Session 2: The Nature and Practices of Science

Overview
Science is a way of knowing and attempting to explain and understand the world around us. It's seen as a social enterprise that advances scientific understanding over time. Science is both a *body of knowledge* that represents current understanding of natural systems and a *process* through which that body of knowledge has been established and is being continually extended, refined, and revised (National Research Council, 2007). Although this description of science sounds straightforward, questions about the essential elements of what constitutes the nature of science abound in the literature. Just what is encompassed by the nature and practice of science? Is there agreement as to what constitutes the "ideas about science" and what should be taught? Is science objective reality or socially constructed? What is the relationship between culture and science? How does understanding and reflecting on the nature of science influence our practice? How can we as scientists and educators help others, including students and the public, to have a better understanding of the nature of science, and why might that be important? These questions are addressed below through a brief review of the literature about these topics.

Background Information for the Presenter
What is the Nature of Science?

Almost everyone in science education agrees that more attention should be paid to teaching about the nature of science explicitly and that doing so should be an integral and important element of learning science (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). However, just what constitutes the nature of science is often hotly debated among philosophers and historians of science and science educators (Lederman, 1999; Osborne et al., 2003; Schwartz & Lederman, 2008). It turns out that the very nature of science is a controversial topic with considerable disagreement about which ''ideas-about-science'' are essential elements that should be included when teaching science. The field of history and philosophy of science has been unable to agree on a general picture of how science works (Laudan et al., 1986; Ziman, 2000). Some of the main areas of contention and question include: (1) is science objective reality with a goal of seeking "the truth," or (2) is it socially constructed with social, cultural, and gender influences shaping what is accepted as science (Collins & Pinch, 1993; Gregory, 1988; Gross, 1996; Haraway, 1989; Harding, 1991; Latour & Woolgar, 1986; Longino, 1990; Montgomery, 1996).

In spite of the controversies about what constitutes the nature of science, Lederman (1999) and Osborne et al. (2003) suggest that many scientists, science educators, historians and sociologists of science, and philosophers, in the U.S. and internationally—as well as important reform documents such as *Science for All Americans* (American Association for the Advancement of Science, 1989), *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993), and the *National Science Education Standards* (National Research Council, 1996)—actually have come to some consensus and contain many of the same elements regarding the nature of science and what students and the public should understand. Scientific knowledge: (a) is tentative (subject to change); (b) is empirically based (based on and/or derived from observations of the natural world); (c) is subjective (theory laden); (d) necessarily involves imagination and creativity (involves the invention of explanations); (e) involves a combination of observations and inferences; and (f) is socially and culturally embedded.

The tentative nature of science stems in part from its reliance on empirical evidence. Evidence is collected, interpreted, and influenced by current scientific perspectives and understandings, and by the society, culture, and even the scientists' personal subjectivity. However, 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 or refines the accepted understanding of the natural world. In this sense, science is self-correcting. School science has been observed by educational researchers as attempting, but frequently failing, to transmit an accurate view of science (Cobern, 1991; Duschl, 1988) in that it often gives students a stereotypical image of science as authoritarian and/or as the absolute "truth."

Cultural Perspectives on the Nature of Science

Culture can be defined as the norms, values, beliefs, expectations, and conventional actions of a group. Within each culture there are also subgroups identified by race, language, and ethnicity, and also gender, social class, occupation, religion, etc. (Phelan, Davidson, & Cao, 1991). Using this definition, science itself can be considered a subculture of Western or Euro-American culture (Baker & Taylor, 1995; Ogawa, 1986; Pomeroy, 1994), since scientists share a well-defined system of meaning and symbols with which they interact socially. It can be difficult for students and the public to cross the border from their life-world culture into the culture of science, with its specialized tools, language, and a social network quite "foreign" to most (Driver, Asoko, Leach, Mortimer, & Scott, 1994, p. 11).

If the subculture of science is at odds with a student's life-world culture, science instruction tends to disrupt the student's worldview by trying to force that student to abandon or marginalize his or her life-world concepts and reconstruct in their place new (scientific) ways of conceptualizing (Aikenhead, 1996; Hawkins & Pea, 1987). One of the ways to help with this "border crossing" is to embrace a cross-cultural perspective on science education and realize that traditional knowledge, personal beliefs, and modern Western science may all co-exist within a learner. Looking at these "other ways of knowing" about the world, and having students share ideas and bring their culture into the subculture of science, can help ease the border crossing. Learning about science does not have to replace their culture—these subcultures can exist side-by-side. Science can benefit from the diversity of viewpoints and problem-solving approaches from a diverse community of scientists.

However, it's important to note that some science philosophers are opposed to treating science as a cultural enterprise. They argue that such a viewpoint tends to undermine "the universality of science"—that science is the same everywhere, that science uncovers knowledge or solves problems irrespective of the culture, race, or gender of the individual scientist involved (Doran, Lawrenz, & Helgeson, 1994).

Why Teach the Nature of Science?

Most students leave school with naïve or limited conceptions of science (Driver, Leach, Millar, & Scott, 1996) and yet it is precisely an understanding of the nature of science that many have argued is essential for the education of the future citizen (Fuller, 1997; Irwin, 1995; Jenkins, 1997; Millar, 1996; Ziman, 2000). In a society where science is increasingly important in our daily lives, some understanding of its underlying methods and practices is essential if the public is going to be able to engage with the myriad issues confronting society today and have the means to critically evaluate the claims of science and scientists (Osborne, et al., 2003). Determining which ideas-about-science might be important for the future citizen to know takes on a new importance and relevance. Teaching the nature of science and its processes should be at the core rather than the margins of science education. Not only will this help young people make sense of the science in their daily lives, it can also lay the groundwork for a more sophisticated understanding later in life.

