BACKGROUND INFORMATION FOR PRESENTERS

Why Reflecting on the Nature and Practices of Science Is Important. We're constantly presented with scientific and non-scientific information. We vote on many issues that are informed by scientific ideas. To understand the meaning and value of scientific information, it's important to understand how scientists gathers information, and come up with explanations. (The National Science Education Standards, National Research Council, 1996). According to *A Framework for K-12 Science Education (NRC, 2012)*:

"...when students carry out an investigation, develop models, articulate questions, or engage in arguments, they should have opportunities to think about what they have done and why. They should be given opportunities to compare their own approaches to those of other students or professional scientists. Through this kind of reflection they can come to understand the importance of each practice and develop a nuanced appreciation of the nature of science."

The *Next Generation Science Standards* call on science educators to move beyond having students just learning about science. They encourage teachers to guide students to inquire about the natural world, using the methods that scientists use themselves. Being able to critically inquire about the world prepares students not only for future science studies, but also to increase their ability to make informed decisions based on evidence and to acquire new knowledge. Teaching students about the nature of science also increases their interest in science (Lederman, 1999; Meyling, 1997; Tobias, 1990).

Understanding the nature of science is important particularly for anyone who teaches science. Science teachers who do not have a background in the nature of science tend to teach vocabulary and facts, neglecting more important aspects of science, such as how scientific knowledge is generated, and how knowledge claims are cautiously evaluated. Children and adults, including science teachers, hold both accurate and inaccurate ideas about what science is. Many science teachers have not had the opportunity to reflect on the nature of science. (Gess-Newsome & Lederman, Examining Pedagogical Content Knowledge.) DATE??

What is Science? Science teachers and scientists agree that science is a valuable way of knowing. Science is a set of practices as well as the historical accumulation of knowledge. The scientific enterprise is a union of science, mathematics, and technology, as well as logic and imagination. Science assumes that the world around us is understandable, and that the basic rules that exist in one part of the universe can be applied to others. Like many other systems of thought, science is a quest for truth, yet in science, nothing is ever completely proven. Science is open to new evidence and ideas, and actively seeks them out. Science helps us understand the world around us, and in a practical sense, it has great predictive value. See the handouts, "Science is..." on page 36 and "Science is not..." on page 37

Science, Evidence, and Explanations. At its core, science is about evidence. Science is an attempt to understand the natural world (i.e., everything that is not supernatural). Scientists make observations and collect data in as objective a manner as possible. Scientific explanations are based on all the available evidence. Explanations that are based on selective evidence, and ignore or exclude evidence that doesn't support the explanation, are "pseudoscience."

Science is Self-correcting and Durable. In science, evidence, investigations, and explanations are discussed and reviewed by peers. Investigations are repeated, and if the results are not comparable, the results are questioned. More evidence is always sought out, and if an accepted explanation doesn't match new evidence, it is revised or replaced. In this sense, science is self-correcting. Scientific knowledge and explanations are accepted within the scientific community based on consistency and strength of argument. Scientific knowledge evolves over time as the community of scientists inquires in different and deeper ways to uncover new evidence that changes and/or refines the accepted understanding of the natural world. Despite this embrace of change, and acknowledgment that science cannot attain "absolute truths," most scientific knowledge is durable. New evidence sometimes leads to refinement of current ideas, rather than complete rejection.

The Myth of the Scientific Method. A common misconception about science is that there is a single scientific method—a series of sequential steps scientists follow to arrive at a conclusion. This myth has been spread widely by science educators, but is a source of frustration for scientists who are aware of its limitations in describing what they do. The source of the myth is described in the following quote:

"In the 1940s a man named Keeslar wished to describe the different elements of scientists' work. He began by generating a list of all the things he imagined scientists did: carefully making measurements, maintaining detailed written records, defining a research problem. This list was then turned into a questionnaire and given to many professional scientists for their response. Keeslar took the questionnaires as they were returned to him and put the items receiving the highest rankings into an order that seemed "logical" and published these findings in an education journal (McComas, 2000). Even though he was reporting on scientists' uses of different thinking strategies without trying to describe a nice neat sequence, that's unfortunately how his work has been used. A science textbook writer saw Keeslar's list and turned it into The Scientific Method—touting it as THE way science proceeds. Indeed, there is really no such thing as a singular scientific method and this list doesn't accurately portray the work of most scientists (which makes us wonder what teachers are trying to portray by drilling students on the scientific method)." [From Settlage, J. and Southerland, S.A. (2007). Teaching Science to Every Child: Using Culture as a Starting Point. New York, Routledge.]

