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Ideas for enhancing primary and high school science education

Did you Know?

Atmospheric Carbon Dioxide

During 2005, carbon dioxide levels in the atmosphere rose to 381 parts per million (ppm), which is 100 ppm above the average in the pre-industrial age. What is more, the levels are rising at twice the rate of 30 years ago. Humans certainly appear to be changing the earth's climate.

Connecting Inquiry and the Nature of Science

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Abstract

Inquiry has been one of the most prominent reforms in science education. One of the goals of teaching through inquiry methods is to enable students to have experiences that are authentic to scientists' experiences. Too often, inquiry science is taught as either the "scientific method" or as "hands-on," disconnected activities (Bybee, 2004), which is only a sliver of the continuum of experiences inquiry science offers. Quality inquiry investigations can be implemented by using the aspects of the nature of science, the inherent understanding that scientists use to generate knowledge, as a guide. Often, process skills and the nature of science are confused due to their close relationship. Process skills are necessary for inquiry science, but do not provide the underlying concepts that guide the development of scientific knowledge. The aspects of the nature of science provide the rationale for the importance of process skills and how these skills are used to develop new scientific knowledge. The research literature converges on seven aspects of the nature of science that defines science as a discipline: 1. Scientific knowledge is durable, yet tentative; 2. empirical evidence is used to support ideas in science; 3. social and historical factors play a role in the construction of scientific knowledge; 4. laws and theories play a central role in developing scientific knowledge, yet they have different functions; 5. accurate record keeping, peer review, and replication of experiments help to validate scientific ideas; 6. science is a creative endeavor; and 7. science and technology are not the same, but they impact each other (Lederman & Lederman, 2005; McComas, 2005). Each aspect of the nature of science is discussed in detail, with examples demonstrating how to explicitly incorporate the nature of science into classroom inquiry investigations. Teachers can help students learn to independently monitor their own learning and think scientifically by using the nature of science as a guide for inquiry investigations.

One of the most prominent reforms in science education is inquiry science (American Association for the Advancement of Science [AAAS], 1993). The *National Science Education Standards* (National Research Council, 1996) refer to scientific inquiry as “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (p. 23). When science content is taught through inquiry methods, student understandings and explanations about the real world improve and learning is more meaningful (Hogan, 2000; Hogan & Maglienti, 2001;). One of the goals of teaching through inquiry methods is to enable students to have experiences that are aligned more closely to scientists’ experiences. Too often, inquiry science is taught as either the “scientific method” or as “hands-on,” disconnected activities (Bybee, 2004), which is only a sliver of the continuum of experiences inquiry science offers. How can teachers guide students to more significant scientific experiences? When students are constructing their knowledge from open-ended inquiry investigations, what can teachers do to promote scientific thinking?

Process Skills and the Nature of Science

Because methods of inquiry science attempt to make students’ experiences authentic, they should be guided by the inherent guidelines of the discipline of science. If students don’t understand the principles by which scientists conduct research, then their inquiry experience would not be meaningful in a scientific way. Students could go through the motions of doing an experiment and become proficient in the process skills that are required for scientific investigation, but they may not be thinking like scientists. Process skills are necessary for inquiry science, but are often mistaken for the underlying concepts that guide the development of scientific knowledge. The aspects of the nature of science provide the rationale for the importance of process skills and how these skills are used to develop new scientific knowledge. Table 1 shows connections between process skills and the nature of science. The nature of science, the inherent guidelines that are used to conduct methods of discovering scientific knowledge, provides the underlying principles that show students why the correct choice and use of process skills will lead to scientific knowledge.

Using the Nature of Science to Provide Quality Inquiry

Open-ended inquiry can be daunting because of the countless numbers of outcomes of student-initiated investigations. A classroom teacher could not be expected to know in advance all of the outcomes of possible student investigations, so how can the quality of the investigation be guaranteed? Students can have quality inquiry experiences when they reflect on the nature of science in their decisions regarding research questions, procedures, measurement techniques, data recording methods, and reporting methods. The teacher can be a resource by offering ideas to the student so that the investigation in conducted in a scientific way. The teacher can be a filter, making sure all student decisions correspond to the nature of science. For example, in an investigation exploring the effect of the type of material used to restrict heat transfer from boiling water, students may decide to measure only three trials for each type of material. The teacher should intervene and ask students if data would be reliable if the three trials produced drastically different results. The teacher could lead students to understand that a greater number of trials make the results more valid. Table 2 lists some possible teachable moments regarding investigations and the nature of science. Even if an investigation proves to be inconclusive, the students gained the experience of how knowledge is obtained in a scientific realm.

Table 1
Connections Among Inquiry Activities, Process Skills, and the Nature of Science

Inquiry activity	Process skill	Nature of science concept
Using senses to identify phenomena	Observation	Empirical evidence is used to support ideas.
Organizing information so that it is accessible	Classification	Knowledge production in science shares common factors; science is a creative endeavor.
Using tools to quantify phenomena	Measurement	Science and technology impact each other, but are not the same.
Creating data tables	Organization of data	Accurate record keeping, peer review, and replication of experiments help to validate scientific ideas.
Working in groups	Cooperation, collaboration	Social and historical factors play a role in the construction of scientific knowledge.
Connecting ideas to other activities	Generalizing	Theories help to connect and explain scientific facts. Scientific knowledge is durable, yet tentative.

Elaborating the Nature of Science

During the past 10 years, the thinking of researchers on aspects of the nature of science has converged, and more recently there has been agreement on some of the elements of the nature of science (Lederman, 1992; McComas, Almazroa, & Clough, 1998). The research literature converges on seven aspects of the nature of science that defines science as a discipline: 1. Scientific knowledge is durable, yet tentative; 2. empirical evidence is used to support ideas in science; 3. social and historical factors play a role in the construction of scientific knowledge; 4. laws and theories play a central role in developing scientific knowledge, yet they have different functions; 6. accurate record keeping, peer review, and replication of experiments help to validate scientific ideas; 6. science is a creative endeavor; and 7. science and technology are not the same, but they impact each other (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; McComas, 2005). When guided by the nature of science, student inquiry can become more than merely following the “scientific method.” Even when students pose unique research questions and the outcomes of the investigation are unknown, teachers can feel confident that students will receive meaningful scientific experiences when the nature of science is used as a guideline for the inquiry. A deep understanding of each aspect of the nature of science will help facilitate quality inquiry investigations.

The idea that scientific knowledge is durable, yet tentative, is difficult for many students to understand. After all, the content that makes up scientific knowledge is printed in the book, and resembles the “answers” to how the world works. Many students have had the experience of memorizing facts their entire school career, so students may experience difficulties when faced with the thought that these facts can change, based on new data. At the beginning of the year, I confront the idea that science content is in its final form by introducing students to “sewer slugs” (McCormack, 1990). I explain in the form of a demonstration that three slugs can biologically convert 50 mL of urine to potable water in 1 minute and 30 seconds. I then produce a beaker of "urine" and place the slugs in the urine. The slugs begin swimming around in the urine. I ask students to make observations and I record the observations on the board, carefully pointing out which statements are observations and which are inferences. After all observations have been made, I drink the urine and snack on a few of the slugs. When students have gotten over their disgust in the demonstration, they begin to wonder how it worked. They experience cognitive dissonance because what they just saw doesn't fit with what they think. Based on the new information that I would drink the urine and eat the slugs, students reconfigure their thinking and ask probing questions. They eventually find out that the urine was soda with food coloring and the slugs were raisins. A discussion about why the raisins "swim" connects their observations of the bubbles sticking to the raisins to the topic of buoyancy. During this activity, I take time to explicitly talk about the changes in their thinking when confronted with new information. Scientists, when confronted with new information, must also think about how the new information fits in with the old information. In this way, scientific knowledge is tentative, yet durable.

Table 2
Using the Nature of Science to Promote Quality Inquiry

Aspect of the nature of science	Opportunities to show scientific thinking during inquiry
Scientific knowledge is durable, yet tentative.	Take a discrepant event, such as "sewer slugs," and have students make observations given only limited information. Disclose more information about the situation and discuss how students' ideas have changed given the additional information.
Empirical evidence is used to support ideas in science.	Where possible, base observations on a standard of comparison, such as a measurement system, and ensure all observations are free of judgment and recorded accurately.
Social and historical factors play a role in the construction of scientific knowledge.	Demonstrate how scientific achievements sometimes occur in short spurts over a length of time, and that each idea is built on prior knowledge, such as the development of the structure of DNA.
Laws and theories play a central role in developing scientific knowledge, yet they have different functions.	Ask students how their prior knowledge affected the results. Did their results correspond with their expectations, or did they experience cognitive dissonance? How did their observations help to build ideas about their topic? Did students follow the rules of a phenomenon (using laws) or did they try to explain the mechanisms involved (using theory)?
Accurate record keeping, peer review, and replication of experiments help to validate scientific ideas.	Have students trade data tables with another group and have the group explain what the data table means. After inquiry investigations are complete, have students present the results to their peers for evaluation.
Science is a creative endeavor.	How is the investigation different from experiments that have already been performed? What new ideas did you have to create to connect your observations to your conclusions?
Science and technology are not the same, but they impact each other.	How are scientific ideas different from technology? Identify the ideas used in the inquiry and the technology used in the inquiry. How did they impact each other?

Most students understand that science is different from other ways of knowing because ideas are supported by empirical evidence. Teachers can use inquiry investigations, with explicit reference to the nature of science, to enhance student understanding of evidence that is free from bias. Objective evidence can be compared against a standard. For example, the conclusion that "the change in temperature was big" is not based on objective evidence, because not everyone can agree on the meaning of the term *big*. An objective statement would be "the change in temperature was 15°C," which is a statement that includes a standard measurement. Whenever possible, students should strive to collect data that is objective. Teachers can encourage students to write more objective observations by asking them if other students could understand what is meant by their recorded observations. Trading data sets emulates the way the scientific community shares information through publications and replication of experiments.

The idea that social and historical factors play a role in the construction of scientific knowledge is a difficult one to present, especially if only content is presented in classrooms. History and sociology are difficult to fit into class lessons because they encompass large periods of time, whereas much of the historical focus in science is on singular experiments. One way to show students that some scientific achievements occur in short spurts of progress over long periods of time is to teach the history of the development of the ideas involving the structure and makeup of DNA. Gregor Mendel, although not directly addressing the structure of DNA, was important in developing the ideas of genes and heredity in the 19th century. The next breakthrough in understanding DNA did not occur until 1928, when Frederick Griffith was trying to find a vaccine against streptococcus pneumoniae. In his experiments, he injected two different strands of bacteria into mice, one that was harmless and one that was harmful. In his first experiment, he injected harmless live bacteria into the mice and they lived. In his second experiment, he injected the live harmful bacteria into the mice and they died. In his third experiment, he killed the harmful bacteria with heat and injected them into the mice and the mice lived. In his fourth experiment, he added live harmless bacteria to the dead harmful bacteria and the mice died. Since Griffith did not destroy the hereditary material, the disease continued to propagate. Picking up on Griffith's work, in 1944 Oswald Avery found that it was not protein, but DNA that carried hereditary substances. Erwin Chargaff figured out the equations for the different DNA bases in 1952 and Rosalind Franklin followed closely behind in 1953 with her photo of the DNA molecule. In April of 1953, James Watson and Francis Crick came up with the double helix structure. This progression points out two important aspects of the history of science; namely, that ideas usually build upon each other over time, and that scientific ideas sometimes occur in short segments over long periods of time.

