Science Literacy and The Nature of Science

(and some bonus material)

The for WSTA, March 13, 2010

Taken from my in-progress dissertation titled

*Under One Big Sky: Elementary pre-service teachers use inquiry to learn about the moon, construct knowledge, and teach elementary students around the world via the Internet.*

Inquiry learning and teaching can be precursors to constructing knowledge about the natural world. The general public holds many misconceptions of nature; if schools are expected to produce scientifically literate citizens, teachers must be scientifically literate. Various methods of teaching science are currently practiced by elementary teachers. Each method holds merit, yet most children attend schools employing various combinations of these methods. These children graduate and continue through adulthood without knowing how to critically evaluate policy about technology, the environment, legislative issues regarding research, or even their own health.

Missing from this picture is a cadre of scientifically literate teachers. Children are more likely to achieve higher levels of scientific literacy when taught by teachers who themselves are scientifically literate and possess the pedagogical skills to share this understanding with their students (Bianchini & Colburn, 2000; Brunkhorst, 1992; Goodrum, Hackling, & Rennie, 2001; Yager, 1966).

Teachers’ deep understanding of scientific concepts, teaching with technology, and pedagogical content knowledge (PCK) constitute a fair proportion of the literature. There is little research published to date that examines the impact of these three pieces taken together on elementary science teacher literacy and PCK.

Literature indicates that students as well as their instructors have a hard time understanding the causes of the phases of the moon (Abell, 2001; R. K. Atwood & Atwood, 1997; V. A. Atwood & Atwood, 1995; Trundle, Atwood, & Christopher, 2002). National Science Education Standards (NSES) standards include “science as inquiry” as one of 8 categories in their content standards. (National Research Council, 1996)

Additionally, the National (NSES) for Grades K-4 in Earth and Space Science state that “students should develop an understanding of objects in the sky, and changes in earth and sky.” (page 130) According to Earth and Space Science standards for students in grades 5-8, “all students should develop an understanding of Earth in the solar system.” (page 158). This study explores the answers to these questions: Do pre-service teachers themselves possess this understanding? Do they have the pedagogical skills to help their future students construct an up-to-standards understanding?

Common sense suggests that a quality teacher with a solid understanding of content, pedagogical content knowledge (PCK), and teaching of inquiry would be would be more likely to help students reach standards. NSES teacher standards state “teachers of science plan an inquiry based science program for their students.” (page 30)

Clearly, a competent, quality teacher must have the content knowledge, the pedagogical content knowledge (PCK), the understanding of and ability to facilitate inquiry learning in students (J. E. Shymansky, Kyle, & Alport, 1983; vonSecker, 2000), and a working knowledge of the necessary technology for these standards to be realized in the classroom. Measuring teacher quality is not such a simple common-sense decision.

The National Board for Professional Teaching Standards (NBPTS) has developed a measure of teacher quality, and this measure has been shown to identify teachers who have a positive impact on students as measured by standardized test scores (Goldhaber & Anthony, 2004). National Board Certification is a voluntary, rigorous process involving independent, anonymous assessment of the teacher’s classroom videos, evaluation of the teacher’s analysis of student work and the ability to show student growth as a result of the teaching, contextual analysis of lessons by the teacher, and reflection by the teacher, all providing evidence that the teacher can apply the NSES in the classroom in a manner that is most appropriate for a particular group of students at that time and in that setting. There is also an assessment center examination measuring content knowledge, PCK, and the analysis and remediation of student misconceptions.

It follows from both NBPTS and NSES that exemplary teachers should be content-knowledgeable, possess PCK, be proficient at teaching by inquiry, and be proficient with computer and message board technology. Exemplary teachers should specifically possess:

1. A high degree of scientific literacy including the Nature of Science and content, (Yager, 1966), in this case, the moon.
2. Pedagogical skill at facilitating scientific inquiry among students (Bianchini & Colburn, 2000; Brunkhorst, 1992; Goodrum et al., 2001; National Research Council, 2000).
3. Appropriate proficiency with electronic communication methods needed to lead discussions with students (Boone & Anderson, 1995).
4. The ability to recognize and remediate misconceptions among both students and themselves (Tamir, 1983).

Much research has been done with each of these individual ideas (Brunkhorst, 1992), yet no literature to date examines possible relationships among content knowledge, learning to teach using inquiry and the Internet, pre-service teacher learning, and pre-service teachers’ perceptions of their learning.

