SCIENCE SURPRISES
TEACHER'S GUIDE

Exploring the Nature of Science

by Lawrence Flammer

PRE-PUBLICATION DRAFT

Pre-Publication Version 3
Published by ENSIweb, LLC

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# Science Surprises: Teacher’s Guide

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Preface

This Teacher’s Guide is intended to provide structure and direction for integrating several of the ENSI NOS lessons with the Science Surprises student booklet. In fact, a few of those lessons should be experienced by the students even before they begin reading the student booklet. Therefore, this Teacher’s Guide should be reviewed along with the Science Surprises student booklet and the suggested ENSI NOS lessons. In addition, it would be very helpful if you used at least a few of those interactive lessons with your students before using them in your introductory unit with Science Surprises. A good time to do that could be near the end of your current school year, or even earlier. The recommended lessons are listed below, roughly in the sequence they could be used. When you access the NOS lessons index on the ENSI site, you should scroll down to the synopses for more convenient sampling.

Be sure to carefully read each NOS lesson you plan to use, and prepare the materials for each planned lesson (see Teacher’s Appendix TA-7: Preparation for NOS Lessons). This is best done long before school even starts, if you can. This takes lots of pressure off your preps for this unit. You might even need to contact the author for the keys to some lessons. These classroom-tested interactive lessons are freely accessible from the NOS index or go to: http://www.indiana.edu/~ensiweb/natsc.fs.html.

For further help in selecting appropriate lessons, see Teacher’s Appendix TA-3: ENSI NOS Lesson Matrix, With Key Elements of NOS, TA-4: NOS Concepts by Chapters and Lessons, and TA-5b: ENSI NOS Lessons that fit STEM, NGSS and Common Core Expectations.

- False Assumptions
- The Oat Seed Lab
- Checks Lab
- Sunsets, Souls & Senses
- Perception is Not Always Reality
- The Magic Hooey Stick
- Palpating Pachyderms
- Mystery Boxes
- Crime Scene: Case of the Missing Microchip
- Therapeutic Touch
- How’s Your Horoscope

About the Author: Lawrence Flammer is a high school biology teacher with an MS in zoology, retired after 38 years of teaching. He specialized in using the themes of evolution, the nature of science, and human evolution. He also developed and maintains the ENSI website (Evolution and Nature of Science Institutes): http://www.indiana.edu/~ensiweb/. He has published articles in The American Biology Teacher (The Evolution Solution, and Chromosome Connections: Compelling Clues to Common Ancestry) and Science Scope (Patterns in Time).
“Science literacy is a vaccine against the charlatans of the world that would exploit your ignorance.”- Neil deGrasse Tyson

Part 1. Introduction
When you read the first chapter of most secondary science textbooks, there is the usual explanation of the “scientific method” and what science is, along with an introduction to the particular field of science presented in the text. You might also notice that there is little if any mention of some of those features of science that are so often misrepresented by anti-science factions in our society. Through all the diverse media forms, we often hear and see science rejection (or denial) and anti-science claims by people who are against the widely held scientific positions on climate change, vaccinations, the “Big Bang” theory, the origin of life, a very old earth, evolution, etc. When these misconceptions are examined closely (Teacher’s Appendix TA-1c), you learn that much of this talk reflects a lack of accurate understanding about what science really is and how it actually works. So where do students learn the effective tools for critically addressing these issues? See TA-1a.

This widespread science illiteracy has provided a rich feeding ground for people who try to misrepresent science for their own purposes. As a result, we are confronted on TV and in books, magazines and newspapers with many examples of poor science and pseudoscience. We see ads for quick medical fixes make claims like “Medical science has proven that this pill works wonders.” Some political propaganda, and even some scientists, say “Many scientists agree that there is little evidence for human-caused climate change.” But most textbooks provide little help for why these assertions should be suspect, and how students can become critical thinkers about such issues.

Goals of the Science Surprises Unit
This unit provides vivid experiences for students in science classes with some of the key aspects of the nature of science*. This goes beyond the basic methods of inquiry or the processes of science. The focus here is on the several important features of science that are widely misunderstood by our society, and are often misused by those who want to “kidnap” science for their own purposes. And you probably won’t find them in your science textbook, either!