Younger students find it difficult to relate to abstract sociological factors, making this topic even more difficult to teach. Another way to emphasize the impact of social factors on science is to have students recognize how their lab groups interact socially to develop knowledge. After groups of students conduct identical inquiry investigations, have students compare their results. Usually, the results among the groups will be slightly different. A whole-class discussion can look into how the differences occurred and the implications that student interactions had on the results. For example, if one student dominated the lab equipment and made all of the measurements, that student greatly influenced the data. If all students in a group took measurements, then erroneous measurement techniques might have been identified because more than one person contributed to the measurement techniques. The discussion could be broadened to focus on the whole scientific community and the cultural and sociological influences that impact science today.

Most students can define laws and theories according to their textbook, but students often lack the ability to explain the role of laws and theories in developing scientific knowledge. Students often misunderstand a law to be a higher form, or a more agreed-upon form, of a theory (McComas, 1998). Dunbar (1995) makes a useful distinction between laws and theory by calling laws the rules to be followed, whereas theoretical science attempts to explain why the rules work. When students understand that they use laws to apply rules in order to predict outcomes and theories are applied to explain phenomena, they may better grasp that theories and laws are two different types of knowledge. Understanding that laws and theories are different types of knowledge puts students in a better position to articulate their own scientific thinking.

Students may be better able to understand the central role of laws and theories by reflecting on the theories that they currently have. Using the word *theories* may turn some students off immediately, so a more appropriate approach may be to ask what students already know about the inquiry topic being studied. By tapping into their prior knowledge, teachers can begin to grasp the current theories the students use to operate. Observations made by students in inquiry investigations are greatly influenced by students' current cognitive theories. For example, student A has experience observing how water will run from a high point to a low point and carry small amounts of soil to another location. Student B has no experience with erosion or deposition. When both students are given a picture of a landscape and asked to identify where erosion might occur, student A uses his or her prior experiences to find a slope where water might carry soil from a high position to a low position. Student B has no prior ideas upon which to base an answer, and might choose a location based on where he or she thinks water is more likely to fall. Student B's lack of theories inhibits the ability to assimilate new knowledge. Conversely, new observations help to build theories. In the same situation, Student B may be sufficiently intrigued by the erosion question to do some independent investigation. A model terrain with hills and valleys is built and water poured from a watering can to simulate rain. Observations about how the water runs and the water's ability to carry soil from one place to another are used to make generalizations about the characteristics of erosion. Additional observations in different contexts help to codify his or her personal theory about erosion. Meaningful learning occurs when students' personal theories more closely resemble theories accepted by the scientific community.

Accurate record keeping, peer review, and replication of experiments can be integrated into inquiry investigations through initial requirements. Teachers can arrange classroom environments so that the importance of the legitimacy of student data sets and conclusions is central to the task of inquiry. Often students ask: "Should I write down what I saw, or record what should have happened?" Students have preconceived ideas regarding the outcome of their inquiry and try to fit their observations to their prior ideas, even if they conflict. Scientists spend a great deal of time ensuring their data and conclusions are beyond reproach, because their credibility depends on it. Teachers can encourage accurate record keeping, peer review, and replication of experiments by asking students to evaluate each other's inquiry investigation reports. Requiring peers to ask clarification questions is an effective way to transfer the content, as well as the process, from one group of students to another. Students can teach each other the information they learned through their inquiry experiment, as well as teach how the information was obtained.

Students often view science as an activity lacking creativity, where observations are reported and this evidence supports or refutes a hypothesis. From this understanding, a conclusion can be reached. To generalize observations that can lead to a new understanding of a particular topic takes creativity. Creativity can be demonstrated in the science class by encouraging students to investigate relationships that are unknown to them, because student learning may be optimized in such circumstances. When students are unaware of the outcome of an inquiry, they can't impose their preconceived ideas about a topic on the data or conclusions. Posing a challenge to build a car that runs exactly 10 meters, using only the energy of two 1-kilogram weights dropping a distance of 1 meter, offers students a creative environment that requires the application of science content. Students must think about the mechanisms that will transfer energy from the dropping weights to the propulsion of the car. Once students begin to understand about the amount of force needed to propel their cars, they must also wrestle with ways to solve the problem of halting the car at the ten meter mark. On a broader scale, geologists are required to think in a creative way when performing retrodiction. They must construct rigorous explanations to make up for gaps in the information provided. For example, geologists must find creative ways to explain how tectonic plates fit together in the light of fossil records and plate boundaries.

Lastly, students can deepen their epistemological understanding about scientific knowledge when they can see the differences between science and technology. Often students confuse science and technology because of the impact they have on each other. Generally, scientific ideas help to further technology. When technology advances, mainly in the form of measurement instruments, more data is contributed to scientific thinking, which in turn advances scientific theories. For example, ideas regarding the movement of planets were very different before the invention of the telescope. Because observations could only be made with the unaided eye, the prevailing idea in science was that all other planets and the sun revolved around the Earth. After the invention of the telescope, a technological achievement, the movement of other planets could be documented and the idea that all planets revolved around the sun became the prominent scientific idea. In this example, sociological factors slowed down the acceptance of the heliocentric model! In order to identify the concepts in science and the concepts regarding technology, students can be asked to reflect on their selection of measurement techniques. If they chose a different method, or a different precision of measurement, how might that influence their conclusions? How might more sophisticated tools change their ideas in the inquiry investigation? How might the measurement of pH using pH paper, universal indicator, or a pH meter be different?

The teacher’s role in open-ended inquiry is vital to the quality of content achieved in the outcome and to the quality of scientific thinking used throughout the investigation. When teachers effectively monitor students’ decisions and their alignment to the discipline of science, two learning goals are achieved: Students understand the scientific content investigated because they understand how it was obtained, and they understand what they learned in light of current theory. Teachers can use the nature of science as a guide for open-ended inquiry investigations to enable students to think scientifically. Many of the barriers teachers find in conducting inquiry investigations can be overcome with a deep understanding of the nature of science. Teachers can help students become lifelong learners, and help students think like scientists, by using the nature of science as a guide for inquiry investigations.

References

American Association for the Advancement of Science (AAAS). (1993). *Benchmarks for scientific literacy.* New York: Oxford University Press.

Bybee, R. W. (2004). Scientific inquiry and science teaching. In L. B. Flick and N. G. Lederman (Eds.), *Scientific inquiry and nature of science* (pp. 1-14). Boston: Kluwer Academic Publishers.

Dunbar, R. (1995). *The trouble with science.* Cambridge: Harvard University Press.

Hogan, K. (2000). Exploring a process view of students’ knowledge about the nature of science. *Science Education, 84,* 51-70.

Hogan, K., & Maglienti, M. (2001). Comparing the epistemological underpinnings of students’ and scientists’ reasoning about conclusions. *Journal of Research in Science Teaching, 38,* 663-687.

Lederman, N. G. (1992). Students' and teachers' conceptions about the nature of science: A review of the research. *Journal of Research in Science Teaching, 29,* 331-359.

Lederman, N. G., Abd-El-Khalick, F., Bell, R., & Schwartz, R. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners’ conceptions of nature of science. *Journal of Research in Science Teaching, 39,* 497-521.

Lederman, N. G., & Lederman, J. (2005, April). *Promoting systemic change: Transforming "ICAN" into "WECAN."* Paper presented at the meeting of the National Association for Research in Science Teaching, Dallas, TX.
McComas, W. F. (1998) The principal elements of the nature of science: Dispelling the myths. In W. F. McComas (Ed.), *The Nature of Science in Science Education* (pp. 53-70). Boston, MA: Kluwer Academic Publishers.
McComas, W. F. (2005, April). *Seeking NOS standards: What content consensus exists in popular books on the nature of science.* Paper presented at the meeting of National Association for Research in Science Teaching, Dallas, TX.
McComas, W. F., Almazroa, H., & Clough, M. P. (1998). The nature of science in science education: An introduction. *Science & Education*, 7, 511-532.
McCormack, A. J. (1990). *Magic and showmanship for teachers.* Riverview, FL: Idea Factory.
National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.

Reassessing Possible Naturalized Ideology Regarding Science, Education, and Religion

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Abstract

This manuscript asks questions about what may be the naturalized, or taken for granted, ideologies in science education regarding religion. There have been times in history when religion has taken a dogmatic role in limiting the practices of science (e.g., the Roman Catholic Church and Galileo). This manuscript reflects on the dogmatic rule of religion and argues that now science may be in danger of imposing dogmatic ideals through reaching beyond the capacities of an empirical way of knowing. A Science, Technology, and Society (STS) approach to science teaching is considered as a possible mechanism for honoring both science and religion as valid yet different ways of knowing and better addressing students' integration of science learned in school into their everyday lives.

> Absence of evidence is not evidence of absence. (Roy, 2006)
>
> Behe's conclusion is that since complex biochemical systems in advanced organisms could not have evolved through strict Darwinian evolution, the only possible explanation is that the system was designed and put into place deliberately. (Card, 2006, ¶ 10)

These two quotes, in differing ways, get at relevant imperatives that I believe should be considered in science education. In his address, Rustum Roy (2006), Evan Pugh Professor of the Solid State, Professor of Geochemistry, and Professor of Science, Technology, and Society at The Pennsylvania State University, discussed the "change in guard" that he believes has taken place since the days of the Roman Catholic Church in the time of Galileo. In this earlier period, the Roman Catholic Church belief system, or worldview, represented what could be described as the dogma of the time, "a definite authoritative tenet" (Merriam-Webster Online dictionary). The change in guard that Roy argues has taken place, which may be accurate, is the new rule of Science. Roy posited that science has taken the role of the dogmatic authority of today.

Feyerabend (1975) illuminated dangers associated with an unchecked dogmatic rule of science in his writings pertaining to the potential dangers of an objective search for truth that disconnects the humanity from science and in his critique of rigid methodologies portrayed as the norms of scientific investigations. Feyerabend (1978) also argued that science should be separated from the state, just as religion has been in many states, so that a free society can be established that gives equal rights to all traditions, thereby giving them equal access to the power of the state. As a science educator with some 9 years of science and post-secondary education training, the resonance through which Roy's argument caught my attention led me to believe that there may be some credibility to his claims, or at the least cause for consideration. I feel that science educators are in danger of implicitly teaching society that absence of evidence is evidence of absence, through counting only those things that can be understood through science to be the only things worthy of being considered a purer grade of knowledge. This idea is manifested in the translated writings of Auguste Comte, in which he counts scientific knowledge as the only authentic knowledge, and the influence that the positivistic philosophy he helped articulate has had in science, and continues to have to some extent (Martineau, 2003).