The theoretical framework on which this study is based is rooted in 3 suggestions from the literature. First, independent studies suggest that to most effectively develop excellent teaching skills, pre-service teachers should be taught as they are expected to teach (Lim, 2001; Parker & Heywood, 2000; Sprinthall, 1995). Second, elementary teachers lack content and science process skills especially in inquiry learning to adequately develop these skills in their students. Then, knowledge newly-constructed by pre-service teachers learning to teach using inquiry over the Internet can replace existing and possibly incorrect knowledge, or misconceptions, but this process is both difficult and unlikely.

Astronomical Knowledge

It is common knowledge that the moon and the sun are astronomical bodies and that the sun is visible as it lights the day, while the moon is visible at night after the sun has set. While most people acknowledge that the moon changes shape or that it rises and sets at different times during different seasons, very few can describe the patterns observed. Still fewer can explain these patterns (Bailey & Slater, 2003-2004; Barnett, 2002; Callison & Wright, 1993; Schneps, 1988; Trundle et al., 2002) although the National Research Council has stated that knowledge of the sun, the moon, and their patterns in the sky is important and basic for students as young as the elementary grades (National Research Council, 1996).

Although there is clearly a need among the general population for the understanding of natural phenomena, it is not unusual for people to lack such understanding (Yager, 1991). In 1996, the National Science Board found that although 40% of all Americans expressed an interest in science and engineering, most of these Americans had no real idea how science operates. Two percent of the adults surveyed knew that scientists develop and test theories. An additional 21% did not understand the relationship of scientific methodology to the development of theories but were able to describe the importance of a control group in experiments. Thirteen percent did not understand the need for a control group but did describe science as based on careful and rigorous measurements. A full 64% of the American public surveyed had no clear understanding of science as the development of theory, the importance of a control group in experimentation, or the role of precise measurement and careful comparisons as a basis for scientific findings (National Science Board, 1996). A fundamental understanding of the basic premises of science is needed by anyone who needs to make decisions about the environment, funding space travel and other research, the use of technology, and even personal health. According to studies about American’s knowledge of the nature of science, most citizens will be unable to use science in making such decisions.

Astronomy in particular, is basic to public scientific literacy. There are many common, easily debunked myths based on a lack of understanding of astronomical concepts. One myth popularized by mainstream media in the spring is that an egg can be made to stand on end only at high noon on the vernal equinox (try this; with practice it can be made to work as well on most any day at most any time, depending on technique.) Another myth is that the Coriolis effect causes flushed toilets to spin in opposite directions in the North and South Hemispheres. Some physicists have found this to happen in sinks left standing and allowed to drain a few drops at a time over 3 weeks, but concur that in toilets, water is forced in at one direction or another regardless of hemisphere (Plait, 2002). People believe that the sky is blue because it reflects the color of the oceans.

Even recent graduates from an academically prestigious university could not correctly explain the cause of seasons, when asked. The classic video, *A Private Universe* (Schneps, 1988), made at a Harvard University graduation shows young graduates and faculty being asked the question, “Why is it warm in the summer and cold in the winter?” Twenty-one out of 23 people interviewed incorrectly stated that summer is warmer because the earth is closer to the sun. The correct answer is, of course, that the tilt of the earth (which remains constant as the earth orbits the sun) puts each hemisphere at an angle to receive maximum sunlight during the season we know as summer. The increased radiation from the sun results in a temperature increase. The distance from the earth to the sun varies very little; Earth is actually a little closer to the sun in January than it is in June (Schneps, 1988).

Astronomical concepts, then, account for a large portion of science misconceptions. Within the field of astronomy, misunderstandings about moon phases take many forms. One commonly held misconception of moon phases is the belief that the shape changes of the moon, known as phases, are caused by the shadow of the Earth falling on the moon. When the moon is almost completely in the Earth’s shadow, it is a thin crescent we call a new moon. When the moon appears full, it is reasoned that the moon must be completely out of the Earth’s shadow. Alternative and equally incorrect conceptions are that different fractions of the moon are lit by the sun at different times or that planets cast a shadow on the moon.

