knowledge, which would also align with the NRC definition indicated above.

Research results suggest that the participants did not indicate an idea for the definition of scientific literacy within the scope of technology. Technology held an important role for each professor, predominately for the execution of assignments and online classes, which dovetailed into the incorporation of scientific literacy, but not as a definition.

Results of the study indicated that participants displayed an idea of a definition of scientific literacy relating to collaboration and participation when discussing scientific issues and knowledge within a collaborative or social setting with their peers which related to three of the five NRC definition components. One participant specifically stated that student collaboration was crucial to a conceptual view of the content material and without it he feared only sequential learning took place. Another professor referred to the socio-scientific decision making that took place when collaboration occurred. Two of the four participants suggested that they encouraged students to study together to gain different perspectives on topics and increase conceptual understanding that studying alone does not enhance. This would align with the NRC definition that everyone needs to be able to engage intelligently in public discourse and debate about important issues that involve science and technology. Also, the NRC component that everyone needs to use scientific information to make choices that arise everyday is included. Subsequently, this would also align with the component relating to keeping pace in global markets and having capable citizenry because the first two mentioned definitions would be inclusive with capable citizenry.

Incorporation of Scientific Literacy

Results suggest that the incorporation of scientific literacy was evidenced through storytelling, real world connections, technology and collaboration. However, the strategies implemented to facilitate the incorporation within these themes were diverse among the participants.

Storytelling as a component to perpetuate the definition of scientific literacy was included by each participant; however, the incorporation of storytelling differed. Through the incorporation of either using themselves as a character in the story, or telling stories from a third person point of view, the participants clearly showed the idea of sharing in the excitement and fulfillment that can come from understanding and learning about the natural world. For example, one participant utilized anecdotal experiences to craft his stories and another participant framed his stories with historical narratives that perpetuated a continuum between past and present events. Two of the participants mentioned the use of rhymes, allegories and metaphors when relaying content information through storytelling, and showing how the characters came to decisions that would happen in connection to the science material. According to the NRC, this fits with the component that everyone needs to use scientific information to make choices that arise everyday. Another professor not only mentioned telling stories from a historical account but also used narratives that related scenarios from the world of commerce that would students apply connections to problem solving, which aligns with NRC component directly relating to problem solving and thinking creatively. Within this theme, there was not a direct correlation to engaging in public discourse and debate about important issues that involve science and technology or capable citizenry.

Although participants collectively used storytelling, there was no observable confirmation that the incorporation of storytelling led students to becoming more scientifically literate. The data do suggest that by the incorporation of storytelling the participants provided a learning environment necessary to encourage the growth of scientific literacy within their students.

Four of the five components of the NRC definition of scientific literacy through real world connections were evident in the participants' explanations of their class or in the observation of their class. All participants incorporated scientific literacy within the theme of real world connections yet each had a unique way of presenting it to students. Not all participants used the same strategies for incorporating real world connections. One participant promoted diverse usage of real world connections through guest speakers, field trips and nature walks. Three of the four participants incorporated real world connections in their teaching either using potential scenarios that required students to think about ethical decision making, incorporation of current science issues with content material, and connections to commerce and entrepreneurship. Another participant exposed students to real world scenarios that included ethical decisions that might have to be made if they were in charge of a nuclear power plant. This incorporation would relate to the NRC definition regarding advanced skills in the job market requiring people to be able to learn, reason, think creatively and problem solve. The NRC definition relating to sharing in the excitement and fulfillment that can come from understanding and learning about the natural world was visible with all participants either through field trips to locations with natural specimens, labs with actual geological rocks and minerals, or working with chemicals or technology. For example, one participant took his students to a nearby botanical institute which allowed students to come in direct contact with

real plant specimens and learn of their uses to society. Another participant used real geologic specimens in his labs that correlated to pictures used in his lectures so students could observe and touch actual rock and mineral specimens and relate them to geographical areas within Texas and abroad that have these types of rocks. The NRC component involving capable citizenry was not directly aligned within this theme.