Now, the new national science standards are expecting students to learn elements of the nature of science, including critical thinking and scientific argumentation skills. Science Surprises comes to the rescue, and provides you with all the materials and structure needed to explicitly teach these things.

* See Teacher Appendix TA-1a for Key Concepts of the Nature of Science
Science Surprises, was developed to fill that gap: to give students more accurate insights into the nature of science (NOS), and give them clues for recognizing the misuse of science when they see it. There are many trade books and articles for teachers that point out these issues – but precious little is intended directly for student use. And the first chapters of most science textbooks are not very helpful. A few NOS elements may be mentioned, but there are few if any interactive opportunities where students get to work with those important aspects explicitly. NOS material in most textbooks focuses mostly on inquiry, primarily on the oversimplified “Scientific Method,” giving students the impression that this is all there is to the NOS (Shipman 2006, Abd-El-Khalick et al 2008; Lederman 1999).

Having read this far, if you are still reluctant to devote the first 2-3 weeks of your course to a strong focus explicitly on the nature of science, then be sure to take a look at the research on this subject. Go to the list of Useful Websites following the Teacher References of this Teacher’s Guide, and access the excellent Understanding Science website. Specifically, paste (or key) in the URL there for “Educational Research on Teaching the Nature and Processes of Science.” Hopefully, this will convince you to bring a strong focus on NOS experiences for your students.

Science Surprises is intended for students in any science, grades 7-10, as either an engaging replacement for their first chapter, or as a supplement to it. It has a reading level adjusted to about the 8th grade. This Teacher Guide is intended to help you choreograph and integrate several selected interactive NOS lessons from the ENSI website with the Science Surprises student booklet so that the entire unit is most effective. In addition, elements of the NOS should be integrated throughout the course wherever appropriate. In fact, you should treat the NOS as one of your themes in the course. Together, this should help improve both student and teacher understanding of the nature of science.

Research (Hake 2002) has shown that students understand and retain concepts much better when they discuss observations and concepts rather than taking notes in lectures (see examples online: Hanford 2012; Lambert 2012). Therefore, the proper use of this booklet involves first doing a few interactive, classroom-tested lessons such as those found in the Nature of Science section of the ENSI website. Those lessons provide the initial engaging and exploratory experiences that are rich with discussion prompts. These in turn become the focus of what Science Surprises explains, elaborates and evaluates. Importantly, technical terms are not introduced until after students have experienced the concepts for those terms earlier in the interactive lessons. Then integrating those NOS experiences and concepts throughout the rest of your course repeatedly reinforces them.

The ”surprises” of Science Surprises—in case anyone asks – are some of the many aspects about the NOS that are frequently unknown or misused. This includes what science can do, what it cannot do, and how it works. These are elements of science that may be new to the students as they proceed through the unit. If students ask, you might tell them to list the “surprises” in their notebook as they are discovered, copying the phrase or sentence that appears to be the surprise. They should also include the page number where each appears, and perhaps indicate if that surprise is indeed something new to them. Then they can share and discuss them near the end of the unit as part of review. There are about 30 “surprises” in Science Surprises, with about 5-6 in each chapter. Many students even treat the search for these surprises as “treasures” in a scientific treasure hunt!
This new information about science should enable students to start using certain key words and concepts of science properly. They should also become better critics of distortions, fallacies, fraud and other strategies used by pseudoscience promoters, propagandists, and false advertisers. This will help them to become critical consumers, skeptical of claims based on mysterious forces and untested ideas. It will, hopefully, reduce their chances of being taken in by medical quackery, distorted use of science in advertising, and political propaganda about science-related issues.

Having used these materials, students should clearly recognize what is scientific and what is not. They will learn what science can do, and what it cannot do. They will see why science is the powerful, reliable and effective tool that it is for building our understanding about the natural world. They will become more empowered citizens. These experiences and skills will open doors into many fields that expect some science (or a lot of science) background for the employees. And whether they use science or not, they may end up working in business, law, politics, construction, medicine, various service occupations, teaching, or parenting, they can be working ambassadors for what science really is all about.