The natural place to begin the exploration of misinformation leading to conceptual misunderstandings of natural phenomena by the general public is to examine an initial source of early learning about astronomy. This source of early learning about astronomy is most likely those who teach astronomical concepts to children in elementary school. Pre-service teachers as well as practicing elementary teachers have been found to harbor their own misconceptions about the greenhouse effect (Groves & Pugh, 1999), concepts in physics such as the process of heat transfer (Aiello-Nicosia & Sperandeo-Mineo, 2000) and motion (Halim & Mohd. Meerah, 2002), vision (Gregg, Winer, J.E.Cottrell, K.E.Hedman, & J.S.Fourneir, 2001), chemistry concepts such as solutions (Halim & Mohd. Meerah, 2002), and the nature of science in general (Abell, 2001; Howes, 2002). They also harbor misconceptions about the moon and moon phases (R. K. Atwood & Atwood, 1997; V. A. Atwood & Atwood, 1995; Trundle et al., 2002). Not surprisingly, these elementary teachers and pre-service elementary teachers are among the adults who also are lacking in their understanding of the business and nature of science.

Scientific Literacy

Since Sputnik’s launch in 1957, various committees and task forces (Carnegie Forum on Education and the Economy Task Force on Teaching as a Profession, 1996; No Child Left Behind Act of 2001," 2001; The National Commission on Excellence in Education, 1983), have studied scientific literacy in the United States. One result has been a concerted effort to determine the most effective teaching strategies for promoting scientific literacy among students. Scientific literacy, a term introduced in 1958 (Hurd, 1958; McCurdy, 1958), has no universally accepted definition (DeBoer, 2000), yet fostering it is a task conventionally left to teachers during times when preparation of students for the future requires more and different knowledge and skills than teachers currently receive from their schools of education (Darling-Hammond, 1997). Generally speaking, having scientific literacy describes

that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it (National Research Council, 1996, p. 23).

Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (Schneps, 1988) and to form scientific habits of mind. Scientific habits of mind are the thought processes needed to understand the Nature of Science (NOS) as interconnected and validated ideas about the physical, biological, psychological, and social worlds that are particular ways of observing, thinking, experimenting, and validating ideas (American Association for the Advancement of Science, 1990). NOS has been referred to as the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of science knowledge (Lederman & Zeidler, 1987; McComas, 1998). Other common descriptions include science as a body of knowledge, a method, and a way of knowing (Lederman, 1992). It is generally agreed that there is more agreement than disagreement in various descriptions, particularly at the practical application level for the elementary science teacher.

Knowing and understanding science concepts and content, that is, possessing content knowledge is important if one wishes to share this knowledge. Content knowledge, or subject matter knowledge, is the information about a concept and the manner in which the information is structured in the teacher’s own way of understanding. A teacher must also know the specific curriculum to be taught and must understand how to best implement the prescribed activities with the materials available. Additionally, an effective teacher must also possess “pedagogical content knowledge,” or according to Shulman (1986), the ability to go beyond “knowledge of subject mater per se to the dimension of subject matter knowledge *for teaching*.” Going beyond the knowledge of subject matter and curriculum would include knowing the places where students trip, diagnosing student difficulties and misconceptions, and remediating appropriately when necessary. This interplay between rich understanding of content and concepts, understanding of and ability to implement curriculum, and a strong mastery of the teaching skills and methods (pedagogy), combined with the skill to make decisions about the best plan for a given student at a given time has been shown to be important in student learning (Goldhaber & Anthony, 2004; Halim & Mohd. Meerah, 2002).

Inquiry Learning and Teaching

Inquiry learning and inquiry teaching, or the methodology needed to foster inquiry learning, have been described since the early 1900’s (Dewey, 1910). Rather than prescribe a strict instructional methodology, Dewey described a preferred educational outcome - citizens whom we would consider to be scientifically literate. As a contrast to lecture, memorization of facts, and simply duplicating laboratory work, Dewey wanted science taught in a manner that engaged students in thinking about their work and thus, their constantly changing world. Dewey’s ideas have resurfaced over the last several decades as inquiry teaching and learning.

Inquiry learning, at its simplest, takes place when a scientist or student notices a phenomenon and begins to ask questions about it. According to the National Science Education Standards, inquiry in science is

… a multifaceted activity that involves making observations; posing questions, examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence’ using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (National Research Council, 1996, p. 23).