In the second quote introducing this opinion piece, I see an unjustified argument that represents the danger some fear may be assumed if Science pulls back from anything but a dogmatic rule. Through the argument/logic put forth in this quote, if evidence for evolution is found as problematic, the only possible explanation is a deliberate placement. There have been times in our human history that we have recognized or experienced a paradigmatic shift in understanding or thinking (Kuhn, 1962). One such shift referred to earlier was from the geocentric view of our universe to the heliocentric view. Through changing our lens, mankind was offered a different perspective that consequently offered new vantages for observation. Let us consider that there may be other paradigmatic shifts on the horizon. If this is the case, the logic that problems with the theory of evolution leads to proof of a deliberate placement seems close-minded, or perhaps even bordering dogmatic.

Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) offer this explanation of a theory: "Theories serve to explain large sets of seemingly unrelated observations in more than one field of investigation" (p. 500). They go on to explain that theories "are well-established, highly substantiated, internally consistent systems of explanations" (p. 500). However, they also go on to discuss the tentative nature of science, whereby "scientific knowledge, although reliable and durable, is never absolute or certain" (p. 502). If scientists find a theory that is problematic, then the options for dealing with the problem are modification of the theory to deal with anomalies or dismissal of the theory. I believe we can find examples in mankind's history where this has happened (e.g., the recognition of plate tectonics as the geological explanation for large-scale physical changes of the earth, or the shift from a behaviorist emphasis to a cognitive one in psychological studies). Theories, because of their very essence as human explanations, can be changed. The National Research Council (1996) discussed this tentativeness and how it should be understood:

> Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirmations and are therefore unlikely to change in the areas in which they have been tested. In areas where data or understanding are incomplete, such as the details of human evolution or questions surrounding global warming, new data may well lead to changes in current ideas or resolve current conflicts. In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest. (p. 201)

So, while I as a science educator want to be sure that neither a dogma of science nor a dogma of church exists, I find myself wondering what might be done on this front.

Interdisciplinary Considerations

As an educator, I have developed a philosophy that has me believing that teaching interdisciplinary programs, like the cross-curricular science and reading program shared by Creech and Hale (2006) or the cross-curricular programs involving math, science, and social studies shared by Yager and Lutz (1995), leads learners toward a more meaningful understanding. This approach does not leave to chance the construction of the pieces of the school curriculum into a meaningful final educational product, as it allows students to work at these constructions in the presence of a facilitator and peers. Likewise, a Science, Technology, and Society (STS) approach to teaching, "the teaching and learning of science in the context of human experience" (National Science Teachers Association, 1990-1991, pp. 47-48), might reach farther in allowing learners to construct the pieces of life's curriculum, one part only of which is learned in school.

As I consider these ideas that make up the fabric of my educational philosophy, I have recognized a contradiction in my thought or understanding or education. At some point in developing my philosophy, I have accepted the idea that science and religion cannot be discussed in the same context. It is unclear if I justified it as the separation of church and state, or as what has been described by Fairclough (1995) as the naturalization or opacity of an established ideology. One can find staunch opposition to anything seeking to merge education and religion in the following position, which may justify me attributing my current understanding to separation of church and state:

> Professor of political science Marjorie George argues that the U.S. Constitution and the Supreme Court have created a solid wall between the educational system and religion. Despite the efforts of creationists to find ways around or through that wall, she holds, religion "can play no role in the classroom." (Easton, 2005, p. 40)

Whether or not this thought is held by all, it seems reflection on established ideologies can be helpful in guarding against the emergence of dogma and helping students to attain a more cohesive understanding.

Whatever the case, I have always held as part of my philosophy that science cannot be in an interdisciplinary context with anything associated with religion. In my own life, the very absence of consideration for how science and religion interact, or the confusion of how this may be possible, has long left me concerned. This is the thought I am now beginning to reexamine, in a practice of reflection. This brings me to the following new questions:

1. Can science and religion be taught in an interdisciplinary way?
2. Should science and religion be taught this way?

Then, if the answers are *yes*,

3. In what respect should science and religion be taught in an interdisciplinary manner?
4. What benefits might emerge from such an unorthodox suggestion?

To be clear here, I am not entertaining the thought of teaching religion and science in an interdisciplinary manner in our schools, at least not in the way that would have students accepting and practicing one religion. What I am entertaining is the thought of employing STS instruction without the exclusion of religion. From within a culture consisting of many religions, I am considering the implementation of STS instruction whereby science as a way knowing is considered alongside religion as a way of knowing, in whatever context or community the students find themselves. If science literacy is contingent in part on students understanding that science is a way of knowing, I cannot think of a more meaningful way of gaining deeper understanding about knowing in science than contrasting it with another way of knowing. This would allow learners to recognize the similarities and difference between the two and better distinguish between them. It would also help students better understand the causes of tensions arising among debaters, all of which lie well within the boundaries of STS instruction.

STS instruction has these core components:

- Science, technology, and social studies are taught in a socially relevant context.
- Students experience active citizenship by actively exploring issues, processing information, forming opinions, and making personal judgments on real-world events.
- Lessons encourage awareness and acceptance of differing viewpoints.
- Students use problem solving to make personal commitments and take responsible social action. (Alaska Department of Education & Early Development, n.d., section 5)

"STS is active learning on relevant topics that, in addition to the acquisition of information and skills, results in commitment, action and acceptance on the part of the student" (Alaska Department of Education & Early Development, n.d., section 5). In additional to contrasting ways of knowing through discussion of science and religion, STS instruction also offers students space, as well as a medium, for exploring the interaction of the two.

An example of how this may play out in the school science curriculum could be in the study of world populations, or the issue of population control. When a student of mine chose to research assertions made about population controls, he found that one of the reasons offered for population control was that it retains economic prosperity and a high standard of living. This reason went against this student's beliefs, as he stated: "I consider population control policies to be morally wrong and want to know the extent of their effectiveness." While this student did not specifically state that this belief was a religious one, it should be noted that I teach in a state where the vast majority of citizens are practicing members of The Church of Jesus Christ of Latter-Day Saints, known also as the Mormons, and consideration of population control in this context can be informative. Teachings from this religion pertaining to population control can be seen in Conference Reports or other influential Mormon resources. The following are three excerpts documenting teaching on this subject at various times:

> Children are a heritage from the Lord, and those who refuse the responsibility of bringing them into the world and caring for them are usually prompted by selfish motives, and the result is that they suffer the penalty of selfishness throughout eternity. There is no excuse for members of our Church adopting the custom of the world. . . We have been better taught than they. (Smith, 1917, p. 72)

"When the husband and wife are healthy and free from inherited weaknesses and disease that might be transplanted with injury to their offspring, the use of contraceptives is to be condemned" (McKay, 1943, p. 30). "The first commandment that God gave to Adam and Eve pertained to their potential for parenthood as husband and wife. We declare that God's commandment for His children to multiply and replenish the earth remains in force" (Hinckley, 1995).

Another member of this class was an Evangelical Christian. These discussions prompted this member to explore and share his own religions beliefs about population control.

“We cannot train people in single disciplines and expect them to deal with the multifaceted nature of their work. Including interdisciplinary instruction will help students better integrate ‘school learning’ into their lives” (Alaska Department of Education & Early Development, n.d., section 5). As the first student mentioned above moved forward with his study on whether the population control policies suggested by Brown, Gardner, and Halweil (1999) have been effective, he devised a study that collected empirical data to inform conclusions that he would make at the end of his study. Discussions at the end of the project pertaining to the moral reasons related to population control, as well as the teachings of the various religions, were then also grounded in empirical data supported by the study. Here is the point that comes from this example. We as science educators in the classroom can choose to examine the influences that are at play when students in the classroom are learning and/or making decisions, or we can allow them to go unacknowledged, but either way they still exist. I believe that these discussions at the conclusion of the project, allowing for grappling between the answer to questions about population control based on religious teachings and scientific evidence, can be every bit as important as the process of completing the scientific investigation that precedes them. This process allows the students to work at integrating school learning into their lives.

This consideration seems even more valid in the context of the interdisciplinary rationale fueling a further belief in STS instruction. If students experience “the teaching and learning of science in the context of human experience” (National Science Teachers Association, 1990-1991, pp. 47-48), this human experience by its very nature includes religion. Likewise, this approach does not leave to chance the construction of the pieces of the school curriculum into a meaningful final educational product. It allows the students to work at these constructions in the presence of a facilitator, a family, and/or peers and reach farther in allowing learners to construct the pieces of life’s curriculum.

William Vanderburg (2006), president-elect for IASTS and professor in the Department of Mechanical and Industrial Engineering at the University of Toronto, Canada argued the analogy that “if the only tool we have is a hammer, all problems look like nails,” but in reality all problems are not nails and cannot be addressed with a hammer. He went on to ask: “Can we have a society based on a thinking that this is the answer to all questions?” Science is one way of knowing, a hammer if you will, but it is not the only way of knowing. Lederman et al. (2002) suggest “science is empirical” (p. 500). It is a hammer for approaching nails that have empirical possibilities, but the latter is not always the case. Empirical study may not lead us to justice or ethics, and in these realms a different way of knowing may be needed; perhaps a screwdriver, which may represent religion (Foltz & Foltz, 2006). Gould (1994) similarly concluded:

> The myth of a war between science and religion remains all too current and continues to impede a proper bonding and conciliation between these two utterly different and powerfully important institutions of human life. How can a war exist between two vital subjects with such different appropriate turfs--science as an enterprise dedicated to discovering and explaining the factual basis of the empirical world, and religion as an examination of ethics and values? (p. 18)

If our schools continue to leave out ways of knowing that are not science, are we truly serving to educate the student populace? Are we taking away from their arsenal one tool for approaching problems rather than adding to the toolbox?

I will end this opinion piece by requesting that these observations and possibilities be regarded as dialogue for the science education community. To grow as a community, I believe we must always be open to question the naturalized, or opaque, ideologies (Fairclough, 1995) in order to consider how well they sit with the shifting understandings and thoughts of educators, scientists, and each community's current research. I welcome thoughts and comments from other science educators on this issue, and offer one final assertion that identifies the need for the entertainment of questions such as the ones raised in this paper:

> There must be no barriers to freedom of inquiry. There is no place for dogma in science. The scientist is free, and must be free to ask any questions, to doubt any assertion, to seek for any evidence, to correct any errors. (J. Robert Oppenheimer)

References

Alaska Department of Education & Early Development. (n.d.). *Mathematics and science* (Chapter 5: Instruction). Retrieved June 1, 2006, from http://www.eed.state.ak.us/TLS/FRAMEWORKS/mathsci/ms4inst.htm#sciencetechnologysocietyinstructionalstrategies .