*Science Surprises* was not intended to be a comprehensive, academic or detailed text about the NOS for teachers, or even for students. Academics can’t even agree on what NOS elements are characteristic to all kinds of science in all fields. This is merely an engaging but intensive introduction to several of those elements that are critically and commonly misunderstood. Anyone who wants to explore certain aspects more deeply can do so. There are a number of excellent resources listed in both the student booklet and the *Teacher’s Guide*. Many of these are easily accessible online. There are also a number of appendices (in both books) that can provide deeper exploration for the interested.

**How to get Science Surprises as an eBook:**

*Science Surprises* is available as an eBook at Smashwords.com. If you're looking for a unit to teach the nature of science (NoS), with lessons for practicing critical and skeptical thinking, this is it. This new text supplement is intended for students in any science class, grades 7-10. It particularly addresses the many misconceptions about NoS. It also satisfies virtually all of the new NoS science standards (in NGSS and CCSS). Click Read More or go to: <http://www.indiana.edu/~ensiweb/ss.ebook.html> for link to the new eBook *Science Surprises*.
Part 2. Important Background Elements

Meeting New Science Education Standards.
The new national Framework for K-12 Science Education (NRC 2012) reinforces and extends the national science standards established in 1996 (NRC 1996). For example, “…there is a strong consensus about characteristics of the scientific enterprise that should be understood by an educated citizen.” However, as mentioned earlier, the treatment of these NOS characteristics in most science textbooks and state science standards are seldom specified. Most textbooks focus primarily on “The Scientific Method,” as do some of the lessons they provide. The 2012 Framework points out that “…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 (italics added).” The Next Generation Science Standards (NGSS) (NRC 2013) clearly reflects this. We’ve actually known this for a long time, but do your state standards point this out? And what does your textbook say about this?

Science Surprises reflects virtually every Learning Outcome listed in the two matrices found in Appendix H of the NGSS (NRC 2013) on how the NOS is handled in the NGSS (pages 5 and 6). Science Surprises even includes a few NOS expectations from the 2012 national Science Framework that were overlooked by the NGSS. Some of those Learning Outcomes are not as clear as they could be, and a few important elements are missing, but this is still much better than in any earlier set of national standards. If your state has not yet developed new science standards, you might want to point out those few suggested changes and additions to your state standards committee if you have the chance. Perhaps you could work with your state science teacher’s association in doing this. If you like, you can contact the Science Surprises author for a copy of the NOS suggestions he sent to his state committee.

Scientific Argumentation: This is another major goal of both the NGSS and the Common Core State Standards (CCSS) (NGA 2010). The term appears in the new Framework for K-12 Science Education (2012) nearly 100 times. And several of the ENSI NOS lessons do provide opportunity to practice scientific argumentation, as does the Science Surprises text in several places.

Critical thinking has also been a stated goal in past science frameworks, and the latest one (NRC 2012) expresses this as engaging in “…critical and evidence-based argumentation…” But this, too, requires that certain strategies be actively and explicitly modeled and practiced. Even if a textbook were to describe those strategies, it’s the teacher who must do the modeling and guide the practicing students. Since critical thinking is an important part of this unit (and science itself), teachers and students will find practical examples in Science Surprises and the ENSI NOS lessons that they can use to learn and practice this skill.

Studies have clearly pointed out that students will not learn or acquire understanding of the many important elements of the NOS simply by doing investigative studies (Khishfe & Abd-El-Khalick 2002; Schwartz, et al 2004). Specific elements of the NOS must be pointed out explicitly, and students must practice them in interactive lessons. The Science Surprises unit does this.
STEM and Common Core Standards: For an annotated list of the ENSI lessons that are STEM-Ready and reflect NGSS and CCSS, see Teacher Appendix TA-5b; ENSI NOS Lessons that fit STEM, NGSS and Common Core State Standards. (See Useful Websites section for link to STEM concepts).