Inquiry teaching encompasses all method used in the classroom to foster inquiry learning in students. Teaching methods include a continuum starting with asking open-ended questions to facilitating a completely student-designed investigation. Direct instruction is usually limited to introducing a concept, explaining something causing difficulty, or reinforcing something that all students should know. In science, investigations are commonly laboratory or field investigations including some type of data collection and analysis. Inquiry learning is not limited to this type of original research. It may include many means of information-gathering by students and many sources of data and knowledge including what is already documented by others. The teacher’s role is to guide, facilitate, and support learning rather than to simply deliver the information by lecture. The teacher may assist the student in finding and evaluating resources, by acting as a sounding board as students develop research questions, hypotheses and experimental designs, or interpret their findings. Inquiry teaching involves choosing or developing a variety of lessons that invite and expect students to become actively involved in their learning process. The goal of inquiry teaching is to produce inquiry learning in students because inquiry learning is both an important science skill and an effective means by which students can make their learning their own.

Students form, or construct, their own interpretations and understandings of phenomenon as they proceed through inquiry work. (Lowrey, 1997) These understandings described as knowledge that has been actively built up by a learner as opposed to having been transmitted from another source is known as constructed knowledge. A classroom is said to be constructivist in nature when the teacher focuses students on the reflection on changes in thinking, and stresses logic and fundamental principles as opposed to memorization of unrelated facts (Cobb, 1988; Driver, 1989; Tobin, Tippins, & Gallard, 1994; vonGlaserfeld, 1987).

Constructivism

Constructivism is a learning theory (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Noel, 2000; J. A. Shymansky, 1992; vonGlaserfeld, 1987; Yager, 1991) which describes knowledge as being actively built by the learner, not directly transmitted from another source. It describes learning in children, has gained acceptance among educators as they work to develop models of effective teaching practices. Constructivist teachers hold that student-constructed knowledge benefits the student because the knowledge is personalized and incorporated into the student’s own cognitive schema. The knowledge of others may influence the student’s construction or re-construction of knowledge, especially if the student is working in a social or community setting as is usual in the classroom.

Constructivist learning generally fits one of two broad categories or brands (Staver, 1998): social constructivism as described above, or radical constructivism. As defined by the radical constructivist von Glasersfeld, constructivism is a “set of beliefs about knowledge that begin with the assumption that a reality exists but cannot be knows as a set of truths because of the fallibility of human experience” (von Glaserfeld, 1989).

Radical constructivism as a developmental theory was developed by von Glasersfeld and rooted in Piaget’s Genetic Epistemology Theory (Piaget, 1970). This theory used the term *genetic* in the sense of the more currently used term *developmental* in his model of how children built up knowledge (von Glaserfeld, 2001). Radical constructivism makes the claim that no two minds equally identify an experience so the learning or knowledge gained by each mind would now be unique. Because there is no uniqueness in knowledge, then, there is no knowable reality. Each learner would have his own unique set of knowledge, or conception (De Zeeuw, 2001). Because there is no reality, a radical constructivist would accept each alternative conception as reality for that learner. Agreement with the knowledge constructed by others is not necessary.

Constructed knowledge, then, is a gateway for alternative conceptions in learners. Scientists are not so accepting of such alternative conceptions when they are in contradiction to the conceptions that are commonly held by the science community. An alternative conception, then, becomes a misconception to scientists. Some science education researchers distinguish *misconceptions*, or a misunderstanding a student derives from instruction, from an *alternative conception* that a student has formulated as a result of life experiences and brings with him to instruction (Driver & Easley, 1978). In this study, misconception and alternative conception will be used as distinct and different entities.

Knowledge constructed by the learner may become a misconception due to misunderstanding or lack of understanding. A misconception may arise as a naïve idea about an everyday experience. Misconceptions may also be passed along to students by teachers (Yip, 1998).

Once a concept, correct or not, has rooted itself in someone’s framework of knowledge, it can be very difficult to change (Driver & Easley, 1978). High school students interviewed in *A Private Universe* were found to have their own private theories of which their teachers were unaware as they conducted lessons. At least one student perceived by her teacher to be very bright and high-performing harbored an initial misconception about the moon’s path around the Earth and she was able to correctly revise her private theory after 2 weeks of instruction. However, this student was not, when asked, able to revise her private theory about the moon’s phases. Would it be likely for this student to carry her conception of moon phases into a classroom, should she become a teacher? The misconceptions and alternative conceptions about moon phases held by pre-service elementary teachers and changing those conceptions is the focus of this study.

Definitions

Except where noted, the definitions are operational definitions constructed by the researcher for the purpose of this study.