Brown, L., Gardner, G., & Halweil, B. (1999). Sixteen impacts of population growth. *Futurist, 33*(2), 36-41.

Card, O. S. (2006). *Creation and evolution in the schools*. Retrieved February 4, 2006, from http://www.ornery.org/essays/warwatch/2006-01-08-1.html .

Creech, J., & Hale, G. (2006). Literacy in science: Natural fit promoting student literacy through inquiry. *The Science Teacher*, 73(2), 22-27.

Easton, T. (2005). *Taking sides: Clashing views on controversial issues in science, technology, and society* (6th ed.). Dubuque, Iowa: McGraw-Hill/Dushkin.

Fairclough, N. (1995). *Critical discourse analysis*: *The critical study of language*. Harlow, England: Longman Group.

Feyerabend, P. (1975). *Against method: Outline of an anarchistic theory of knowledge*. London: Verso.

Feyerabend, P. (1978). *Science in a free society*. London: New Left Books.

Foltz, F., & Foltz, F. (2006, February). *Technology, religion, and justice: Power, inequality, and survival*. Presentation at the 21st Annual Meeting and Conference of the International Association for Science, Technology, and Society (IASTS), Baltimore, MD.

Gould, S. (1994). Irrationality and dogmatism are foes of both science and religion. *Natural History*, *103*(3), 12-19.

Hinckley, G. (1995, September). *The family: A proclamation to the world.* Address to the General Relief Society Meeting, Salt Lake City, UT.

Kuhn, T. (1962). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Lederman, N., Abd-El-Khalick, F., Bell, R., & Schwartz, R. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, *39*, 497–521.

Martineau, H. (2003). *Positive philosophy of Auguste Comte, Part I (1855).* Whitefish, Montana: Kessinger Publishing.

McKay, D. O. (1943, October 10). *Conference Report*, p. 30.

National Research Council. (1996). *The national science education standards*. Washington, DC: National Academy Press.

National Science Teachers Association. (1990-1991). The NSTA position statement on science-technology-society (STS). In *NSTA handbook* (pp. 47-48). Arlington, VA: Author.

Roy, R. (2006, February). *The clash of two fundamentalisms: Scientism and religious fundamentalists from an STS perspective*. Address to the 21st Annual Meeting and Conference of the International Association for Science, Technology, and Society (IASTS), Baltimore, MD.

Smith, G. A. (1917). Birth control. *Relief Society Magazine*, *4*(2), 72.

Vanderburg, W. (2006, February). *From STS to STSB and the need to reinvent our mission for the next decade.* Address to the 21st Annual Meeting and Conference of the International Association for Science, Technology, and Society (IASTS), Baltimore, MD.

Yager, R., & Lutz, M. (1995). STS to enhance total curriculum. *School Science and Mathematics*, *95*(1), 28-35.

Critical Incident

An Invitation

Readers are invited to send, to the Editor at editor@ScienceEducationReview.com , a summary of a critical incident in which you have been involved. A critical incident is an event, or situation, that marks a significant turning point, or change, for a teacher. The majority of critical incidents are not dramatic or obvious, but are rendered critical through the analysis of the teacher (see Volume 3, p. 13 for further detail). You might describe the educational context and the incident (please use pseudonyms), analyse the incident (e.g., provide reasons to explain your observations), and reflect on the impact the incident made on your views about the learning and teaching process. Upon request, authors may remain anonymous.

We have undoubtedly all done things about which we were very pleased, and perhaps done other things about which we did not feel so pleased, and we all need to remain reflexive of our practice. While teachers will view an incident through the lenses of their own professional experiences, and may therefore explain it differently, this does not detract from the potential benefits to be gained from our willingness to share our experiences and thus better inform the practice of other teachers.

Alternative Conceptions

By: Sue Cavell, Techniquest, Cardiff, UK suec@techniquest.org

This incident had a major impact on my teaching, and aided in identifying my PhD research project. At the time, I was teaching Sound to Year 9 Science and demonstrating that, when an alarm clock is ringing in a bell jar and all the air is evacuated from the jar, one no longer hears the sound. Even though I had told the students that I was pumping the air out of the jar, one of them said “the clock has stopped ringing” and a couple of others agreed. I realised then that these students did not understand that the air was needed in order for the sound to be heard, despite previous demonstrations of how vibrations are transmitted and about the transmission of sound in different media. This incident led me to research on students’ alternative conceptions of sound and hearing, and to design a curriculum unit that better developed their understanding of the role of air in the transmission of sound to the ear, a project that was part of the larger study Linking Cognitive Development and Curriculum Design.

Science Poetry

Reading and/or listening to poems that have been composed by other children their own age can inspire and reassure students as to their ability to understand and write poetry, and the science poems in this regular section of *SER* may be used for this purpose. Please find information about the *International Science Poetry Competition* at http://www.ScienceEducationReview.com/poetcomp.html .

Asteroids

Asteroids oh so scary
Some are big and some are glary
When you see one in the night
It could give you quite a fright

Flying across the sky so fast
It's quite a surprise they really last
They killed out dinosaurs in the past
It must have been quite a blast

They've been known to fly everywhere
Day and night here and there
Some of them in the asteroid belt
If one hit Antarctica it could melt

They could hit a truck and kill a duck
And kill a bull about to buck
Riding one would be quite fun
You'd be going faster than a bullet from
a gun

Camden McCosker, 11 years
Australia

Poem

Neutron, photon, electron and ion
Science only turns my brain on.

Bugs and animals, plants and trees
Give me some biology please.

Explosion, reaction, chemicals and test tube
Chemistry loves me, chemistry loves you.

Einstein, Friction, Motion, Lotion
Physics gives me a sweet emotion.

Science, Science, it's so good for me
Won't you come and experiment with me?

Brock Didenko, 15 years
Hong Kong

A Writing Template for Probing Students' Geological Sense of Place

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Abstract

Because many incoming geoscience students did not acknowledge their previous personal encounters with the earth's geological processes or products, we developed the Geological Sense of Place (GSP) template as a convenient way to assess students' earth science backgrounds through short answer, mini-essay, and induced associative responses. The GSP was administered in introductory earth science courses for elementary education majors (n = 42, n = 56), and in a non-major introductory physical geology course (n = 148) at a large research university in Louisiana (US). Student opinions about the GSP were gathered as part of anonymous electronic surveys at the end of the semester (earth science courses, n = 45, n = 56; physical geology course, n = 134). Students reported that the GSP integrated their past life experiences with geology, and initiated geological thinking. Our research indicates that the GSP provides teachers with a standard method to ascertain students' personal geological knowledge and experiences before instruction begins, and to incorporate these experiences into the classroom. Teachers can determine the impact of instruction on knowledge integration by comparing initial GSP student responses with responses in the post-instruction section of the GSP.

Because very few states in the United States of America mandate geoscience or earth science courses in the school science curriculum, the majority of students do not systematically encounter formal earth science courses in their secondary education. Although North Carolina mandates earth and environmental science as one of three high school science courses required for graduation, it is one of the few US states to do so. Some students may be introduced to the geosciences in middle school as part of an integrated science curriculum (such as Louisiana's seventh- and eighth-grade middle school science courses), and some high schools may offer earth science or geology as elective courses (such as in Texas high schools). This sporadic and inconsistent geological instruction means that many US high school teachers and college instructors encounter students who have had little formal geoscience instruction for several years. Some students will also equate *experience* in the earth sciences with *instruction*, and thus believe that they have had very little interaction with geology and geological products throughout their lives. After all, most of the students have not witnessed earthquakes and volcanoes, considered by many of our incoming, non-science majors to be the typical geological processes.

We developed the Geological Sense of Place (GSP) writing template to encourage secondary and postsecondary students to reflect upon their previous interactions with the earth, and to stimulate students to demonstrate to themselves that, as citizens of our planet, they have encountered and engaged the earth in numerous aspects other than during standardized instruction. Our memory-probing and open-ended questions serve as a guide for student self-reflection and diagnostic assessment. Through the GSP, students can access their prior geoscience experiences before instruction begins. Equally as important, the GSP allowed us to build, during instruction, upon what students already knew.

Theoretical Rationale for the GSP

When our students enter the earth science or geology classroom, their previous, dissimilar geological instruction is compounded by the fact that they are not carbon copies of each other. However, even when geoscience educators acknowledge that each learner is different, and that each learner brings different knowledge and experiences into the classroom, the typical blueprint for an introductory geoscience course often allows little deviation from the standard curriculum. The variations among students' experiences and knowledge are far from insignificant. Ausubel's (1978) famous dictum can be paraphrased: "The most important thing that the learner brings to class is what the learner already knows; find out what that knowledge is and teach accordingly." Furthermore, the human constructivist learning theory advocates that new knowledge encountered by students during instruction be linked with the student's prior knowledge and/or experiences (Mintzes, Wandersee, & Novak, 1998, 2000). The administration of the GSP at the beginning of a class provides an easy and efficient way for teachers to ascertain prior student knowledge about, and individual experiences with, the earth. It also provides the impetus for students to reflect upon their previous personal encounters with earth processes. Through the GSP, an instructor facilitates metacognition by encouraging students to become self-monitors of their geological knowledge and feelings toward the earth and its products. This also forms the base upon which the teacher can scaffold instruction. Therefore, the GSP allows the teacher to ascertain each student's prior geological experience, and potentially custom-fit the curriculum to the varying degrees and types of earth interaction current students have had.

Probing Students' Previous Geoscience Experiences

The Geological Sense of Place template (Figure 1) is used to uncover the past experiences of each learner when she or he enters the classroom. This writing template is designed to elicit and probe

Geological Sense of Place Writing Template

Name: ____

The goal of this learning tool is to help you recall, and connect, the experiences you had with geological products, landforms, and processes as a youth with the concepts you are learning about physical geology this semester.

PART I: Write short answers to each of the 17 "memory probes" below.

1. Which geological product was an important part of "playtime" in your yard?
2. What part of the earth interested you the most as a child?

3. Was there a particular rock or earth-related item that you enjoyed collecting during your childhood?
4. Did you have a particular chore or job as a youth that involved rocks or minerals?

5. Was there a favorite rock or landform you used to sit on or climb in your neighborhood?
6. As a youth, what was your favorite geological process to read about, view on television, or experience?

7. Did any of your childhood crafts involve making things from rocks or geological products?
8. Did any particular kind of rock have a texture you enjoyed touching as a youth?

9. What was the most unusual rock, landform, or geological process you encountered as a child?
10. Did you have your own rock or fossil collection? If so, which types did you have?

11. What geological formation or product was your town or geographic area most famous for?
12. Was there any particular geological object or landform you avoided, or were afraid of as a child?

13. What exotic geologic location made a big impression on you as a child?
14. Were there any sounds associated with geological processes or events you can remember from your childhood?

15. Did you have a person in your youth who was your geology mentor, and what did you learn from her/him about identifying or understanding rocks, fossils, or earth processes?
16. What was your favorite gemstone as a child, and why?