Understanding the nature and practices of science is important for students and the general public, and for anyone who teaches about science. Science can be introduced to even the youngest students in ways that engage them in the firsthand collection and evaluation of evidence. When an educator explicitly teaches the nature and practices of science to her students, they are more likely to understand and appreciate scientific enterprise and the importance of evidence in making explanations. Participating in the scientific process and assuming the role of a scientist can be a powerful way for students to come to understand science as a way of knowing and to see themselves as potential scientists.

Note to Facilitator: *Before presenting this session, even if the facilitator is an experienced science educator and/or scientist, it's strongly recommended that the facilitator spend some time exploring the UCMP (University of California Museum of Paleontology) Understanding Science website: http://undsci.berkeley.edu*

In this session, participants gain insight into the nature and practices of science in the best way possible—by ***doing*** and ***reflecting*** on science. After an introductory activity on "What is science?" participants investigate and experiment with an object, to try to determine how it works. This "Mystery Tube" experience provides a sense of the actual practices involved in doing science and helps communicate the nature of science. Participants also take a critical look at what is and is not an accurate view of science. These misinterpretations, conscious and unconscious, are widespread, and examining them can help hone our own understanding of what science is and is not. Through attempting to define science, we gain understanding of its strengths and limitations. If you're going to be teaching about science, it's extremely worthwhile to spend time thinking about the nature of science and how it can be communicated to students.

Session Objectives

— Discuss "what is science?" and the nature of science.
— Discuss that evidence is collected, interpreted, and influenced by current scientific perspectives and understandings and by the society, culture, and even the scientists' personal subjectivity.
— Discuss the value and effect of a deeper understanding of, and reflection on, the nature and practices of science.

Session Activities at a Glance

Homework done in advance of this lesson:

- Read *Surely You're Joking Mr. Feynman! (Adventures of a Curious Character)* (Feynman, 1985). Section titled "The Amateur Scientist"
- Read about Global Warming's Six Americas: http://www.americanprogress.org/issues/2009/05/6americas.html
- "Informal Environments Observation Worksheet"

Quick Write and follow-up article. (15 minutes)
Participants are asked to respond to two prompts about the reading assigned for homework:

- Would you say that Feynman was doing science or did it just appear scientific? What specifically about his process makes you think that?
- Why do you think that we chose to assign the Feynman reading, both for the overall course and specifically for this session on the nature and practices of sciences?

They are then given a short follow-up article, *"Outsmarted by Ants,"* that provides a different perspective about the process Feynman used to investigate ants. Participants discuss their ideas using the following prompts:

- What do you think about Feynman's science experiments with ants now?
- How do these ideas fit into your schema of "What is Science"?
  For the Feynman article, see:
  http://www.nature.com/nature/journal/v436/n7050/full/436465a.html
  It can also be found as the "Outsmarted by Ants" PDF on this site.

Introduction to Nature of Science session. (5 minutes)
Participants are introduced to the rationale for why it is worthwhile to learn about the nature of science, both for scientists and science educators, and why and how this can be communicated to students.

Think-Pair-Share: What is Science? (or Digest of online discussion responses). (10 minutes)
Participants think silently about the following prompts, discuss them with a partner and then with the whole group:

- What is science?
- How does science work?

Activity: Mystery Tubes. (20 minutes)
Participants work in groups to determine what the interior construction of a mystery tube looks like—without looking inside the tube. This activity sets up a discussion about what scientists do and how science works. The Mystery Tube activity was adapted from three versions of this activity:

- *Mystery Tubes* — A lesson on the Understanding Science website. University of California Museum of Paleontology. See: http://undsci.berkeley.edu/lessons/mystery_tubes.html
- *The Mystery Tube* — Author: Aaron Debbink, Partners Investigating Our Environment
- *Tube Hypothesis and the Nature of Science* — Author: Kirk Brown, science teacher, Tracy High School
- A version of this activity also appeared in the National Academy of Science's publication *Teaching About Evolution and the Nature of Science*

Activity: How Science Works Flowcharts. (20 minutes)
Participants review *How Science Works* flowchart and relate it the activities they did in this session. They trace their steps on the charts, which portray science inquiry as a dynamic process. The *How Science Works* flowchart is from the Understanding Science website: http://undsci.berkeley.edu. Details for downloading or purchasing the poster can be found in the Getting Ready section, below.

Activity: Sorting Statements. (25 minutes)
Participants work in groups to sort statements into accurate and inaccurate descriptions of science and the scientific process and discuss them in terms of what is science and how science works. The sorting statements were adapted from the "Misconceptions about science" section of the Understanding Science website: http://undsci.berkeley.edu/teaching/misconceptions.php

Key Ideas from the Literature about Science. (20 minutes)
Participants are given a handout describing key ideas about science from the literature. They read the statements and then discuss the following prompts with a partner and then the whole group:

- What are the implications of these key ideas from the literature?
- How are these ideas about science relevant to you as a student, potential scientist and/or educator?