*Alternative conception* – a difference in the idea held by an individual of group of individuals from the generally accepted idea. Taken in this study to be derived by the individual from his own specific observations or life experiences and brought to instruction (see *misconception*.)

*Attitude* - a predisposition to respond positively or negatively toward things, people, places, events, and ideas (Simpson, Koballa, Oliver, & Crawley, 1994, p. 211)

*Asynchronous messaging* – individuals can contribute to a discussion at their leisure over the Internet by using specially designed software; convenient across time zones because it is not necessary for all parties to be available at the same time.

*Belief* – the general acceptance or rejection of basic ideas (Simpson et al., 1994)

*Blackboard*™ - web-based messaging system used by many learning institutions to facilitate discussions among specific groups of learners who can post written responses to a given prompt and then respond to one another’s posts.

*Conception* – a general idea inferred or derived from specific observations or instances

*Conceptual Change* – generally defined as learning that changes an existing conception (belief, idea, or way of thinking).

*Constructivism* – the assimilation of data into information which, when applied in a useful manner, becomes knowledge. – knowledge that is actively built by the learner, not directly transmitted from another source (Driver et al., 1994).

– includes such teaching strategies as invitation to inquiry, exploration, proposing explanations and solutions, taking action through decision-making, application of new knowledge and skills, sharing of information, and asking new questions (Yager, 1991).

*Critical thinking* – the use of scientific data to find the preferred explanation (National Research Council, 1996)

*Elementary students* – due to differences in grade level divisions in different countries and even within school districts in the United States leading to varying classroom teacher assignments, participating elementary students ranged from ages equivalent to Grade 2 to Grade 8. These extreme age groups were not a part of the study semester’s elementary students. Students were in classrooms equivalent to Grades 3 -5.

*Grounded theory*  — systematic, flexible guidelines for collecting and analyzing qualitative data for the purpose of constructing a theory arising from and grounded in the data itself.

*Inquiry* – the methods and activities that lead to the development of scientific knowledge (Schwartz, Lederman, & Crawford, 2004); a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena for the purpose of acquiring knowledge and understanding concepts. (National Research Council, 1996) In this study, the term *inquiry* describes the acquisition of data, and the term constructivism is used to define the organization of data into information and the creation of knowledge from that information.

*Knowledge* – an awareness and collection of facts

*Methods class* - Teaching Science in the Elementary School. Methods for teaching

Science concepts, skills, and attitudes are developed through classroom and clinical experiences. Special emphasis on making connections between science and other areas of the elementary curriculum.

*Misconception* – an idea held by an individual or group that is different from and in contradiction to the generally accepted idea; taken in this study to be derived incorrectly by an individual from his own interpretations of instruction or directly from the instruction itself.

*MOON Project* - an externally funded multinational exploration of inquiry teaching via e-learning connects middle school students around the world with pre-service elementary teachers in a long-term (16-week) investigation of the Moon and provides an opportunity to share their observations, via the Internet using Blackboard™. Each semester, pre-service teachers from 8 universities in 3 countries and 300-500 elementary school students from 7 states and 8 countries take part.

*Nature of Science* – interconnected and validated ideas about the physical, biological, psychological, and social worlds that are particular ways of observing, thinking, experimenting, and validating ideas (American Association for the Advancement of Science, 1990); the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of science knowledge (McComas, 1998).

*Orbit* - the usually elliptical path described by a celestial body as it revolves around another body

*Paradigm* – world views on belief systems that guide researchers (Guba & Lincoln, 1994)

*Pedagogical Content Knowledge –* the whole of the knowledge a person has of the subject concerned, as well as knowledge of the learning and the teaching of that subject (Shulman, 1986).

*Perception* – the model created by an observer as he gathers data in attempt to understand and explain the phenomena; the model may shift as the observer gathers more information.

*Pre-service teachers* – elementary education undergraduate students enrolled in as elementary science teaching methods course.

*Rotation* – the process of turning around an axis. Applies to both the earth and the moon.

*Revolution* – orbital motion about a point, as distinguished from rotation about an axis. Applies to both the earth and the moon.

*Scientific habits of mind* –a manner of thinking in which scientific reasoning is used to construct knowledge, draw conclusions, and/or make decisions.

*Scientific Literacy* – the ability to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (National Research Council, 1996).

*Shadow* - a dark figure or image cast on the ground or some surface by a body

intercepting light ("shadow. (n.d.) Dictionary.com Unabridged (v 1.1) ")

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