Worth noting about the Science Surprises program: There are several STEM-related lessons and Common Core-related elements incorporated there. STEM standards are clearly embedded in those lessons involving scientific creativity. These include Magic Hooey Stick, Perception Not Always Reality, Great Volume Exchanger, Mystery Boxes, and the Checks Lab. They all involve practice in hypothesizing of reasonable testable explanations, and designing tests for those hypotheses. Three of them also provide a basis for reverse engineering (Magic Hooey Stick, Great Volume Exchanger, and Mystery Boxes).

Math: There are also at least three of ENSI’s NOS lessons that use and apply math in science (meeting STEM, NGSS and Common Core standards): The Oat Seed Lab (teaches statistical analysis, growth measurements, graphing and their analyses). The Perception Not Always Reality lesson involves measuring percent differences between estimated and measured degrees of difference. How’s Your Horoscope involves calculating likely results due to chance.

Common Core connections can be found in the math-using lessons (above) and also those lessons that involve reading comprehension of scientific material and/or scientific argumentation. In the Student Appendix of Science Surprises (SA-4.1), students are asked to read an article written by a scientist about science and confirmation bias in science, including a common medical pseudoscience (homeopathy), then discuss the article in a guided class discussion. They are also asked to read another part of that same article (SA-4.2) where the author describes how science actually works, using one of his studies as an example, taking it through peer review and conference experiences. This, too, involves guided class discussion about elements of the nature of science in a real scientific study.

In Student Appendix SA-4.3 (Good Science vs Poor Science), students are asked to find examples of good science and poor science in a list of excerpts from a letter sent by scientists critiquing a research report in the journal Science. They point out problems in the article that led to the (unwarranted) banning of cyclamate sugar substitute from the market. Students then respond to several prompts and engage in guided class discussion about the issues. Students are also asked to read about and discuss other science-related socio-political issues, e.g., the GMO controversy (SA-4.5), and the Climate Change Issue (SA-5.1). All of this is included in the student book, which itself involves reading about other commonly misunderstood elements of the nature of science, and engages students in guided class discussions and some scientific argumentation about those issues. But be careful: Choose controversies wisely. Selecting a wrong topic can actually impair understanding. Details for selecting useful controversies can be found in TA-15b. Lots of Common Core stuff here!
**Most Common Misconceptions About the Nature of Science**

At the beginning of field testing of *Science Surprises* (fall 2012), the students were given a 40-item survey of the more important NOS misconceptions. This was done for three main reasons:
1. To determine which NOS myths were most common in this population of students.
2. To acquaint students with those misconceptions.
3. To compare with same test after unit is finished to learn the effectiveness of the unit.

That 40-item test was taken as their pre-test by 1,104 students from middle school and high school science classes in four different states. Item analysis results for that original pre-test was used to sort the items according to their scores. Those items showing the most misconceptions are listed in the **Teacher Appendix TA-1c: Most Common NOS Misconceptions in the Student Population**. It provides a fair sampling of what to expect from your students.

That original test has been shortened to 25 items and carefully revised to reduce ambiguity, have about the same number of A and B answers (randomly mixed), and reflect key points of each chapter in *Science Surprises*. This new test is available in **Teacher Appendix TA-19: Science Surprises Quiz**. This is the quiz you should use for pre/post testing of *Science Surprises*.

**Dealing With Misconceptions**

Many studies have shown that it’s very difficult to get people to replace their deeply held misconceptions with understandings that are objectively more accurate today. Therefore, every effort has been made to incorporate in *Science Surprises* those teaching strategies shown to be effective, if carried out properly. **Effective Debunking** of misconceptions is one of those strategies.

**Effective Debunking**

From the research of Stephan Lewandowsky and others on effective strategies for debunking misinformation, a useful **Debunking Handbook** (Cook & Lewandowsky 2011) is freely available online. The strategies explained there are summarized here:

1. First, present the Core Fact (current understanding) in a headline (with no mention of the related myth).
2. Reinforce the Core Fact with a brief, easy-to-read opening paragraph (again, no myth).
3. Embed in that paragraph an easy-to-grasp graphic that reinforces the Core Fact.
4. Then, provide an explicit warning that warns the reader that the misinformation is coming, indicating the nature of the misinformation.
5. Briefly present the myth related to the Core Fact.
6. Explain the “gap” between the Core Fact and the myth. This could be an alternative causal explanation for why the myth is wrong. This could be done by exposing the rhetorical techniques used to misinform, e.g., logical fallacies involved. Also, optionally, point out the likely reason why the misinformants promoted the myth in the first place, e.g., conflict of interest, or confirmation bias.