Interactive Climate Change Discussion, Presentation and Activity. (25 minutes)
We have chosen to focus on climate change for this session as an application of how student's perceptions of how science works can influence their view of science and scientific evidence. (See Science Content Index for PowerPoint slides and activities)

Discussion: The Six Americas. (15 minutes)
Facilitate a discussion about the homework reading, "Global Warming's Six Americas" using the following prompts:

- What are the varying views about climate change?

- Do you think a better understanding of the process of science changes people's views about climate change?

Quick Write—self-reflection. (5 minutes)
Participants do a Quick Write as a self-reflection using the following prompts:
- How is a scientific view distinct from other ways of knowing?
- What did you find most interesting, thought–provoking, or applicable to you from today's session about the nature and practices of science?

Homework. (5 minutes)
(Note – this homework is assigned as part of the UC Berkeley course; other institutions may decide to use these assignments or develop different assignments.)

Online Discussion:
As we discussed in class, science is a distinct way of viewing and exploring the natural world.
- Ask two people "Do you think that global warming is happening and is caused mostly by human activities?" "Why or why not?" Record their ideas and a bit about the tenor and content of the discussion you had with them.
- What is the value of teaching students and the general public to think scientifically and how might they apply scientific thinking in their everyday lives?

Reading:
- Hohenstein, J. M., & H. King. (2007). Learning in and outside of school. In J. Dillon & M. Maguire (Eds.), Becoming a teacher: Issues in secondary teaching (3rd ed., pp. 163–174): McGraw-Hill International.
- Peruse the Understanding Science website: http://undsci.berkeley.edu/

Time Frame

Total Workshop: 2 hours, 50 minutes
- Quick Write, Reading (10 minutes)
- Introduction to session (5 minutes)
- Think-pair-share (10 minutes)
- Mystery Tubes (20 minutes)
- How Science Works Flowcharts (20 minutes)
- Sorting Statements: Misconceptions about Science (25 minutes)
- Key Ideas from the Literature about Science (20 minutes)
- Climate Change Discussion, Lecture and Activity (25 minutes)
- Discussion: Six Americas (15)
- Quick Write–self-reflection (5 minutes)
- Homework (10 minutes)

Materials

For the class

- ❑ PowerPoint presentation
- ❑ Digital/data projector
- ❑ Whiteboard or flip chart paper and pens

For each participant

- ❑ 1 copy of *Outsmarted by Ants* article
- ❑ 1 copy of *Key Ideas from the Literature*
- ❑ 1 copy of *How Science Works Flowchart—Complex*
- ❑ Optional handouts (1 copy each)
    - *Terms Used in Describing the Nature of Science*
    - *Science is…*

For Sorting Statements

For each group of 4–6 participants

- ❑ 1 set of *Scientific Statements* (see Getting Ready)
- ❑ 1 copy of *Misinterpretations of the Scientific Process*

For the Mystery Tubes activity

For each group of 2–3 participants

- ❑ 1 Mystery Tube
- ❑ 1 sheet scratch paper

For How Science Works

For each group of 4–6 participants

- ❑ 1 *How Science Works* poster
- ❑ 1 pad of post-its

Preparation of Materials

1. Construct Mystery Tubes.
    - Instructions for making the Mystery Tubes can be found at the following website: http://undsci.berkeley.edu/lessons/mystery_tubes.html
    - Make one tube for each two–three participants according to the directions on the website.

2. Prepare Sorting Statements.
    - Duplicate one set of *Scientific Statements* for each small group of 4
    - For each set, cut apart strips into individual statements and paperclip together for easy distribution

3. Copy handouts for each participant
    - *Outsmarted by Ants*
    - *Key Ideas from the Literature*

- Complex *How Science Works* flowcharts. These flowcharts can be downloaded from the web: http://undsci.berkeley.edu/lessons/pdfs/complex_flow_handout.pdf

4. Download *How Science Works* poster and have it made at a copy shop. The flowchart poster can be downloaded from the web:
http://undsci.berkeley.edu/teaching/teachingtools.php
The poster can also be purchased from the American Institute of Biological Sciences Webstore: http://webstore.aibs.org/Understanding-Science-Flowchart-Poster/M/B002R1K00A.htm

5. Copy "Misinterpretations of the Scientific Process" for each small group.

6. Label two sections of the white board, or make two posters. Label one "What is Science?" and the second one, "What Scientists Do."

7. Determine if you would like to distribute the two optional handouts to your participants: *Science is…* and *Terms Used in Describing the Nature of Science.*

8. Determine if you will use the climate change lecture, discussion and activity included, or if you would prefer to focus on a different science content area.

Instructor's Guide—Session Details

Quick Write

1. Begin Quick Write. Ask the participants to do a five-minute written response to the questions below as a means of engaging and assessing their learning from the reading assignment.

- Would you say that Feynman was doing science or did it just appear scientific? What specifically about his results make you think that?
- Why do you think that we chose to assign the Feynman reading, both for the overall course and specifically for this session on the nature of science?

2. Distribute the *Nature* article about Feynman's ant work. Distribute the *Nature* article and tell them that this also discusses Feynman's work, but puts a different spin on it. Tell them that you are interested in hearing what they think about it. Give participants a few minutes to read the short article.

3. Display questions and pairs discuss. After most participants have read the article, display the following questions and ask them turn to a partner to discuss:

- What do you think about Feynman's science experiments with ants now?
- How do these ideas fit into your thoughts of "What is Science?"