17. When you hear the word *rock*, which color do you associate with the word?

PART II: Complete two mini-essays using memories that you've "tapped into" during PART ONE. Choose any of these "take-off sentences" to begin each essay you write. Use the two attached blank pages for the actual essay writing.

A. It was one of the very best days of my childhood, and it involved the rock/mineral/landform called . . . .

B. The geological process I learned the most about from practical experiences in my childhood was . . . .

C. I had been warned about the . . . (geological object, landform, or process), but I didn't . . . .

D. When I think of my grandmother/grandmother/father/mother (circle one), the geological object, event, or landform I associate most with that person is the . . . . My memories revolve around . . . .

E. From my youth, I remember this geological object/process/landform was featured in the story . . . , most prominently--of all the children's books that I read--because . . . .

PART III: What connections do you NOW see between your own memories of your geological sense of place and three selected physical geology concepts that you are learning about in this geology course?

Geology concept A: ____________ Connection: . . . .

Geology concept B: ____________ Connection: . . . .

Geology concept C: ____________ Connection: . . . .

Figure 1. The Geological Sense of Place (GSP) writing template designed to probe students' past interactions, associations, and knowledge of the earth, its processes, and products.

students' prior interactions, associations, and knowledge about the earth and earth products that they have encountered in their daily lives, from childhood up to the present.

Each student brings a unique geological sense of place to the classroom. A student's GSP is defined as an affective and intellectual state, as determined by our GSP writing template. Students reflect upon the questions in the GSP, which are designed to probe the particular geological products, processes, and experiences that made an impression on them during their lives to date. Once accessed through writing, this background information is useful to both the instructor and the student as a foundation for teaching and learning about the geosciences. Having a standard writing template also allows teachers in different schools to use a common instrument for probing and comparing the geological backgrounds of their students across classes.

Our GSP writing template comprises 17 initial "memory probes," a choice of five mini-essay prompts, and three geological associations. The template questions and probes are based upon the existing science education research literature, as well as the geography education and environmental education literature, where the general concept of *sense of place* is already familiar (Matthews, 1992; Nabhan & Trimble, 1994; Schneider, 2000). Anne Whiston Spirn (1998) stated that the landscape of our youth has been "read" with our senses, and we are, therefore, "imprinted" with it. Spirn further declared "a person literate in landscape sees significance where an illiterate person notes nothing" (p. 22). Therefore, the purpose of the GSP writing template is to help students recall, notice, see significance, and reflect upon the geology--or landscape--surrounding them. Since we believe that a landscape has a biological component as well as a geological one, we have also designed and tested a parallel writing instrument, the Botanical Sense of Place (BSP) writing template for use in introductory botany courses (Wandersee, Clary, & Guzman, in press).

Administration of the Geological Sense of Place

Parts I and II of the Geological Sense of Place writing template are administered at the beginning of a course in geology and/or earth science. Students often enter the earth science or geology classroom believing they have had few or no geological interactions throughout their lives, thus making the course appear irrelevant. However, students have lived with the earth and its processes, even if they have not consciously reflected upon their relationship with their physical environment.

Within the first week of class, the teacher should assign Parts I and II. The teacher should emphasize that, unless a student requests that his or her stories and responses not be shared, students' stories and summaries may be incorporated into the class during the semester, but that students' names will not be revealed--unless a student elects to reveal his or her identity. At the end of instruction, the teacher should assign Part III to the students, either as a writing assignment within class, or as an electronic assignment outside of class. The GSP was originally designed as a printed, in-class handout. However, in a pilot test with a large introductory geology class primarily comprised of recent high school graduates, the GSP template was modified into a web-based electronic survey to be completed by students outside of class.

Pilot Studies of the GSP

Methods. We conducted pilot studies of the GSP at a large research university in Louisiana, USA, where the majority of students are commuting, local residents. Two sections of the Earth Science course (Pilot A, n = 42; Pilot B, n = 56) and one section of the introductory Geology and Man course (Pilot C, n = 148) were administered the GSP at the beginning of the semester. (For all three pilot studies, *n* here represents the number of students who successfully completed all three parts of the GSP. Data were not used from those students who completed Parts I and II of the GSP, but who subsequently dropped the course and/or were not present for Part III of the GSP.) The first author was the instructor for all three classes. The Earth Science course consists of education majors who are required to take the class for their teaching degree and certification. Since this may be the only geoscience course that students take at the university, the projects that are assigned--such as the GSP--are chosen so that they can also be included in these future teachers' own classes after graduation. The Earth Science course (maximum lecture capacity 60 persons) consists of 2 lecture hours and 2 laboratory hours per week, with the students subdivided into three sections for laboratory work (maximum capacity 20). Students are primarily exposed to physical geology content, with minor introductions to historical geology, oceanography, meteorology, and astronomy. The introductory Geology and Man course is comprised of non-science majors, who are mainly recent high school graduates. This course is taught in a large lecture format, with 3 lecture hours per week (maximum capacity 200). Since the geology content of the two courses is similar, students may not receive credit for taking both courses.

Students were instructed to access the GSP (Parts I and II) electronically on the course website. They were informed that the goal of this exercise was to help them recall their personal experiences with the earth so that they could connect these past interactions with the material that would be introduced in the course. The instructor asked students to skim the chapter titles of their textbooks (Lutgens & Tarbuck, 2002; Monroe & Wicander, 2001) in order to become familiar with the topics that would be covered during the semester. Directions for retrieving the GSP survey were posted in class and on the *Announcements* page of the course website. The instructor also demonstrated in class how to locate and answer the GSP. The students were encouraged to access the GSP within 2 days, and to answer the questions themselves, without assistance from other students. No student in any of the three pilot studies requested that his or her answers not be utilized in class. The GSP was counted as a quiz score, with full points (10/10) being awarded if the student completed the entire activity.

The instructor compiled the responses and provided the class with feedback, at the end of the week, in the form of a general summary. Throughout the semester, the instructor integrated, where appropriate, some of the interesting stories that were submitted for Part II of the GSP. In all but one case, the students very willingly identified their stories.

At the end of instruction, students received Part III of the GSP and were asked to make connections to, and associations with, the concepts plate tectonics, geological agents, and rock cycle. Students were allowed to see and reflect upon their previous responses to Parts I and II as they completed Part III. Finally, as part of anonymous, end-of-semester surveys, students were queried about their impressions of the GSP (Pilot A, n = 45; Pilot B, n = 56; Pilot C, n = 134). Data was collected using the questions "what is your opinion of the Geological Sense of Place Survey?" and "did this survey help you to connect with the Earth and/or geology in any way at the beginning of the course?" as well as spontaneous responses to "what was the best thing you liked about this course?" Because the anonymity of these surveys made it impossible to determine which responses could be attributed to students who fully participated in all three parts of the GSP, all responses from the end-of-semester surveys were used in our analysis. (In Pilot A, not all students were present during the completion of Part III of the GSP, and their data were not utilized in this study. However, since we were unable to determine the identity of the responses in the end-of-semester surveys, we did utilize all 45 student responses.)

At the last class meeting, students were asked whether their data from the GSP and surveys could be later used anonymously by the researchers in science education studies. They were told that denying permission would not affect their grade in the course, and a collection box for the permission forms was set up at the front of the classroom, with students turning in the signed forms face down. All students agreed, and signed written release forms to this effect.

Data and results. We determined through informal interactions that students in all our pilot studies had fairly similar backgrounds, indicative of the university's local student population which shared a common geological landscape and comparable earth experiences. For example, more students identified rocks as important during play time (Pilots A = 40.5%; B = 50.0%; C = 40.5%), with dirt and mud also scoring high marks (A = 40.5%; B = 41.1%; C = 27.0%). Only a minority of students had not made collections of earth materials during their youth (28.6%, 14.3%, and 22.6%, respectively), and those students who did have collections overwhelmingly reported they had rock collections (35.7%, 42.9%, and 39.7%, respectively).

Surprisingly, many students could not identify a favorite rock or landform from their youth (42.9%, 26.8%, and 25.7%, respectively). Typical of the Gulf Coast South, students who could identify a favorite landform chose local features such as hills, mounds, or levees more often (26.2%, 32.1%, and 22.3% respectively). We were able to build upon many students' previous knowledge of levees, and discuss potential downfalls of channeling a river system. Interestingly, when students were asked to name their favorite process, they chose something that they had never personally encountered! All pilot groups chose volcanoes as their number one process (40.5%, 37.5%, and 43.2% respectively). Therefore, we modified instruction to include more discussion on volcanic processes, and we incorporated several video clips.

The smoothness of crystal faces made the largest tactile impression among students in all three pilot courses (57.1%, 60.7%, and 47.3% respectively). Auditory associations, however, were difficult for many students (26.2%, 33.9%, 48.6%). Those students who could recall a sound associated with their youth answered "running water" (19.1%, 12.5%, 18.2%) or "ocean waves" (14.3%, 16.1%, 9.5%) most frequently. Students' responses for colors mimicked those that are typical of the limestone or Mississippian-aged chert gravel often used as road metal in the area: brown" (47.6%, 48.2%, 46.6%) and gray (40.4%, 60.7%, 50.7%) were chosen repeatedly. Some students could not think of a geological object or landform with which their town was associated; however, students who did respond typically stated "river," "bayou," "farmland," "salt," "swamps," or "petroleum." Because of these responses, we modified instruction to build upon the petroleum and salt industries in classroom discussions. Although atypical for the physical geology and earth science classes, students were introduced to the ancient conditions that were responsible for petroleum and salt accumulation. Students also explored the interconnectedness of these processes.

One discouraging result was that many students did not feel they had an earth mentor while growing up; 50.0%, 48.2%, and 60.8% of students responded that no one served as such a mentor. Encouragingly for us, students who did identify a mentor chose a teacher more often than any other response (19.0%, 21.4%, and 15.0%).

We were impressed by the quality of the stories that students composed for Part II of the GSP. The teacher was able to use many of these stories, as well as the responses from Part I, as portals through which class-tailored instruction could be delivered during the semester. At the end of the semester, most students constructed interesting and insightful connections in Part III of the GSP between their childhood experiences and the provided concepts of plate tectonics, the rock cycle, and geologic agents. However, some students did experience difficulties connecting plate tectonics with their past experiences (Pilot A = 31.0%; Pilot B = 35.7%; Pilot C =35.1%), which indicated to the instructor that more emphasis on plate tectonics tied to the local geology was needed in future classes.

Content analysis (Neuendorf, 2001) and database analysis of all students' GSP template responses (*n* = 235) revealed three conclusive findings. The GSP template (a) helped students to reconnect to their experiences with the earth in their youth (92% of the total responses); (b) helped students to reactivate past emotions associated with geological processes from their youth, such as those evoked by past experiences with wind and water (62% of the total responses); and (c) helped students to recognize and answer their probing earth-related questions they had posed while in their youth, and which they now recalled (80% of the total responses).