Overall, avoid mentioning or displaying the myth unless it’s necessary. Instead, display and repeatedly talk about the Core Fact, as such. Definitely avoid headlining the myth. It’s always best to focus on the Core Facts as we know them, wherever possible.
Also, keep any communication about the Core Fact simple, succinct, easy to read, easy to understand. Remember, a simply stated myth is easier to retain than a complicated correction. You don’t want that. Remember KISS (Keep It Simple & Succinct): Use simple language and short sentences, subheadings and paragraphs. Use a clear graphic, if possible, that gets the Core Fact across quickly. Avoid dramatic language and derogatory comments that alienate people.

In addition, you should consider whether your content may be threatening to the worldview and values of your audience. If so, you risk a worldview backfire effect, which is strongest among those with firmly held beliefs. The most receptive people will be those who are not strongly fixed in their views. You may want to focus on that undecided majority as your priority.

If you must present evidence that is threatening to the audience’s worldview, you may be able to reduce the worldview backfire effect by presenting your content in a worldview-affirming manner (e.g., by focusing on opportunities and potential benefits of the Core Fact rather than risks and threats about the myth) and/or by encouraging self-affirmation.

You can also circumvent the role of the audience’s worldview by focusing on behavioral techniques, such as framing the Core Facts in a way that is less threatening to one’s worldview.

The ENSI NOS lessons and Science Surprises tries to follow these “Effective Debunking” suggestions. A good example of this approach is shown in Science Surprises with the first few pages of Chapter 1. You can also see this with the treatment of Climate Change (see Chapter 5 and Student Appendices SA-5.1 and SA-5.2). If you ever find that this approach is clearly missing where you think it should be, please let the author know!

Why NOS as the First Unit?
It’s clear that, at some point in their K-12 education, students should be introduced to learning and using strategies for critical and skeptical thinking. Because this is the core of how science works, it seems that science classes would be a logical place for doing this. But many teachers are apprehensive about it. Why is that? A major reason why some teachers avoid controversial topics is that they don’t feel comfortable in confrontational situations. They may not have learned the strategies for dealing effectively with such issues. So they try hard to be neutral or non-committal about those topics so as not to offend or appear to be taking sides. Or they avoid them altogether, if they can. Another reason is that those teachers may not feel they know enough about the different views in a controversial topic to easily recognize the causes of misunderstanding that create the conflict.

It turns out the much of the anxiety that students may have about certain science-related topics is due to their misunderstanding of the NOS, not so much the topic itself. Issues like climate change, vaccinations, alternative medicine, and evolution are perceived by many as being scientifically controversial. In fact, there may be considerable political controversy over those topics, but very little scientific controversy. Students need to know the difference. But be careful: Choose controversies wisely. Selecting a wrong topic can actually impair understanding. Details for selecting useful controversies can be found in TA-15b.
One of the main reasons for introducing this NOS unit at the beginning of your course is that you can deal with the NOS elements in a positive way and in a fairly neutral context. Using a few milder, less emotional “controversies” in a NOS context helps immensely later in the course when you encounter a topic perceived as very controversial by some people (e.g., evolution or geological time). Referring back to their earlier NOS experience is usually sufficient to prevent emotional confrontations. This also sets the precedent of not being seen as attacking personal beliefs, but rather trying to repair misconceptions about the science of the topic.