4. Whole group discusses. Facilitate a whole group discussion about their thoughts and ideas about the questions.

Notes about facilitating whole group discussions:

- *Listen to their responses.*
- *Ask for evidence, explanation, or clarification.*
- *Ask for agreements, disagreements, and alternative opinions and views about the ideas put forth.*

Introduce Nature of Science Session

1. Mention student ideas about scientists and science. Tell participants that the image of a scientist (whether positive or negative) has a certain mystique and aura, much of which may be fantasy, and some of which is accurate. Young students often enjoy wearing the stereotypical trappings of science, such as goggles and lab coats, and doing activities that make them feel "scientific," such as making observations and collecting data. Similarly, non-scientists sometimes dress up their ideas in the language and trappings of science to try to tap into its mystique. This can create confusion for students about what science is and what it is not.

2. Explain rationale for session. Tell the participants that if they are going to be teaching about science, it is extremely worthwhile to spend some time thinking about the nature of science and how this can be communicated to the public.

Think-Pair-Share (or Digest of Online Discussion ideas)

Note: *the Think-Pair-Share question prompts below are the same questions participants answered in the online discussion. If you are having your participants do the online discussions, you may want to share an overview or digest of their responses and ideas rather than do a think-pair-share here. In either case, record their ideas about what is science on the board to refer to later.*

1. Remind how to do Think-Pair-Share. Remind participants that in a Think-Pair-Share, participants *Think* individually about the question or idea(s) put forth, *Pair* up with someone to discuss their thinking, and then *Share* their conversation with the whole group.

2. Display the Think-Pair-Share prompts. Display the prompts and have participants spend a minute or two **THINKING** about the questions.

- What is Science?
- How does science work?

3. Participants PAIR up to discuss. Ask participants to turn to someone next to them and discuss their responses to the questions. Tell them to take two minutes to discuss this in their PAIR, with each person getting some time to talk.

4. Participants SHARE with whole group. After a few minutes, ask a couple of participants to share their ***partner's*** thoughts with the entire group. Encourage others to participate in the discussion by asking questions, such as: "Does anyone have a different idea?" "Did anyone notice anything different?" "Might someone be able to explain that in a different way?" "Can you tell me more about that?" Call on a few participants and try to keep your acknowledgment of and responses to their comments as neutral as possible.

5. Record on board. Record participants' ideas about what science is on the board.

Mystery Tubes Activity

1. Introduce the Activity. Participants work in twos or threes to share ideas and propose a hypothesis about what the interior construction of a "Mystery Tube" looks like, and how they might test their ideas—without looking inside the tube! This activity sets up a discussion about what scientists do and how science works.

2. Distribute a mystery tube to each pair (or threesome). Tell them their goal is to determine what the interior construction of the tube looks like. Remind them that they cannot open the tube to look inside. Give them about five minutes to work with and investigate the mystery tubes.

3. Draw the internal structure. Provide paper so partners can draw a diagram about what the internal structure of the tube looks like and what they think is going on inside of it. Tell them that these diagrams are models of their hypotheses about the internal structure of the tube. Walk around and ask them how they might test and be more confident about their ideas and hypotheses. Encourage them to figure out how they might test their hypotheses (as long as they don't look inside or destroy the tube).

4. Small groups share models. Have each small group share with another small group: a) their model (diagram), and b) what they would say if they were going to publish their findings about the mystery tubes right now**.** Encourage them to comment and ask questions about each other's models.

5. Sharing models and whole group discussion. As each small group shares their model with the whole group, encourage them to comment on each other's models using some or all of the following prompts below. Remember to listen to their responses, ask for evidence, explanation, or clarification and encourage participants to share agreements, disagreements, and alternative models.

- Did something you hear from sharing with another small group lead you to change your model?
- How confident are you about your hypothesis?
- What fits your observations and what doesn't?
- Which models are possible? [Likely most, or all]
- Is there a way to decide which model most closely fits all the available evidence we have right now? [Possible answers may include: arguing, voting, revisiting our evidence/observations, the best drawing, the most complicated/least complicated]
- What additional evidence would we need to decide between the models? How could we be more confident? [Obtain more evidence; cut the tube open; create a 3D model]

6. Collect the tubes. *Do not reveal how the ropes are actually connected!*

7. Debrief Mystery Tubes. Facilitate a discussion to debrief participants' experience in the activity. Ask participants the following questions:

- – Were you doing science?
- – What were you doing that is similar to what scientists do?

Record on the board as participants share their ideas about "What scientists do."

Activity: How Science Works Flowcharts

1. Introduce complex flowchart. Distribute the complex flowchart to each participant and the *How Science Works* poster and post-it pad to each table group. Say this is a diagram showing another way to illustrate how science works. Give them a minute to review individually and then encourage them to briefly share their reactions and what they find interesting and relevant with their table/small group.

2. Refer back to Mystery Tubes. Have participants think back to the Mystery Tubes activity. What was the first thing they did? Where does it fit on the flow chart? Have them put a #1 on a post-it and place it in that section of the flow chart poster, then have them keep thinking through the process of the Mystery Tubes activity, putting numbers on the post-its and placing them on the flow chart poster in the appropriate places.

3. Comparing flowcharts. Each small group shares their completed flowchart with another group. [Each group will likely have a different path through the flowchart.] Have them spend just a few minutes looking for similarities and differences and then have a few groups place their posters on the wall where everyone can see them.