Finally, students in all three pilot studies believed that the GSP was useful to them for enhancing geoscience content learning during the semester. Only 8.9%, 18.6%, and 12.0% (in Pilots A, B, and C, respectively) believed that the GSP served no useful purpose to them in their courses. More typical responses from the anonymous, end-of-semester survey included the following:

> *Pilot A*: "Yes, it helped me get in the 'geology zone'"; "Yes, it made me realize that geology is a part of everything I see and that I had been involved in geological processes throughout my childhood"; "It was long, but it made me understand that geology has more to it than just rocks."
>
> *Pilot B*: "I really liked this activity! It did help me to connect all my concepts that we went over in class"; "I thought that it was a great idea because when I took the quiz, I felt as thought I was seeing the things that we were going to learn over the semester. It also helped by making connections with other things that we learned about"; "The . . . survey helped to get me thinking about the things I already knew about Geology, and the things I did not know so much about. Throughout the semester, I have reflected back on what I wrote about, which helped me to construct upon my prior knowledge. Now thinking back on my answers, I realize how much I have learned over the semester."
>
> *Pilot C*: "Yes, it did because thinking of all the things that I have seen in my past relates to geology: the rocks, the rivers I used to play in, the looking at the moon at night with [its] gravitational pull and everything else. THANK YOU"; "In a way I feel the survey helped me to remember some of my past experiences with the Earth and Geology. I am ashamed to admit that before I took this class I really had a narrow mind about Geology. I had no idea that so many things were connected with this subject"; "When taking the [GSP] survey, I reflected upon my past experiences with the geology of the earth. Now having completed the course, I now know how some of my favorite geologic processes occur."

Student responses in both Part III of the GSP and the anonymous end-of-semester survey indicated that the GSP not only helped students to reconnect with the earth interactions of their youth, but also provided a rough outline of the material to be presented during the course when students skimmed chapters and reflected on possible associations in their own lives. Students also reported that their horizons were expanded with the GSP, since many of them had a strict, or inappropriate, definition of geology or earth science when they entered the classroom.

Conclusions

Although the implementation of the GSP requires an investment of classroom time at the beginning of a course, we feel that the time we spent compiling and analyzing our students' GSP responses was time well spent. Student responses from Parts I and II served as a diagnostic assessment to better inform us of our students' incoming geoscience knowledge, their personal interactions with the earth and its processes, and their feelings towards some of the geological processes and products we would be discussing during the semester. We did find some similar responses among classes in Part I of the GSP (perhaps because of similar student backgrounds), but the stories that emerged from the students in Part II were unique to each class. Therefore, we think that the GSP provides a distinctive cornerstone within each class upon which the instructor can build a community of "earth scholars." Responses are typically class-specific, and the instructor's incorporation of the student responses within the course forms the basis for new knowledge integration, as well as the opportunity to make the students shareholders of data within the classroom.

Although there is some variation between pilot studies as to student perception of the value of the GSP, we are encouraged that less than 20% of students in any of the pilot studies felt that the GSP was not a useful tool in the geology classroom. Differences for Pilot C responses may be explained by the fact that the class composition consists of non-science majors, and not elementary education preservice teachers. However, the differences noted between Pilots A and B are perplexing: The class composition was similar, although Pilot A was conducted in the Fall semester and Pilot B in the Spring semester. More research is needed to determine whether this variance is replicated in future classes, or whether Pilot B represents outlier values of student perception.

From shoreline erosion processes to mountain-building events, from rock collections to birthstones, and from intriguing earthquakes to volcanic eruptions, we found that the answers supplied on Parts I and II of the GSP provided potential teaching opportunities with which to connect with our geoscience students. As Marshall McLuhan is widely acknowledged as saying: "There are no passengers on spaceship earth. We are all crew." Our students' past experiences with our planet form the base upon which their intellectual, psychomotor, and affective geoscience education must be built. Our research suggests that the GSP may provide an opportunity to effectively ascertain your own students' backgrounds, and utilize them in your geoscience classroom instruction.

Authors' Note: Additional resources may be accessed at our research group's website, http://EarthScholars.com .

References

Ausubel, D. P. (1978). *Educational psychology: A cognitive view* (2nd ed.). New York: Holt, Rinehart and Winston.

Lutgens, F. K., & Tarbuck, E. J. (2002). *Foundations of earth science* (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Matthews, M. H. (1992). *Making sense of place: Children's understanding of large-scale environments*. Savage, MD: Roman & Littlefield.

McLuhan, M. (1994). *Understanding media: The extensions of man*. Cambridge, MA: MIT Press.

Mintzes, J.J., Wandersee, J.H., & Novak, J.D.(Eds.). (1998). *Teaching science for understanding: A human constructivist view*. San Diego, CA: Academic Press.

Mintzes, J. J., Wandersee, J. H., & Novak, J. D. (Eds.). (2000). *Assessing science understanding.* San Diego, CA: Academic Press.

Monroe, J. S., & Wicander, R. (2001). *The changing earth: Exploring geology and evolution* (3rd ed.). Pacific Grove, CA: Brooks/Cole.

Nabhan, G. P., & Trimble, S. (1994). *The geography of childhood: Why children need wild places.* Boston: Beacon Press.
Neuendorf, K. A. (2001). *The content analysis guidebook.* Thousand Oaks, CA: Sage Publications.
Schneider, R. J. (Ed.). (2000). *Thoreau's sense of place: Essays in American environmental writing*. Iowa City, IA: University of Iowa Press.
Spirn, A. W. (1998). *The language of landscape.* New Haven, CT: Yale University Press.
Wandersee, J. H., Clary, R. M., & Guzman, S. M. (in press). How-to-do-it: A writing template for probing students' botanical sense of place. *The American Biology Teacher*.

Students' Alternative Conceptions

Students' alternative conceptions have been variously called misconceptions, prior conceptions, preconceptions, preinstructional beliefs, alternative frameworks, naive theories, intuitive ideas, untutored beliefs, and children's science. The tasks in this regular section of *SER* are based on the literature and may be used at the beginning of a constructivist learning segment to arouse the curiosity of students and to motivate them, while simultaneously eliciting their ideas or beliefs. They are designed to address areas about which students are likely to have an opinion, based on personal experiences and/or social interactions, prior to a specialist learning sequence, or areas that might be considered important for the development of scientific literacy.

Our Natural World

Science Beliefs Quiz (n.d.) provides a 47-item, web-based test of conceptions concerning aspects of the natural world, including plants, animals, motion, forces, electricity, light, electromagnetic radiation, energy, heat, density, particles of matter, temperature, atmospheric pressure, humidity, clouds, magma, earthquakes, rocks, day and night, phases of the moon, seasons, dissolving, boiling, chemical reactions, and condensation. Stein, Barman, and Larrabee (in press) includes information about the reliability and validity information of the instrument.

Reference

Science Beliefs Quiz. (n.d.). Retrieved July 19, 2006, from https://www2.oakland.edu/secure/sbquiz .
Stein, M., Barman, C., & Larrabee, T. (in press). What are they thinking? The development and use of an instrument that identifies common science misconceptions. *Journal of Science Teacher Education*.

Teaching Techniques

This regular section of *SER* describes thinking, cooperative learning, and other teaching techniques.

The Formula Triangle

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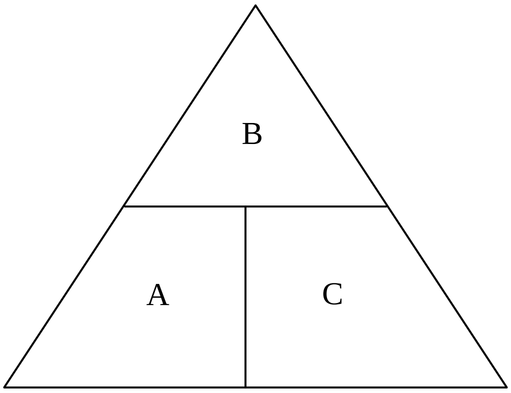
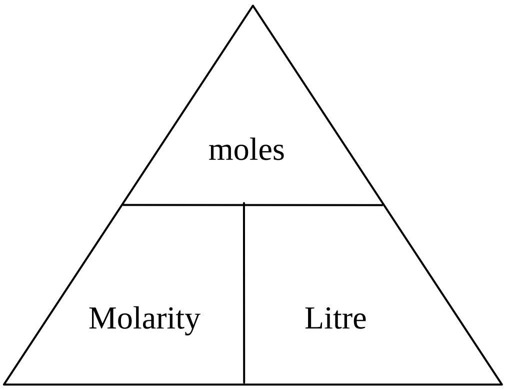
The following technique involves the use of an aid to manipulate mathematical equations, especially in Chemistry, and also represents a critical incident in my teaching career. The aid was passed to me by a student, who had presumably been given it by a teacher to assist her to derive equations for solving various formulae. I have adopted and adapted it in teaching Introductory Chemistry as a bridging course for first-year university students.

The triangles below can be used to represent any formula of the general structure A = B/C. To effectively use the triangle, a student must first learn the chemical formulae. While memorising is not popular as a teaching technique, rote is a powerful tool that some students develop and use effectively and should not be disregarded by educators. For others students, I aid learning through understanding. I draw links to how they work out everyday mathematical relationships such as the number of marbles I would have in each container if I divide 120 marbles equally between 12 containers. Most students can identify that they have divided the number of marbles by the number of containers to arrive at the conclusion that there will be 10 marbles in each. I then illustrate that there is a similar relationship for formulae such as Molarity equals moles per Litre. Students are free to choose the method they prefer to recall formulae.





Having committed a formula to memory, or being able to recall it by the "understanding method," I then show the students how to substitute the formula into the triangle. The subject of the formula (in this case, Molarity) is placed in the lower left hand corner. The two other parameters (moles and Litres) are placed so that the horizontal line inside the triangle is the equivalent of the divisor line in the mathematical expression. The vertical line separating the lower two portions of the triangle is the equivalent of the product (or times) expression when the lower two parameters are being used to calculate an unknown.

The triangle now graphically illustrates the relationship between the three parameters of the Molarity equation, and can be used to predict the formula needed to solve for the third parameter when the other two are known. For example, if the number of moles is the unknown quantity, then it will be equal to Molarity multiplied by Litres (since they are separated by the vertical line which represents the product). Similarly, Litres will equal moles divided by Molarity. Note that for formulae of the form force equals mass times acceleration, the subject of the formula needs to be placed in the upper portion in the first instance.

I often encounter students who can "parrot" a formula such as c equals n on v while lacking a full understanding of the maths and chemistry behind it. Therefore, I also encourage students to learn their formulae in words, a form I have used here, rather than as mathematical symbols. Notice that I use the term *Litres*, rather than the more generic term *volume*. I adopt this technique because Molarity, in contrast to Molality, is a specific relationship that requires the volume to be in Litres. This serves to remind students both of the need to convert any volume to Litres before performing a calculation and of the units of Molarity. I also deliberately use the upper case L here to reinforce the use of same as the unit symbol.