All participants showed incorporation of scientific literacy through technology use for student learning and instruction. All participants utilized a program such as PowerPoint or Keynote as a tool to present content material when instructing students. They exposed students to technology as a means for researching and developing research reports, one of which specifically instructed students on how to create a Power Point for their research presentations to the class. They used outside websites as instructional tools to enhance student knowledge gained during class. The NRC definition that could be seen within the technology theme was that of using scientific information to make choices that are dealt with on a daily basis because the information the students were extracting was scientific information to relate to reports dealing with current issues in science. Results indicate that through the theme of collaboration, two of the components of the NRC definition of scientific literacy were found. Results showed all participants interacting with students during the course of teaching a science topic. Three of the four participants indicated interacting with students outside of class for the purposes of assisting students who did not understand the science material study strategies, and questions that students may have with assignments. These align with the NRC definition that everyone deserves to share in the excitement and fulfillment that can come from understanding and learning about the natural world. One participant, who indicated he taught online classes, allowed students to collaborate while doing research papers for an online

assignment. In doing this assignment he enacted strategies which correspond to the NRC definition of needing to be able to engage intelligently in public discourse and debate that involve science and technology. Due to the fact that this is an online class, the format for the public discourse would be via the threaded discussions and electronic format. One participant clearly indicated his encouragement of student collaboration when studying for a test so that students would ask each other questions and see the holistic view of the content and not view it in a linear manner. He also mentioned that by doing this, students see different perspectives and perhaps where their own thinking needs to be changed, which would also align with the NRC definition about using scientific information to make choices and engaging in public discourse.

Evaluation of Scientific Literacy

Results of the study suggest that evaluation of scientific literacy was evidenced through real world connections, technology, and collaboration. There was no immediate evaluation of storytelling with any of the participants, but rather one that could present itself in the future.

The evaluation of scientific literacy through storytelling was not shown, but rather a connection of scientific literacy evaluation to storytelling emerged as an inference. Three participants recognized research of scientific literature with the reporting of this information in the form of an oral exam or conversation with the professor or turning in a literature review. One participant indicated he had not tried to actually evaluate scientific literacy, but would see the evaluation as the ability of students to share the science knowledge that he/she has gained in a public forum. The NRC definition component - being able to engage intelligently in

public discourse and debate about important issues involving science – is being assessed/evaluated in the public way these students report findings.

Three of the five components of the NRC definition of scientific literacy were evident through the use of real world connections. For example, two of the participants stated that science majors should be held accountable for more specific knowledge of their field, whether that was geology, chemistry, biology or otherwise, which is an indication of understanding and learning about the natural world and keeping pace in the global market. All participants suggested an idea of the evaluation of scientific literacy through real world connections through student research of current science topics or the analysis of misconceptions or inaccuracies in the media regarding scientific topics, such as dinosaurs. When comparing the participant views on evaluation, one reflected an evaluation that was futuristic in nature. He suggested that his view of scientific literacy evaluation was to see if a student could share his/her knowledge in a public format with their fellow citizens. Therefore, these explanations relate to the NRC definitions regarding the use of scientific information to make choices that arise everyday, engage in public discourse and debate about science issues and to keep pace in global markets, the United States needs to have equally capable citizenry.

Results suggest that although all participants evaluated scientific literacy within the theme of technology, mainly through the use of student research projects, only one definition became evident. Two of the four indicated the incorporation of library personnel to show students technology available for their reports, one participant used research reports in his online classes, and one professor referred to an oral report instead of a written version. Only one participant mentioned the use of technology as means for evaluation by teaching students how to think, which he referenced as a university goal. This corresponds to the NRC

definition regarding that people need to be able to learn, reason, think creatively, make decisions and solve problems.