4. Lead group discussion. Participants share their reactions to the *How Science Works* flowcharts. Use some or all of the following prompts to lead a discussion about what they did in this session related to the flowcharts and how science works:

- What do you notice about your pathway shown on the flowchart? [Pathways drawn by different groups are not the same.]
- How does this differ from how you were taught about the science process in school? [Scientific Method will likely be mentioned.]
- Which part(s) of the science process and practices did we address in this session (including the Mystery Tubes and our discussions)?
- Which part(s) did we not address?
- Which part(s) do you think are most often addressed in K-12 education? Why do you think that is?

Note: *there is an interactive version of "How Science Works" on the Understanding Science website at http://undsci.berkeley.edu/article/0_0_0/howscienceworks_02 Click on the "Guide to Understanding Science 101" button, then click on "How Science Works." These pages address what scientists really do, as opposed to the scientific method that is commonly taught.*

Sorting Statements

1. Introduce activity. Determining what is science or scientific and what is not is sometimes not as straightforward as one might think. We all likely harbor some ideas about "what is science" that perhaps others in this room might not agree with. Students' and the general public's perception of science and scientists varies greatly, as do the views of some scientists and educators on what people should know about the nature of science. This has a big influence on how students perceive scientific evidence and explanations about how the world works. This activity will give you an opportunity to enter into further discussions about what is science and scientific behavior.

2. Introduce sorting strips. Tell them each small group will receive a set of science statement strips. Each strip has a different statement about science on it. Their challenge is to discuss each statement with their group and then decide if they think the statements are ***"Accurate"*** statements about science and scientific practices, or ***"Inaccurate"*** statements, and then sort them accordingly. Tell them that after discussion with their group they may decide that all the statements are accurate or all inaccurate.

3. Explain purpose of sorting activity. Let them know that exact "right" answers are not the point of the activity, the purpose is to create an opportunity to discuss and think about what science is and what it is not. They should discuss each statement thoroughly before placing it in a category.

4. Groups discuss reasons for sorting decisions. Let participants know that some statements will be fairly easy to categorize, but others will be challenging. Tell them that even with the relatively easy ones, they should discuss why they think they should be sorted that way.

5. Distribute statements to categorize. Give a set of statement strips to each small group (~4 participants), and tell them to begin.

6. Class discussion about which statements they thought were inaccurate. After most groups have completed the sorting task, get the attention of the whole group. Ask groups to share a statement they sorted into the "Inaccurate" category. Ask them to explain why they decided it was inaccurate. Do this for a few statements.

7. Groups share statements they thought were accurate. Ask groups to share which statements they sorted as accurate. This time do not ask them to explain why they sorted them as accurate.

Note: *In a moment, the groups will learn that all the statements are inaccurate. To avoid participant embarrassment, it's enough that they simply share the statements they thought were accurate, without investing time into explaining why they thought it was accurate.*

8. Use the UCMP Understanding Science website to reveal that all the statements were inaccurate. Tell the group all the statements they just sorted came from a web page, Understanding Science, produced by the University of California Museum of Paleontology (UCMP). Show them the web page on your projector.
Understanding Science website: **http://undsci.berkeley.edu/**
In the "Resource Library" section on the page, click on the "Misconceptions" button. http://undsci.berkeley.edu/teaching/misconceptions.php
Scroll down the list of misconceptions on the page. ***Share with the group that all the statements came from this list, and they all were inaccurate***. Let participants know that these pages address what scientists really do, as opposed to the scientific method that is commonly taught.

9. Groups read about misconceptions from UCMP website sheet. Click on one of the misconceptions, and show how they each have a paragraph of explanation about why it is an inaccurate description of science. Distribute one copy of *Misinterpretations of the Scientific Process* handout to each group, and tell them it is an excerpt of this page. Tell them to have one member of their group read aloud what the handout has to say about each of the statements they classified as **accurate**. Tell them to discuss these again, incorporating this additional information.

Note: *You can share with the group that this wasn't done to intentionally trick them into thinking some of the statements were true, but to push them to think deeply about their beliefs about the nature of science and scientific approaches. Also, using all inaccurate statements provides for a shorter and more straightforward debrief—rather than determining for each statement whether or not it was accurate. And it invites them to explore this useful website later on.*

10. Explore UCMP website. Encourage them to explore the web site later and tell them that part of their homework will be to surf the *Understanding Science* website.

Scientific Statements

Adapted from the "Misconceptions about Science" section of the Understanding Science Website: http://undsci.berkeley.edu/teaching/misconceptions.php

Science is a collection of facts.

Science is complete and we've already discovered most of what there is to know about the natural world.

There is a single **Scientific Method** that all scientists follow.

The process of science is purely analytic and does not involve creativity.

Experiments are a necessary part of the scientific process. Without an experiment, a study is not rigorous or scientific.

"Hard" sciences (e.g. chemistry and physics) are more rigorous and scientific than "soft" sciences (psychology and sociology).

Scientific ideas are absolute and unchanging.

Because scientific ideas are tentative and subject to change, they can't be trusted.

If evidence supports a hypothesis, it is upgraded to a theory. If the theory then garners even more support, it may be upgraded to a law.

Scientific ideas are judged **democratically**.

The job of a scientist is to find support for his or her hypotheses.

Investigations that don't reach a firm conclusion are useless and unpublishable.

Scientists are completely **objective** in their evaluation of scientific ideas and evidence.

Scientists work without considering the applications of their ideas.

In science, a **prediction** usually refers to something that we expect to happen in the future.

Science is a solitary pursuit.