I have found that many students who are not mathematically adept, or secure in their mathematical ability, adopt this triangle technique with confidence and achieve considerable success. It serves to demystify the maths of chemistry and to remove the almost crippling fear of maths that some students, especially older women, bring to their university studies. Having gained some confidence, students can then move on to develop a more mature understanding of the chemical concepts and the maths. The lesson for me was that there are many ways of learning without requiring full theoretical knowledge of all subject areas. It also reinforced my belief that learning is a journey shared, and that as educators we can still learn from our students, as I did from Tennille when she first showed me this triangle.

Levels of Enquiry

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Abstract

Enquiry learning can produce impressive cognitive and affective outcomes. However, there are different types/levels of enquiry. This hierarchy can be used to assess the degree of enquiry of an activity, to suggest how the enquiry level of an activity might be adjusted, to design enquiry activities, and to better sequence enquiry activities during a course of study.

To be regarded an enquiry activity, a learning experience must require students to answer a question by analyzing information themselves (Bell, Smetana, & Binns, 2005). The question, the method(s) used to collect information, and/or even the data itself may be either student-generated or provided by the teacher, the activity need not require the hands-on manipulation of materials, and it may also be conducted at a site beyond the classroom, such as a park, nursery, pet store, or museum. For example, having students observe the Moon over a 1-month period and determine the sequence of its phases is an enquiry activity, and enquiry can also include computer simulations, demonstrations, and the use of authentic data from the World Wide Web. There are also many other types of worthwhile science activities, such as the gathering of information from a library and construction of a scale model of the solar system, that do not satisfy the criteria for enquiry (i.e., students are not analyzing data to answer a question).

The benefits associated with enquiry methods of learning are impressive. They have resulted in “significantly improved mastery of science content, content retention, enhanced critical thinking skills, laboratory skills, and attitudes when compared with traditional teaching methods” (Smith and Mao & Chang, cited in McComas, 2005, p. 25). There are also different levels of enquiry, as summarized in Table 1, which is a modification of the rubric presented by Bell et al. (2005).

The four levels of enquiry shown in Table 1 reflect an increase in the cognitive demand on students as one moves from Level 1 to 4, and are distinguished by what is supplied to students. In a Level 1 enquiry activity, students use given materials/resources, the method to be used to collect data/information, and subsequent questions that show how to analyse the information to confirm something that has already been taught. Changing this to a Level 2 enquiry can be as simple as having students carry out the activity before understanding of a concept is otherwise developed, rather than afterwards, thus requiring them to analyse information to reach their own conclusion (or answer, or solution).

Table 1
Four Levels of Enquiry

Level	Type	Question	Method	Conclusion
1	Confirmation	Yes	Yes	Yes
2	Structured enquiry	Yes	Yes[a]	No
3	Guided enquiry	Yes	No[b]	No
4	Open enquiry	No	No	No

[a]Variations include not showing students how to present their data, mixing up the steps, and providing a less-than-perfect method.
[b]Variations include providing data table headings, providing the first few steps only of the method, and providing the materials to be used.

Level 1 and 2 activities are commonly referred to as “cookbook” activities, reflecting the fact that step-by-step instructions are provided, just as in a cookbook, and are the types of activities most commonly found in textbooks. While they do have a place in the science curriculum, we also need to take advantage of the benefits associated with carrying-out higher level activities, benefits that include greater student ownership of their work and more authentic decision-making.

Remove the methodology from a Level 2 activity and one arrives at Level 3, although various variations can be used to ease this transition. These include the following:

- While students are given the method, they are not shown how to present their data.
- Mix up the steps to be used, requiring students to reorder (cut-and-paste, say) them before proceeding.
- Provide a less-than-perfect method, ideally including common misconceptions, that students first need to evaluate and revise.

The following variations, to Level 3 activities, may also be used to help the transition from Level 2 to 3:

- Provide students with data table headings only.
- Provide the first few steps only of the methodology.
- Provide the materials to be used.

Level 4 enquiry is typified by topic-related research, and science fair, projects.

The progression from Level 1 to 4 has been described as a progression from teacher-directed to student-directed, closed to open, and passive to active learning. Table 1 may be used to assess the degree of enquiry of an activity, to suggest how the enquiry level of an activity might be adjusted, and to design enquiry activities.

We need to provide for students to progress from lower- to higher-level enquiry activities as a course of study, or an academic year, progresses. “Throwing” unprepared students into a Level 4 activity may be as unproductive, in terms of both cognitive and affective outcomes, as the other extreme of restricting their experiences to Level 1 and 2 activities only.

References

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher, 72*(7), 30-33.
McComas, W. (2005). Laboratory instruction in the service of science teaching and learning. *The Science Teacher, 72*(7), 24-29.

Co-teaching as an Approach to Enhance Science Learning and Teaching in Primary Schools

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Abstract

In this article, we explore some of the experiences of student teachers, classroom teachers, science teacher educators, and children in co-teaching contexts in primary schools. The model of co-teaching adopted enabled student teachers (science specialist), classroom teachers, and university tutors to share expertise and work as equals, without mentoring, supervision, or assessment, to affect exciting learning opportunities for the children and for each other. Co-teachers planned, taught, and evaluated lessons together, and were encouraged to experiment with different learning and teaching approaches. The opportunities for all concerned were many. Students experienced an increase in their confidence to teach, and highly valued the more equal relationships they developed with the teachers and university tutors. The tutors also appreciated the improved relationships with students, the increased dialoguing with both students and classroom teachers about science, and the opportunity to reflect more on their own practice. Classroom teachers appreciated the opportunity to reflect in diaries that they kept, and greatly valued their own increased confidence in teaching investigative science. A survey of children carried out 6 months after the student placements evidenced their improved attitudes to school science, and fewer gender differences, compared with non-project children. Co-teaching constraints included the individual concerns of some students and teachers about their respective roles. The opportunities offered by co-teaching arose from processes such as the sharing of expertise, individuals working together with the same objective of enhancing children's science learning, the participation of science teacher educators, and the science workshops that took place in the university. (This paper is a summary, and update, of Murphy, Beggs, Carlisle, & Greenwood, 2004)

To read the full text of this article (10 pages), please **click here**.

Readers' Forum

Depth Versus Breadth

There is a tension between teaching for depth and teaching for breadth. Science education research points to the benefits associated with teaching for deeper, more meaningful understanding. Such an approach:

- Fosters critical thinking.
- Provides the solid foundation necessary for the building of further concepts, and for the

transfer of knowledge to new areas.

- Allows students to experience the fulfillment and satisfaction that comes from attaining a deep understanding of an area.
- Better allows misconceptions to be addressed, misconceptions that we all carry and that are not easily, and quickly, "fixed."
- Gives students practice in the process of thoroughly thinking through at least a few situations/problems.

At the same time, though, guided inquiry and teaching for conceptual change takes a lot of time, thus limiting the amount of content that can be included in a course. By going the route for deeper understanding, we might foster graduates with much expertise in a narrow range of fields but large voids in others. Further, an in-depth knowledge is not always necessary for us to function in today's society. For example, to be able to drive a car, we do not necessarily need to know all the details of what happens inside the engine. All we require is a working knowledge and training in how to drive the car. In other words, although depth can be beneficial and interesting, it is not always crucial to survival in contemporary society.

However, there is also a limit to the amount of information we can remember. People with much superficial knowledge can only remember that knowledge for a short time, and may not be able to apply it to related situations. A superficial knowledge of relationships between random facts is relatively inert and unusable knowledge that most often will be forgotten relatively rapidly. The classic example is where students cram lots of knowledge before a test, only to forget it soon afterwards. What is the point of that type of learning?

Clearly, a trade-off between depth and breadth, or quality and quantity, if you like, is required. While we seem to need an in-depth knowledge in some areas, this might be considered optional in other areas. I think the trick is to decide upon those areas where an in-depth knowledge is advantageous, and this is where a carefully-designed syllabus becomes important.

A good instructor basically needs to prioritize the material and decide which topics need to be covered in depth and which ones can be covered more superficially. Those topics that are being covered in depth need to be chosen carefully and the basic core concepts need to be identified. These core concepts should then be taught so that students obtain a sufficiently deep understanding to be able to construct further arguments from them. The ideas should be well-connected and should make sense to the degree that transfer ought to be possible.

Ideally, we want individuals to be well-rounded yet still have expert knowledge in some areas. So this means that the traditional lecture, say, still has a role in education, as it can convey large amounts of knowledge in small chunks of time.

In summary, a healthy curriculum does cover some breadth, especially if we are dealing with a survey course. However, some of the basic concepts need to be covered in substantial detail. The trick is to decide on which are the most basic concepts and to design a curriculum around that.

Esther Zirbel, Tufts University, MA, USA

? ? ? ? ? Your Questions Answered ? ? ? ? ?

This section of *SER* responds to readers' queries, so please submit your question to The Editor at editor@ScienceEducationReview.com . Have that long-standing query resolved; hopefully!

Motivation, Passion, and Love (three related questions)

a. *How do I get disaffected students motivated?*
b. *How do we make pupils passionate about Science?*
c. *I am a high school teacher teaching Mathematics and Physics. One of my greatest challenges is to make my students love Physics. They say that it has a lot of mathematics in it and they already have enough of the math in Math. How can I make them love the subject because the math in it is inevitable?*

By finding out information about their backgrounds (e.g., a student may be disturbed as a result of home influences). Disaffected students should also be referred to the School Counsellor.

Ojo Odunayo, Nigeria

A good way of catching and sustaining students' attention is to develop relevant and simple activities for the concepts, or topics, to be learned. The activities should be simple ,well-guided, investigative, and use simple materials from the learners' environment. That makes the learner see the concepts in real life, and makes what is to be learnt more meaningful. This approach enhances the development of learners' cognitive, affective, and psychomotor skills. Try, as much as possible, to make the lesson activity-based and student-centered.

Mohammed Kabir Falalu

Students get motivated by the following:

- When they are convinced they are going to learn something relevant and worthwhile, and will be able to solve some problem. So, build the relevance of what you are teaching, using examples from day-to-day life and the world of work.
- Generate satisfaction by providing successful experiences.
- Provide reinforcement.
- Be objective and follow rules.
- Be a role model.
- Involve them in goal-setting.
- Cater to their individual needs.

Paramjit Tulsi, India

We find that when the teacher is passionate about the content, this tends to be passed on to the students. Making contexts relevant to students, and providing a range of interesting, interactive ways of learning, are also ways to get disaffected students engaged.

Lindsey Conner, Christchurch College of Education, New Zealand

If you want to make your students passionate about science, you have to exhibit the same in your behavior. If the teacher is passionate about science, students will develop an interest in it and definitely be active in learning and self-learning.

Anonymous, India

By introducing them to more practical classes, in contrast with theoretical ones.