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Part 3. Components Of The Unit

The General Approach Used
You are encouraged to use something like the effective constructivist strategy of the 5-E Learning Cycle to teach this unit—and, hopefully, your entire course (NAS 1998): Engage: Begin each unit (and as many daily lessons as possible) with an exciting and engaging opening experience for everyone (see Direct Links: Engaging Activities). Then Explore some additional experiences (see Direct Links: Index to NOS lessons). Then students should seek to Explain: after doing some interactive NOS lessons for a few days, show how those experiences involve certain concepts, and begin to attach appropriate terminology for the concepts experienced. This is where you could begin to assign some reading in Science Surprises, to further reinforce, connect and expand their experiences. Then engage in small group discussions followed by teacher-guided whole-class discussions. Be sure that students do the Self Check questions for formative self-assessment and for items to discuss later.

<table>
<thead>
<tr>
<th>The 5-E Learning Cycle</th>
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<tbody>
<tr>
<td>Engage: Intrigue, dramatize, reveal needs, create interest</td>
</tr>
<tr>
<td>Explore: Guided investigation, test predictions, new predictions</td>
</tr>
<tr>
<td>Explain: Focus, clarify, define concepts and terms, listen critically</td>
</tr>
<tr>
<td>Elaborate: New experiences, applications, practice, extensions</td>
</tr>
<tr>
<td>Evaluate: Assess, analyze, demonstrate understanding</td>
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</table>

Elaborate: In this phase, help your students to see other situations where those concepts apply. This would also be a good time to do a little class-wide formative assessment, to quiz students on their understanding of terms and concepts so far, for the purpose of correction and clarification rather than applying toward their final grades. You could include selected items from the Self Check Questions for this. An additional interactive lesson or two would also fit in here, to reinforce and apply key points. Finally, let students know that they should be looking for NOS elements throughout the course, and pointing them out to you.

Evaluate: Desired concepts for each ENSI lesson are provided in the lesson. Formative evaluation is accomplished with the Self Check Questions (SCQs) for each chapter. Each set of SCQs consists of some simple recall questions and some that require higher-order thinking skills. You may assign all SCQs, or any selected questions. Students should use them to self-check retention and understanding, and these should be further discussed in class to clarify and correct lingering misunderstandings. See more details below. For your convenience, see the Teacher Appendix TA-18 for the KEY to the SCQs. There are also several “rhetorical” questions scattered in the text, usually with illustrations. You might also want to use these for part of your formative assessments.
**Answering Self Check Questions:**
This is mainly for students to assess their own understanding of the material as they work through it. This is for their *formative assessment*. Ask them to answer questions in their own words without looking back at the material. When they finish answering one set of questions, students should go back to re-read the material, then revise or add to answers *without looking at the source*. Tell them this will help them remember and understand the material, and is worth the time (and brain effort) it takes. Encourage them to discuss items in their teams, then ask in class about any item still not clearly understood. If you want to count their work with the questions for credit toward their grade, that’s up to you, but I would keep it minimal. Another strategy that’s useful in classes where students might be self-conscious about asking questions in class is to have them put their questions on paper. They should discuss those questions in their teams, then each team selects one or more questions to ask the class. Research tells us that vocally explaining (*not* writing about) a concept to others is one of the best ways for them to discover glitches in that understanding, and also one of the best ways for that learning to be retained. Just be sure that the learning is accurate! Remember, the KEYS to the SCQs are in TA-18.

**Summative Assessment:**
This should be given after students have had sufficient opportunity to experience, discuss and learn the goal concepts, and revise any lingering confusion or misconceptions, with your guided clarifications and reinforcements along the way. Use assessment strategies that actually measure *understanding of concepts*, as well as accurate meanings of terms. *Accurate understanding of the concepts* is the highest priority rather than just memorizing the definitions of terms. A good measure of this would be their ability to apply or recognize appropriate applications of the concepts to new situations. Again, some of the Self Check questions could be used here, even restructured into a discriminating multiple-choice format for quick checking. Develop or use questions that truly require students to discriminate between accurate understanding and popular misconceptions. Don’t allow fuzzy thinking here! A sample *summative multiple choice exam* and key can be found in Appendix TA-20. This is just a resource. If you want to use items from this exam, just copy the ones you like, making changes and/or adding your own as desired. If you would like a Word/.docx copy to work with, just email the author to send same. See further comments about evaluation under *Assessment* near the end of this *Teacher’s Guide*.