Key Ideas from the Literature about Science

1. Introduce key ideas from literature. Introduce these statements as key ideas on the nature of science from the literature. Distribute a copy of the following statements to each participant. Invite participants to read the ideas quietly to themselves and think about the implications of the statements. They should be ready to discuss their ideas in a few minutes with a partner.

Key Ideas from Literature

–Science is evidence-based, consistent, durable, peer-reviewed, self-correcting, and based on observations and hypotheses within a testable framework of ideas.
–Science is a way of looking at the world that may be distinct from other worldviews based on ethnicity, culture, and socioeconomics, including everyday ways of thinking and talking about the world.
–Science is a social enterprise. Evidence is collected, interpreted, and influenced by current scientific perspectives and by the society, culture, and even the scientists' personal subjectivity.
–School science has been observed by educational researchers as attempting, but often failing, to transmit an accurate view of science (Cobern, 1991; Duschl, 1988); rather, the curriculum often provides students with a stereotype image of science as authoritarian and absolute truth.
–Culture can be defined as the norms, values, beliefs, expectations, and conventional actions of a group. Within each culture there are also subgroups identified by race, language, and ethnicity, and also gender, social class, occupation, religion, etc. (Phelan, Davidson, & Cao, 1991). Using this definition, science itself can be considered a subculture of Western or Euro-American culture (Baker & Taylor, 1995; Ogawa, 1986; Pomeroy, 1994) since scientists share a well-defined system of meaning and symbols with which they interact socially.
–Some science philosophers are opposed to treating science as a cultural enterprise. They argue that such a viewpoint tends to undermine "the universality of science"—science is the same everywhere; that is, science uncovers knowledge or solves problems irrespective of the culture, race, or gender of the individual scientist involved (Doran, Lawrenz, & Helgeson, 1994).
–Teaching the nature of science and its processes should be at the core rather than the margins of science education. Not only will this help young people make sense of the science that in their daily lives, it may also lay the groundwork for a more sophisticated understanding later in life.
–"Science is a way of trying not to fool yourself." – Richard Feynman

2. Partner share. Have participants pair up with someone to discuss their responses and reactions to one or more of the ideas. Ask them the following questions to prompt their thinking:

- What are the implications of these key ideas about science?
- How are these ideas about science relevant to you as a student, potential scientist and/or educator?

3. Whole group discussion. Invite participants to share their discussions with the whole group.

- Listen to their responses.
- Ask for evidence, explanation, or clarification.
- Ask for agreements, disagreements, and alternative opinions and views with the ideas put forth.
- Synthesize their ideas, referring to various viewpoints.

Climate Change Interactive Discussion, Presentation and Activity

Note: *We have chosen to focus on climate change for this session as an application of how the public's perception of how science works can influence their view of science and scientific evidence. See Science Content Index for the interactive presentation.*

Discussion: The Six Americas

1. Display discussion prompts for homework reading, The Six Americas. Display the discussion prompts for the reading assigned last week for homework.

- What are the varying views about climate change?
- Do you think a better understanding of the process of science changes people's views about climate change?

2. Lead whole group discussion. Facilitate a whole group discussion about the prompts using the following strategies:

- Listen to their responses.
- Ask for evidence, explanation, or clarification.
- Ask for agreements, disagreements, and alternative opinions and views with the ideas put forth.
- Synthesize their ideas as you refer to their various ideas.
- Pose new questions that build on what the participants are talking about.

3. Distribute other handouts (optional). Distribute any other handouts you would like students to have regarding the nature and process of science. Optional handouts attached to this session include:

- *Science is…*
- *Terms used to Describe Nature of Science*. (Briefly discuss that some words in scientific language, such as theory and law, have a different meaning in everyday speech.)

Quick Write—Self-reflection

Participants do a Quick write as a self-reflection using the following prompts:

1. How is a scientific view distinct from other ways of knowing?
2. What did you find most interesting, thought-provoking, or applicable to you from today's session about the nature and practices of science?

Discussion about last week's homework

1. Lead a discussion about last week's homework. Remind students that last week they were assigned to visit an informal learning environment. Have them refer to their observation worksheet and share some of their observations and experiences.

Homework:

Online Discussion:
As we discussed in class, science is a distinct way of viewing and exploring the natural world.

- Ask two people "Do you think that global warming is happening and is caused mostly by human activities?" "Why or why not?" Record their ideas and a bit about the tone and content of the discussion you had with them.
- What is the value of teaching K–12 students to think scientifically? How might they apply scientific thinking in their everyday lives and when they grow up even if they don't become scientists?

Reading:

- Hohenstein, J. M., & H. King. (2007). Learning in and outside of school. In J. Dillon & M. Maguire (Eds.), Becoming a teacher: Issues in secondary teaching (3rd ed., pp. 163-174): McGraw-Hill International.
- Choose at least one of the biome chapters from the textbook (Chapters 11, 12, 13, 14, 15, 16) to read in full.
- Peruse the Understanding Science website: http://undsci.berkeley.edu/

Scientific Statements

Adapted from the "Misconceptions about Science" section of the Understanding Science Website: http://undsci.berkeley.edu/teaching/misconceptions.php

Science is a collection of facts.

Science is complete and we've already discovered most of what there is to know about the natural world.

There is a single **Scientific Method** that all scientists follow.

The process of science is purely analytic and does not involve creativity.

Experiments are a necessary part of the scientific process. Without an experiment, a study is not rigorous or scientific.

“Hard” sciences (e.g. chemistry and physics) are more rigorous and scientific than “soft” sciences (psychology and sociology).

Scientific ideas are absolute and unchanging.