In actuality, there are many different paths scientists follow to answer questions. The methods used by an astronomer studying a distant star are quite different from those used by a field biologist studying an insect. The scientific enterprise also involves human imagination and creativity. The NRC *Framework* states the benefits of recognizing the breadth and variety of methods used in science:

"For example, the notion that there is a single scientific method of observation, hypothesis, deduction, and conclusion—a myth perpetuated to this day by many textbooks—is fundamentally wrong. Scientists do use deductive reasoning, but they also search for patterns, classify different objects, make generalizations from repeated observations, and engage in a process of making inferences as to what might be the best explanation. Thus the picture of scientific reasoning is richer, more complex, and more diverse than the image of a linear and unitary scientific method would suggest."

Scientific investigations are peer-reviewed, reflecting the fact that the real "scientific method" is bigger than the work of an individual scientist or even the combined work of a particular group of scientists. Scientific discourse and communication are instrumental. Scientific papers are published in journals reviewed by other scientists. Shared critique and discussion of methods and ideas are ongoing within the scientific community.

To clarify the overlapping and iterative aspects of doing science, the Framework for K-12 Science Education uses Figure 3-1, "The Three Spheres of Activity for Scientists and Engineers" to describe scientific activities. The first sphere is observing and investigating the world, and the second is evaluating what is found out through investigation. The third sphere is using what is learned through investigating and evaluating to make sense of data and develop theories, models, explanations and solutions. The arrows from the center sphere show that the discourse-based activities of arguing, critiquing and analyzing are taking

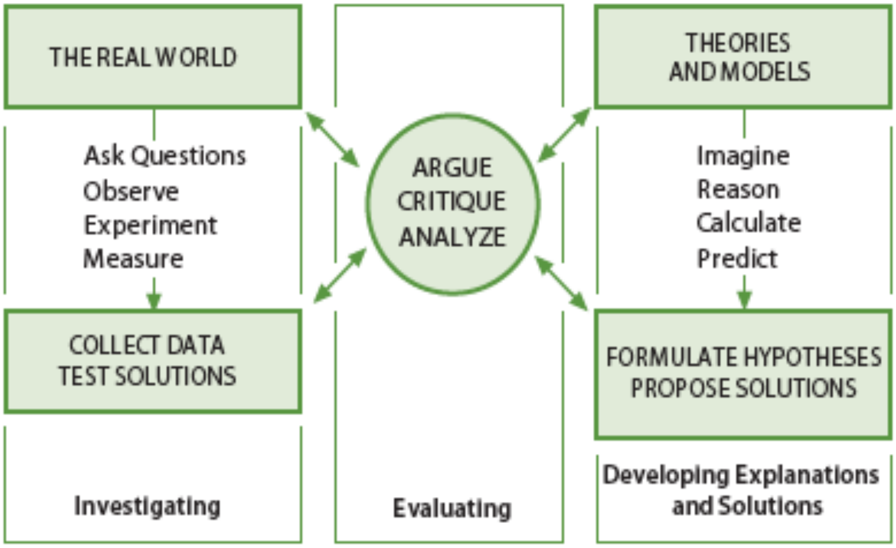

FIGURE 3-1 The three spheres of activity for scientists and engineers.

place all along the way, as we investigate and attempt to explain the natural world. This diagram represents science as an iterative, fluid, self-adjusting endeavor, and NOT as a linear, step-by-step process. The activities of scientists are also represented on the"What Scientists Do" chart, but organized into categories that are related to field activities commonly experienced by students in outdoor science programs.

Science and Human Nature. Although a goal in science is to be objective, in reality, the evidence that is collected is interpreted, and influenced by current scientific perspectives and by the society, culture, and even the scientists' sometimes-unavoidable subjectivity. There are patterns and habits of human thinking that present challenges in scientific endeavors, but the methods of science have been designed and re-designed to try to account for these.

Scientific Facts, Laws, and Theories. These three terms describe important aspects of the nature of science, but are often misunderstood. Each has a meaning in common usage that is different from its meaning in the scientific community, and this can cause confusion. These are the definitions as written by the National Academy of Sciences.

Fact: In science, an observation that has been repeatedly confirmed and for all practical purposes is accepted as "true." Truth in science, however, is never final, and what is accepted as a fact today can be modified or even discarded in the future.

Law: A descriptive generalization about how some aspect of the natural world behaves under stated circumstances.

Theory: A well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses.