**Pre-Test: Science Surprises Quiz**
A special effort must be made for students to have experiences that challenge their misconceptions. To help with this, it’s very useful to administer a quick Scantron®-type pre-test on the first or second day of class, one that will reveal the degree to which certain misconceptions exist in the class. When you score the answer sheets, be sure to run the automatic item-analysis for the entire class, if possible. This will enable you to easily go over at least those items missed by the most students in each class, (along with the percentages of those who selected the preferred answer for each item). If you do this, your students will see that they’re not alone in their misperceptions. In any case, use the pre-test as a post-test at the end of the unit, and perhaps again at the end of the year. This will give you feedback for your efforts, and tell you what you may need to revisit later in the course, and where to revise your approach for next year. You could also share the collective improvement with your classes, for its positive reinforcement value. When the pre/post test was used with this unit during its field-testing, many students
mentioned that they appreciated knowing how much they had improved. The new *Science Surprises Quiz* (with key) is in Appendix TA-19. The 25 items in this quiz were generally found to show the greatest improvement in the field-testing quiz from low pre-test scores to higher post-test scores (out of 40 items used in the field-testing pre/post tests). For details, see *Field-Testing Information* near the end of this Teacher’s Guide. This new 25-item quiz reflects a fair sampling of material from the revised *Science Surprises* unit. Corresponding chapter numbers for each item are shown in the key. There is a *Pre-/Post-Test Analysis* sheet in Excel on the *ENSI* website (see Direct Links).

**The Lessons**

The *ENSI* lessons used in this unit provide critical experiences. To be most effective, learning must involve active and critical student interaction. Therefore, the most important vehicle of this unit must be the several interactive lessons suggested, not the *Science Surprises* booklet. The text (*Science Surprises*) provides structure and context. It also provides reinforcement to the lesson experiences, introducing terminology and formal descriptions for the concepts discovered and discussed in the lesson activities just experienced. When we summarize all of the Nature of Science concepts found in the lessons used in this unit, we get a list of Key Concepts (see Appendix TA-1a). I suggest that those Key Concepts be listed on a large poster for the classroom, so that students and teacher can point to the ones that a particular lesson illustrates. For high school, you may also want to display (or present) the Basic Assumptions and Basic Limitations of Science, the bases for the Key Concepts and “Rules of Science” used in *Science Surprises* (see Appendix TA-2).

**Clarification of “interactive”:** The “interactive” aspect of all *ENSI* NOS lessons means interaction among students and among teacher and students. All of these lessons use experiences and prompts to stimulate discussion. Usually this is done in student teams first, then shared with other teams in the entire class, with the teacher monitoring all discussions for accuracy and appropriateness. None of the NOS lessons are interactive between students and computer. The teacher must download materials from the website and prepare them for students to use.

Therefore, most of the lessons will require significant preparation time, especially the first time you do them. Therefore, long before using any lessons, e.g., during the summer before fall classes begin, be sure to see if they require any major preparations. In fact, I would check out all of the lessons that you might use. Read them over, and start preparing the materials to be used for each lesson. Some require class sets of several pages. It’s much less stressful if you can run those off long before classes begin. Appendix TA-7 summarizes Preparations for Using Nature of Science Lessons, including Lessons Requiring Extended Preparations, and Key Points for Any Nature of Science Unit. Also, if you have never used the suggested *ENSI* lessons, it would help immensely to try them out in a class ahead of time. Many teachers do this in the late spring, after standards testing is over, and they have some flex time to do a few of those lessons, intended for use at the beginning of the fall semester.

Discovery is not open; it must be guided. Use some of the prompts (discussion questions) assigned to the students. Clarify as needed. Be sure students are actively using those prompts in their team discussions, even going beyond the prompts. Your job as the teacher is to make sure the connections are being made accurately and the key ideas are being brought to sharp focus. To
do this, you must move around in your classroom, listening to team discussions, chiming in for reinforcement, asking for clarification, or tactfully correcting as needed. If you plan to point out any misconceptions to the lesson, try to follow the suggestions of Effective Debunking described earlier. Mainly, be sure that you have first conveyed the Core Facts (main points) of the lesson as simply and clearly (graphically) as possible, and that you warn students when you are about to point out any related myth. Then, after you present the myth (briefly), point out clearly the gap or inaccuracy in the myth. It’s best if students “discover” for themselves the evidence that clearly refutes the myth, and supports the current objective understanding. Whatever you do, don’t dwell on the myth.