Because scientific ideas are tentative and subject to change, they can't be trusted.

If evidence supports a hypothesis, it is upgraded to a theory. If the theory then garners even more support, it may be upgraded to a law.

Scientific ideas are judged **democratically**.

The job of a scientist is to find support for his or her hypotheses.

Investigations that don't reach a firm conclusion are useless and unpublishable.

Scientists are completely **objective** in their evaluation of scientific ideas and evidence.

Scientists work without considering the applications of their ideas.

In science, a **prediction** usually refers to something that we expect to happen in the future.

Science is a solitary pursuit.

Misinterpretations of the Scientific Process

These explanations are adapted from the "Misconceptions about Science" section of the Understanding Science Website:
http://undsci.berkeley.edu/teaching/misconceptions.php

Science is a collection of facts. Facts are only part of the picture. Science *is* a body of knowledge that one can learn about in textbooks, but it is also a process. Science is a process for discovering how the world works and building that knowledge into powerful and coherent frameworks.

Science is complete. Science is an ongoing process, and there is much more yet to learn about the world. In fact, in science, making a key discovery often leads to many new questions ripe for investigation. Furthermore, scientists are constantly elaborating, refining, and revising established scientific ideas based on new evidence and perspectives.

There is a single Scientific Method that all scientists follow. "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 done), but it is a grossly oversimplified representation of how scientists generally build knowledge. The process of science is exciting, complex, and unpredictable. It involves many different people, engaged in many different activities, in many different orders.

The process of science is purely analytic and does not involve creativity. Perhaps because the Scientific Method presents a linear and rigid 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!

Experiments are a necessary part of the scientific process. Without an experiment, a study is not rigorous or scientific. Perhaps because the Scientific Method and popular portrayals of science emphasize experiments, many people think that science can't be done *without* an experiment. In fact, there are *many* ways to test almost any scientific idea; experimentation is only one approach. Some ideas are best tested by setting up a controlled experiment in a lab, some by making detailed observations of the natural world, and some with a combination of strategies.

"Hard" sciences (e.g. chemistry and physics) are more rigorous and scientific than "soft" sciences (psychology and sociology). Some scientists and philosophers have tried to draw a line between "hard" sciences (e.g., chemistry and physics) and "soft" ones (e.g., psychology and sociology). The thinking was that hard science used more rigorous, quantitative methods than soft science did and so were more trustworthy. In fact, the rigor of a scientific study has much more to do with the investigator's approach than with the discipline. Many psychology studies, for example, are carefully controlled, rely on large sample sizes, and are highly quantitative.

Scientific ideas are absolute and unchanging. 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. Furthermore, at the cutting edge of scientific research, scientific ideas may change rapidly as scientists test out many different possible explanations trying to figure out which are the most accurate.

Because scientific ideas are tentative and subject to change, they can't be trusted. Especially when it comes to scientific findings about health and medicine, it can sometimes seem as though scientists are always changing their minds. There are several reasons for such apparent reversals. First, press coverage tends to draw particular attention to disagreements or ideas that conflict with past views. Second, ideas at the cutting edge of research (e.g., regarding new medical studies) may change rapidly as scientists test out many different possible explanations trying to figure out which are the most accurate. This is a normal part of the process of science.

If evidence supports a hypothesis, it is upgraded to a theory. If the theory then garners even more support, it may be upgraded to a law. This misconception may be reinforced by introductory science courses that treat hypotheses as "things we're not sure about yet" and that only explore established and accepted theories. In fact, hypotheses, theories, and laws are rather like apples, oranges, and kumquats: one cannot grow into another, no matter how much fertilizer and water are offered. Hypotheses, theories, and laws are all scientific explanations that differ in breadth—not in level of support. Hypotheses are explanations that are limited in scope, applying to fairly narrow range of phenomena. The term *law* is sometimes used to refer to an idea about how observable phenomena are related—but the term is also used in other ways within science. Theories are deep explanations that apply to a broad range of phenomena and that may integrate many hypotheses and laws.

Scientific ideas are judged democratically. 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. But of course, that's not quite how it works. Scientific ideas are judged not by their popularity, but on the basis of the evidence supporting or contradicting them.

The job of a scientist is to find support for his or her hypotheses. Science gains as much from figuring out which hypotheses are likely to be wrong as it does from figuring out which are supported by the evidence. Scientists may have personal favorite hypotheses, but they strive to consider multiple hypotheses and be unbiased when evaluating them against the evidence. A scientist who finds evidence contradicting a favorite hypothesis may be surprised and probably disappointed, but can rest easy knowing that he or she has made a valuable contribution to science.

Investigations that don't reach a firm conclusion are useless and unpublishable. Perhaps because the last step of the Scientific Method is usually "draw a conclusion," it's easy to imagine that studies that don't reach a clear conclusion must not be scientific or important. In fact, *most* scientific studies don't reach "firm" conclusions. Scientific articles usually end with a discussion of the limitations of the tests performed and the alternative hypotheses that might account for the phenomenon. That's the nature of scientific knowledge—it's inherently tentative and could be overturned if new evidence, interpretations, or a better explanation come along. In science, studies that carefully analyze the strengths and weaknesses of the test performed and of different alternative explanations are particularly valuable since they encourage others to more thoroughly scrutinize the evidence and to develop new ways to test the ideas.

Scientists are completely objective in their evaluation of scientific ideas and evidence. 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.