The contention that evolution should be taught as a "theory, not as a fact" confuses the common use of these words with the scientific use. In science, theories do not turn into facts through the accumulation of evidence. Rather, theories are the end points of science. They are understandings that develop from extensive observation, experimentation, and creative reflection. They incorporate a large body of scientific facts, laws, tested hypotheses, and logical inferences. In this sense, evolution is one of the strongest and most useful scientific theories we have. [Adapted from Teaching About Evolution and the Nature of Science (1998). National Academy of Sciences, Washington, D.C.: National Academy Press.]

Scientific Hypotheses According to the Framework. "A scientific hypothesis is neither a scientific theory nor a guess; it is a plausible explanation for an observed phenomenon that can predict what will happen in a given situation. A hypothesis is made based on existing theoretical understanding relevant to the situation and often also on a specific model for the system in question."

Science and Language. Although "scientific proof" is a an expression that's often used by the general public, use of the words, "prove" or "proof" in science is generally inappropriate, because they imply that scientific ideas can be absolute truths. There are also many other words used in science that also are used in everyday language. Misunderstandings often arise when these words have very specific meanings in science, but more vague or sometimes quite different meanings in everyday language. The word "theory" in common language is often used to describe an idea that is a guess or an explanation that has not been well tested. In science, as noted above, it is actually used to describe big ideas that are supported by a large body of scientific facts, laws, tested hypotheses, and logical inferences. See Vocabulary Mix-ups, in the Misconceptions About Science section of University of California Museum of Paleontology (UCMP) Understanding Science website: http://undsci.berkeley.edu/teaching/misconceptions.php

Note: Before presenting this session, even if the leaders are experienced science teachers and/or scientists, we strongly recommend they read the handouts and teaching notes on Science Is… and Science is not… (see "Science is..." on page 36) It's also recommended to spend some time exploring the UCMP *Understanding Science* website: http://undsci.berkeley.edu/

Science Misconceptions and FAQs

Which is most important? Learning science facts and names or learning scientific ways of thinking and doing?

From the NRC Framework:

"Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements—knowledge and practice—are essential. In science, knowledge, based on evidence from many investigations, is integrated into highly developed and well-tested theories that can explain bodies of data and predict outcomes of further investigations. Although the practices used to develop scientific theories (as well as the form that those theories take) differ from one domain of science to another, all sciences share certain common features at the core of their inquiry-based and problem-solving approaches.

"Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. Any education that focuses predominantly on the detailed products of scientific labor—the facts of science—without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science and marginalizes the importance of engineering."

Science classes sometimes revolve around dense textbooks, but these collections of facts provide only part of the picture. Science is a body of knowledge that one can learn about in textbooks, but it is also a dynamic process for discovering how the world works and building knowledge into powerful and coherent frameworks.

Misconception: "It's important to teach the Scientific Method (question, hypothesis, experiment, results, conclusion) in residential outdoor science programs."

"The Scientific Method" is often taught in science courses as a simple way to understand the basics of scientific testing. In fact, the Scientific Method represents how scientists usually write up the results of their studies (and how a few investigations are actually conducted), but it is a gross oversimplification of how scientists build knowledge. Science is exciting, complex, and unpredictable. It involves many different people, engaged in many different activities, in many different orders.

"What appears to [the working scientist] as the essence of the situation is that he (sic) is not consciously following any prescribed course of action, but feels complete freedom to utilize any method or device whatever which in the particular situation before him (sic) seems likely to yield the correct answer… In short, science is what scientists do, and there are as many scientific methods as there are individual scientists." (Percy W. Bridgman —"On Scientific Method") DATE

Misconception: "Scientists are unbiased."

Scientists do strive to be unbiased as they consider different scientific ideas, but scientists are people too. They have different personal beliefs and goals — and may favor different hypotheses for different reasons. Individual scientists may not be completely objective, but science can overcome this hurdle through the action of the scientific community, which scrutinizes scientific work and helps balance biases.

In science, evidence, investigations, and explanations are discussed and reviewed by peers. Investigations are repeated, and if the results are not comparable, the results are questioned. More evidence is always sought, and if an accepted explanation doesn't match new evidence, it is revised or replaced. In this sense, science is self-correcting. Scientific knowledge and explanations are accepted within the scientific community based on consistency and strength of argument. Scientific knowledge evolves over time as the community of scientists inquires in different and deeper ways to uncover new evidence that changes and/or refines the accepted understanding of the natural world. Despite this embrace of change, and acknowledgment that science cannot attain "absolute truths," most scientific knowledge is durable. New evidence sometimes leads to refinement of current ideas, rather than complete rejection.