Results of this study suggest that two of the five NRC components were manifested by the use of collaboration as a means to evaluate scientific literacy. For example, two of the participants showed their idea when they stated that the evaluation of scientific literacy would not be something immediately visible during the semester, but present itself later in a student's life, such as being part of a scientific society or taking part in campus or volunteer organizations. This relates to the NRC component which states that everyone needs to engage intelligently in public discourses and debate about important science issues, as well as the component regarding the United States needing to have capable citizenry. Another good example of the citizenry definition is from one professor who metaphorically referred to this as "planting a seed." One participant specifically said the evaluation of scientific literacy within the theme of collaboration was a student's ability to discuss scientific issues with fellow students, which is also in relation to the NRC definition of engaging in intelligent discourse.

Conclusion

The results of the research study reflect evidence of participants possessing ideas of the definition, incorporation and evaluation of scientific literacy through storytelling, real world connections, technology, and collaboration. Results suggest that diversity in the perception of scientific literacy within these themes did occur, either actually or conceptually. According to the NRC, individuals will display their scientific literacy in different ways, such as using appropriately used technical terms, or applying scientific concepts and processes (NRC, 1996).

Results of the study in connection with a definition, incorporation, and evaluation of scientific literacy through storytelling revealed that all five of the NRC components were evidenced, although not all five appeared in each of the categories for scientific literacy. Results for real world connections indicated that all five of the components were also indicated although all five did not occur within each of the three categories of scientific literacy. For technology, only one NRC component was shown and it was within the incorporation of scientific literacy category. The theme of collaboration evidenced four of the five NRC components yet not all four were found within each of the three categories.

Limitations

One limitation of this study was the sample size. Because this study focused on the mission statement from one university, the sample size included only those professors within the university's college of science. Participants were chosen primarily on the basis of teaching summer classes due to scheduling constraints of the researcher, so only one professor for each natural science department was chosen. Also, since this research was an analysis of natural science disciplines within the College of Science, any department other than those mentioned within the research was excluded.

Future Research

This study utilized qualitative data in order to obtain rich description and insight into the participants' perception of scientific literacy. Analysis should include more than one post-secondary institution to broaden the scope of the study of how scientific literacy is incorporated into college science programs. Additionally, further study could be done to

include the students' perspectives on how they understand scientific literacy after taking science courses within the science department, particularly involving a theme that emerged within the main theme involving student thinking processes and how that affects their assimilation of scientific literacy.

APPENDIX A
Research Design Criteria

Participant	Event	Date	Place
Professor Madrone	Interview	3/18/11	public café
	Follow up	7/26/11	participant's office
	Observation	10/28/10	classroom
	Observation	7/13/11	classroom
	Observation	7/25/11	field trip
Professor Celtic	Interview	7/05/11	participant's office
	Follow up	9/15/11	per email
	Observation	5/11/11	classroom
	Observation	5/12/11	classroom
	Observation	5/12/11	classroom/lab
Professor Stargazer	Interview	6/02/11	participant's office
	Follow up	9/17/11	per email
	Observation	7/11/11	classroom
	Observation	7/14/11	classroom
	Observation	7/15/11	lab
Professor Cesium	Interview	6/02/11	participant's office
	Follow up	9/12/11	per email
	Observation	8/30/11	library
	Observation	8/31/11	lab
	Observation	9/06/11	classroom

The following archival data were collected from each participant:

1. Course syllabus
2. Handouts used during course of class
3. Information retrieved from participant university website
4. Sample exam/study guide questions
5. Lab worksheets/material from fieldtrips

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ABSTRACT

A LOOK AT THE DEFINITION, PEDAGOGY, AND EVALUATION OF SCIENTIFIC LITERACY WITHIN THE NATURAL SCIENCE DEPARTMENTS AT A SOUTHWESTERN UNIVERSITY

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This study focuses on the promotion of scientific literacy within the natural science departments and how faculty within these departments define, incorporate, and evaluate scientific literacy in their courses. The researcher examined data from participant interviews, observations, and archival material from courses taught by the participants. The results of the research study suggest that participants express their idea of scientific literacy through storytelling, real world connections, technology, and collaboration. Results suggest that diversity in the perception of scientific literacy within these themes did occur, either actually or conceptually. The research used the definition and components set forth by the National Research Council as a benchmark when looking at the participants' own definition, incorporation and evaluation of scientific literacy.