Scientists work without considering the applications of their ideas. It's true that some scientific research is performed without any attention to its applications, but this is certainly not true of all science. Many scientists choose specific areas of research (e.g., malaria genetics) because of the practical ramifications new knowledge in these areas might have. And often, basic research that is performed without any aim toward potential applications later winds up being extremely useful.

In science, a prediction usually refers to something that we expect to happen in the future. In everyday language, *prediction* generally refers to something that a fortune teller makes about the future. In science, the term *prediction* generally means “what we would expect to happen or what we would expect to observe if this idea were accurate.” Sometimes, these scientific predictions have nothing at all to do with the future. Ironically, scientific predictions often have to do with past events.

Science is a solitary pursuit. When scientists are portrayed in movies and television shows, they are often ensconced in silent laboratories, alone with their bubbling test tubes. This can make science seem isolating. In fact, many scientists work in busy labs or field stations, surrounded by other scientists and students. Scientists often collaborate on studies with one another, mentor less experienced scientists, and just chat about their work over coffee. Even the rare scientist who works entirely alone depends on interactions with the rest of the scientific community to scrutinize his or her work and get ideas for new studies. Science is a social endeavor.

Key Ideas from Literature

– Science is evidence-based, consistent, durable, peer-reviewed, self-correcting, and based on observations and hypotheses within a testable framework of ideas.

– Science is a way of looking at the world that may be distinct from other worldviews based on ethnicity, culture, and socioeconomics, including everyday ways of thinking and talking about the world.

– Science is a social enterprise. Evidence is collected, interpreted and influenced by current scientific perspectives and by the society, culture and even the scientists' personal subjectivity.

– School science has been observed by educational researchers as attempting, but often failing, to transmit an accurate view of science (Cobern, 1991; Duschl, 1988); rather the curriculum often provides students with a stereotype image of science as authoritarian and absolute truth.

– Culture can be defined as the norms, values, beliefs, expectations, and conventional actions of a group. Within each culture there are also subgroups identified by race, language, and ethnicity, and also gender, social class, occupation, religion, etc. (Phelan, Davidson, & Cao, 1991). Using this definition, science itself can be considered a subculture of Western or Euro-American culture (Baker & Taylor, 1995; Ogawa, 1986; Pomeroy, 1994) since scientists share a well-defined system of meaning and symbols with which they interact socially.

– Some science philosophers are opposed to treating science as a cultural enterprise. They argue that such a viewpoint tends to undermine "the universality of science"—science is the same everywhere; that is, science uncovers knowledge or solves problems irrespective of the culture, race, or gender of the individual scientist involved (Doran, Lawrenz, & Helgeson, 1994).

– Teaching the nature of science and its processes should be at the core rather than the margins of science education. Not only will this help young people make sense of the science that in their daily lives, it may also lay the groundwork for a more sophisticated understanding later in life.

– "Science is a way of trying not to fool yourself." Richard Feynman

Science is…

Evidence-based: There are accepted methodologies, standards of evidence, and logical ways of answering questions in science, all of which are based on observations, tests and other types of data. The importance of the use of evidence in science cannot be over-stated. Evidence always points the way to new understandings. This explains why evidence is mentioned in most of the following points.
Testable or Falsifiable: How will you know if you are wrong about your idea? If an explanation offers no way to be tested, or does not have the potential to be proven false by evidence, then it is not scientific. Repeatability is often a goal in experimental types of science. But many fields of science do not solve problems through experimentation—they rely on inferences from patterns and observations.
Consistent: A scientific explanation needs to do more than provide a plausible account; it must fit all the observable facts better than alternative explanations do. It must be consistent with all available evidence, not just selected evidence.
Practical: Science is useful for solving everyday problems.
Making Explanations: Scientific explanations must show an explicit cause and effect relationship based on observable evidence. They involve looking for patterns and correlations. Explanations deal specifically with explaining the natural world and are not cultural or supernatural.
Reviewed by Peers: Scientific papers are published in journals to be reviewed by other scientists. Anyone can have an idea in science, it is non-discriminating and it is not sentimental. It doesn't matter who proposes an idea, it is judged based on the evidence. Individual scientists may have different agendas and can put forth a variety of opinions—these don't necessarily represent scientific knowledge. Scientific experts in one field may not know about other fields of science. This is why we look to communities of experts to help ratify explanations and judge the evidence for scientific arguments.
Self-correcting: Science is open-minded, not empty-headed. Scientists are very careful about what they say they know and how they know it—scientists must have evidence to support their claims. They try not to overstate their findings and wait to see confirming (or disproving) evidence. Scientific ideas are often changed and revised as we acquire new evidence.

Science is not…
- The absolute truth—but rather our current best approximation based on available evidence.
- Democratic—You can't vote on science, it's based on the evidence. It doesn't matter how many scientists there are with a particular opinion—the evidence is what counts. It's also not the authority of the scientist, but the quality of the evidence, that provides the strength of the argument.

Nature of Science Session Handout (optional)

Terms Used in Describing the Nature of Science

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 may be modified or even discarded tomorrow.

Hypothesis: A tentative statement about the natural world leading to deductions that can be tested. If the deductions are verified, the hypothesis is provisionally corroborated. If the deductions are found to be incorrect, the original hypothesis is proved false and must be abandoned or modified. Hypotheses can be used to build more complex inferences and explanations.

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

Theory: In science, 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, the National Academy of Sciences (Wash, D.C.: National Academy Press, 1998.)

Nature of Science Session Handout (optional)