Misconception: "Science is analytical." OR "Science is creative."

Perhaps because the Scientific Method presents a linear representation of the process of science, many people think that doing science involves closely following a series of steps, with no room for creativity and inspiration. In fact, many scientists recognize that creative thinking is one of the most important skills they have — whether that creativity is used to come up with an alternative hypothesis, to devise a new way of testing an idea, or to look at old data in a new light. Creativity is critical to science.

Scientific analysis often involves jumping back and forth among different modes of reasoning and creative thinking! What's important about scientific reasoning is not what all the different modes of reasoning are called, but the fact that the process relies on careful, logical consideration of how evidence supports or does not support an idea, of how different scientific ideas are related to one another, and of what sorts of things we can expect to observe if a particular idea is true.

The scientific community values individuals who think of creative explanations that turn out to be correct — but it also values scientists who are able to think of creative ways to test a new idea (even if the test ends up contradicting the idea) and who spot the fatal flaw in a particular argument or test. Creativity is involved in all aspects of science whether it is developing new questions, techniques, explanations or hypotheses. Anyone can have an idea in science, it is non-discriminating and it is not sentimental.

Misconception: "Science facts and explanations are the truth." vs. "Science facts and explanations are no more trustworthy than other sources."

The scientific enterprise is a union of science, mathematics, and technology, as well as logic and imagination. Science assumes that the world around us is understandable, and that the basic rules that exist in one part of the universe can be applied to others. Like many other systems of thought, science is a quest for truth, yet scientists recognize that they can never completely arrive at the truth.

Scientific knowledge is only our current best approximation based on all available evidence. In science, no explanations are considered "proven." All explanations are open to replacement or refinement, if warranted by new evidence. Yet most scientific knowledge is durable, growing stronger and more refined over time.

When newspapers make statements like, "most scientists agree that human activity is the culprit behind global warming," it's easy to imagine that scientists hold an annual caucus and vote for their favorite hypotheses. Of course, that's not how it works. Scientific ideas are judged not by their popularity, but on the strength of the evidence supporting or contradicting them. A hypothesis or theory comes to be accepted (usually over the course of several years — or decades!) once it has garnered many lines of supporting evidence and has stood up to the scrutiny of the scientific community. A hypothesis accepted by "most scientists," may not be "liked" or have positive repercussions, but it is one that science has judged likely to be accurate based on the evidence.

Misconception: Scientific ideas are absolute and unchanging.

"Because science textbooks change very little from year to year, it's easy to imagine that scientific ideas don't change. It's true that some scientific ideas are so well established and supported by so many lines of evidence, they are unlikely to be completely overturned. However, even these established ideas are subject to modification based on new evidence and perspectives." Understanding Science, University of California Museum of Paleontology: undsci.berkeley.edu. This openness to new observations and interpretations is what makes science a fascinating topic of curiosity for children and adults!

Since much of what is taught in introductory science courses is knowledge that was constructed in the 19th and 20th centuries, it's easy to think that science is finished — that we've already discovered most of what there is to know about the natural world. This is far from accurate. Science is ongoing, and there is much more to learn about the world. In science, making a key discovery often leads to many new questions ripe for investigation. Scientists are constantly elaborating, refining, and revising established scientific ideas based on new evidence and perspectives.

Misconception: "Science kills wonder & curiosity during outdoor education experiences."

When science is taught only as information that is delivered to learners, it may be true that students can become disinterested. When science is taught only as a linear scientific method to follow, it may also be a turn-off to certain students.. But when science is taught as discovering mysteries everywhere in nature, and trying to figure them out, it's far from boring or dry. When field science is experienced as making careful observations, asking questions, constructing explanations from evidence, and discussing those ideas, it can ignite wonder and curiosity, and can be a powerful vehicle for engaging students directly with nature.

A Quote from the NRC Framework:

"A rich science education has the potential to capture students' sense of wonder about the world and to spark their desire to continue learning about science throughout their lives. Research suggests that personal interest, experience, and enthusiasm—critical to children's learning of science at school or other settings—may also be linked to later educational and career choices. Thus, in order for students to develop a sustained attraction to science and for them to appreciate the many ways in which it is pertinent to their daily lives, classroom learning experiences in science need to connect with their own interests and experiences.

"The actual doing of science or engineering can also pique students' curiosity, capture their interest, and motivate their continued study; the insights thus gained help them recognize that the work of scientists and engineers is a creative endeavor—one that has deeply affected the world they live in."