Ojo Odunayo, Nigeria

Passion for science--a tough nut to crack. Passionate teachers appear to be the only hope for those who don't already possess it. But, wait, young children are all passionate scientists, although undisciplined. Maybe--just maybe--if youngsters are not turned off science, their passion may remain. Is it possible that exploration and discovery can keep kids excited when not bogged down with abstruse vocabulary, intransigent mathematics, and regurgitative testing? Don't know, but would like to. Then, the trick of implementing such a plan remains. Sigh!

Harry Keller, ParaComp, CA, USA *http://smartscience.net*

I am a Year 7 primary school teacher in Queensland, Australia. At the beginning of last year, I took over the running of our Science Club. The students who attended the information session were not all that enthusiastic about the direction of the club during previous years, so we changed the format. One week we would have science equipment available that they could interact with and “play” with, and the following week we would follow the CSIRO Crest Award program (http://www.csiro.au/crest/). Comprising three levels, this program combines science and technology with investigations into various topics such as Rocks and Minerals, Pets, and Food, with certificates being awarded upon completion of each level.

There were only 10 science club members to begin with, but they loved using microscopes, creating electrical circuits, and designing and building moving structures with minimal instruction. I found this a great way to foster interest in many areas of science. In the more formal CSIRO program, we focused on the topic of Rocks and Minerals. The students learnt about minerals and how to recognise and classify them, and made their own collection of minerals which they labelled and described. We had a geologist as a guest speaker and he inspired them.

We entered several competitions, including the Australian Chemical Institute Crystal Growing Competition and a space competition available via the Internet. The students loved the hands-on experience of science. As the year progressed, some students brought friends along, we gained some older students, and our club expanded.

What drew the students was the constructive nature of the learning. This year, I have another teacher to help me, and we have 30 students in the club and a waiting list of 20 more. My answer, then, to the question of how to make students passionate about science is to provide the guidance and the resources, but let the students construct their own learning. Engage them with interesting problems and let them solve them, and present them with seemingly impossible, or amazing, experiments and let them explain them. Allow the students to lead the learning and you will capture their imagination and foster a love of science that will last a lifetime.

Karen McGarvey, St Rita's Primary School, Victoria Point, Queensland, Australia

Using a Killer Straw: Is it possible to stab a raw potato with a plastic straw?
A Moving Experience: Without touching the penny left on the table, can you place it in a small glass of water?
Fire in the Hole: What would happen if a small flame was held at the mouth of a horizontally placed plastic bottle filled with alcohol vapour?

Capturing the attention of learners triggers the desire to see and want to know more. Visual challenges keep students alert and in tuned to science phenomena (Bagrowicz, 2003). Whether you are taking about compressed air pressure, Bernoulli's principle, or Newton's third law, the lesson openers above bring about "oohhs" and "aahhs." To instill science passion in students is to free them into self-directed inquiry science of their choice.

Curious science that triggers passion. To be passionate about science is to be drawn into the subject with curiosity, wonderment, and enthusiasm (Clark, 2004). "Eyes-on and minds-on" activities challenge misconceptions and arouse affective learning. According to Bloom's Taxonomy, affective learning incorporates auditory, visual, emotional, and even motivational learning (Clark, 2001). It is the genuine student enthrallment that educators want to capitalize and continue to inspire.

Developing passion by doing authentic science. Excitingly, curious science induces students to open-ended investigations. Encouraging authentic investigations that are driven by the students themselves often satisfies their knowledge-hunger. Why does the daphnia's (water flea) heart contract rapidly with increased amount of alcohol? Would one bacteria's toxin affect another bacteria's growth?

Setting up an exemplary investigative design outline, students can scaffold with their own exploratory approaches. Being student-centered, the teacher acts as a mentor for conceptual reconstruction (Association for Supervision and Curriculum Development, 2006). Encouraging surveys and communicating with teachers, researchers, other students, and the community brings new perspectives into classroom learning. Feeling like a scientist, students' attitudes and confidence in science are cultured. Providing a chance to immerse in a student's own topic cultivates desire, love, and passion for science.

Extrinsic motivation fuels passion. Empower students to take charge of their learning. Promoting student's own ideas in investigation builds a desire for inquiry science skills. Projects developed with extrinsic motivation by verbal praises, at times even with bonus marks, create a desire to stay alert and open to new ideas. Everyone feels good about being complemented about their accomplishments. Extrinsic motivation is the external recognition that students desire of their work. Active involvement in learning, with positive reinforcement, develops into intrinsic motivation, where students continue to be passionate about science.

Activities that inspire passion. Develop the classroom environment with inspiring activities. Set aside a Wall of Fame, where student's photos and their work are permanently mounted. Seek volunteers and helpers to participate in all the class demos and activities. Encourage the use of technological talents students may have, such as PowerPoint presentations, use of animations, and DVD imaging, by incorporating these into their presentations. Permit students to deviate from the normal routine of standing in front of the class to present. Encourage them to sing (rap) their presentations, dramatize, and/or complement with video imaging. Bring students out of class to observe nature in the field or woods. Observe trees and leaves--classification in the field, not in the classroom. Check the ravines for chemical changes in the water run-offs, using macroinvertebrates as pollution indicators (Ayyavoo, Duchen, Savage, & Shrummet, 2004). Pollution on trees can be studied by identifying lichens. Calculate the speed of cars as they pass on the road by measuring time and distance.

As a teacher, continue to support activities that require after-school supervision. For example, high school science clubs could perform actual chemical demonstrations in elementary schools. Train secondary learners to mentor primary students to conduct environmentally-related activities. Motivate senior students to investigate macroinvertebrate population to predict stream health. Data from student research provide valuable information for the community and local research organizations.

Bring science beyond their laboratory experience. Extend their passion for science by linking the concepts to their personal experience. The world is their laboratory. Fuel their enthusiasm for learning science by doing science. Passionate teachers are contagious (Bagrowicz, 2003). Both students and colleagues may be "turned on to science." Teachers, who are passionate, tend to pass that extraordinary spirit to their students.

References

Association for Supervision and Curriculum Development. (2006). *The definition of constructivism*. Retrieved January 15, 2006, from http://www.ascd.org/portal/site/ascd/menuitem.d36b986168f3f8cddeb3ffdb62108a0c/ .

Ayyavoo, G., Duchen, R., Savage, M., & Shrummet, H. (2004). Seasonal fluctuations of macroinvertebrates in the Don River. *Interactions: Ontario Journal of Environmental Education*, *16*(4), 24-28.

Bagrowicz, J. (2003, March). Ignorance kills the cat: An interview with an award-winning chemistry teacher. *Canadian Chemical News*, pp. 28-29. (Also available at http://www.accn.ca/accn2003/March2003/Pages17-29.pdf)

Clark, D. (2001). *Learning domains or Bloom's taxonomy*. Retrieved January 15, 2006, from http://www.nwlink.com/~donclark/hrd/bloom.html .

Clark, R. (2004). *The excellent 11*. New York: Hyperion.

Gabriel Ayyavoo, Francis Libermann Catholic High School, Toronto, Ontario, Canada

If you want to raise students' interest in physics, begin every new subject with a demonstration, either computer-based or not, and let them make as many laboratory experiments as possible, since you cannot avoid Mathematics at last.

Ricardo Trumper, Haifa University at Oranim, Tivon, Israel

Try introducing your lessons with Computer Aided Instruction, which will help arouse student interest. You may install Microsoft Encarta Premium, which contains many interactive clips for most science subjects, on your system.

Ojo Odunayo, Nigeria

I think that most mathematics classes (as usually taught) spoil students for science. If they learned the mathematics as required to figure out what the science means, or to understand experiments they were investigating, then things would be different.

So, as you can see, it's a non-answer. We must change the entire curriculum, not just apply plasters onto science. Mathematics should be an integral portion of science until students reach the point at which they can understand and deal with true mathematical rigor. Only then should mathematics become a separate discipline.

People are fooled by the conflation of arithmetic and mathematics. Once students learn (and some never do) the basics of addition, subtraction, multiplication, etc., they're then ready for applications. Algebra as a separate subject blows too many students away--unless taught by a truly gifted teacher. You can sneak mathematics into science and teach by guerilla methods--it's there, but not taught by itself.

Harry Keller, ParaComp, CA, USA http://smartscience.net

These are some of the tricks I use to teach Physics. First, I try to concentrate on concepts (zero equations, at least at first). I engage my students in a good discussion with questions such as: "Is the Moon falling or not?" (Yes, it's falling, but it never touches the Earth due to high linear velocity, and so on. I use the example of an increasingly powerful horizontal gun, etc.).

I try to make amusing demonstrations, rather than boring ones. For example, I often use a piece of string and a weight that seem useful from mechanics to waves--and end up behaving like a clown.

I tell good stories, such as Tycho Brahe losing his nose in a duel, and then having a golden nose. Sometimes I include Tycho's death for failing to urinate on time. They love it. Finally, I try to engage them slowly into dimensions, and then equations.

I try to have amusing problems (e.g., I use a calculation of the speed you'll crash into the ground if you jump from a particular height, facilitate a discussion on whether it's a good idea to crash at 40 miles per hour--and end like a broken egg. A little morbid, I know . . .).

I use some good jokes and exaggerations. The idea is to be totally irreverent about the subject. I laugh at my mistakes, and challenge them to correct me. I use examples from subjects they usually like, such as cars, planes, rockets, boyfriends, and girlfriends. I hope it works for you.

Juan Manuel Lleras, Museo de los Niños (Children's Museum), Bogotá, Colombia

Further Useful Resources

SEAR (Science Education Assessment Resources) (http://cms.curriculum.edu.au/sear/) A resource bank of assessment tasks suitable for use across the compulsory years of schooling and indexed according to six levels of scientific literacy.

IMMEX (Interactive Multimedia Exercises) (http://www.immex.ucla.edu) Free, online, interactive problem-solving simulations, involving authentic scenarios, for all levels of education. Multiple cases (clones) are provided for each problem, allowing students to test their conceptual understanding of a topic by working each problem multiple times. While immediate feedback is provided to the student, feedback is also provided for a whole class.

NWABR.ORG (Northwest Association for Biomedical Research) (http://www.nwabr.org/education/index.html) Plans for over 30 classroom lessons related to ethics and science, plus other related materials.

Science & Nature: Prehistoric Life (http://www.bbc.co.uk/sn/prehistoric_life) Resources, including games and quizzes, to help teach about evolution, extinction, and prehistoric life.

Marian Koshland Science Museum of the National Academy of Sciences (http://www.koshland-science-museum.org) A diverse array of interactive activities for middle and high school students.

Kids Can Press (http://www.kidscanpress.com) New children's book titles include *Why do Dogs Have Wet Noses?*, *Who Likes the Wind?*, *Squirt!*, *Discover the Stars*, *Discover Space Rocks*, and *Skunks*. Visit the Web site to find a full book list, sample pages from books, educator resources, author and illustrator biographies, and downloadable activities.

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