**Group Discussions: Structure:** All collaborative group work must have a clear structure that you must establish:

1. Have a clear purpose (provide a goal and perhaps some questions to guide the discussion). This could be posted on the screen or whiteboard, or with a handout to each team leader.
2. Be sure there is at least a team leader and a note-taker for each team. It’s probably best for you to make that selection, and rotate those roles for each new lesson. This is so everyone has a chance to practice those skills. All team members should be encouraged to support and help each job-holder, and actively participate. If anyone is apprehensive about doing these jobs in a small group, ask them to try, and you’ll come around to help out as needed. Ask team members to support the reluctant ones to do their jobs.
3. Each leader should encourage non-participants to speak up, give opinions, ideas, share information, ask questions, get involved.
4. In final “Wrap-up” minutes, each leader must make sure everyone knows the goal(s) they have achieved, and that each member has been assigned a task to do before they meet again (if there are any such tasks). A good way to do this is to have each member re-state their accomplished goal(s), and what she/he will do before next meeting (if necessary).
5. As teams are working, it’s very important for you (the teacher) to circulate, listen, monitor progress, offer advice, suggestions, encouragement, praise, corrections, etc. as needed.
6. Be sure to have teams model the above, and reinforce each time, as needed.

Most of the lessons are intended for small collaborative teams of 2-4 students each. In-team discussions are the critical interactions, as is the subsequent out-sharing of all teams with the entire class. When students verbally explain and defend their explanations, research shows that this is the most effective way for their understanding to grow. Encourage teams to constructively challenge and question each other for clarification on their explanations and conclusions. It’s usually helpful to provide questions – prompts – that get students truly discussing the concepts. The ENSI lessons do provide these, but you may want to omit one or two, or add new ones. Generally speaking, students should do an interactive “lab” or lesson before they read about its concepts and terminology. Experiences and some understanding should come before the introduction of labels, so that the terms will be meaningful to the students when they are introduced in the text. This also helps students to realize that it’s the concepts that are most important, not the labels. The labels are primarily to facilitate future discussions (and assessments).
This program is structured for maximum flexibility. Even though lessons are suggested in context, your selection of lessons and their sequence, are left to your discretion. It depends on your grade level, style of teaching, background and readiness of students. It also depends on the content of the course textbook used, and how much time you can devote to the topic. You should at least read the synopses and concepts for all of the Nature of Science lessons (see the NOS Lessons Index on the ENSI site) so you can see what’s available. All of them illustrate two or more NOS concepts, even though their approaches may vary. In selecting appropriate lessons, you may want to also consult Appendices TA-3: ENSI NOS Lesson Matrix, and TA-4: NOS Concepts by Chapters and Lessons.

It doesn’t hurt for students to experience the same NOS features in different contexts; in fact, the reinforcement is very helpful. Encourage your students to point out those NOS features when they see them, and praise them or reward them when they do. Furthermore, you may notice that some of the lessons have a biological connection. If your class is a physical science or earth/space science, you may want to find a comparable lesson that fits your course more closely.

The Appendices:
For greater flexibility, there are several appendices in the student booklet that delve more deeply into some topics, so they can be assigned as appropriate. Some would be best for high school classes, or they might involve more time than you can dedicate in your NOS unit. Some could be assigned for homework, or suggested for extra credit. Or plan to integrate a few into later topics in the course. In some classes, an Appendix topic might just be too confusing for your students at this time. Read them over, and assign accordingly. That’s your option.

I do recommend that all students use at least these four appendices if possible: SA-1.1 (Methods of Science), SA-3.3 (Hypothesis Explained), SA-4.3 (Activity: Good Science vs Poor Science), and SA-5.3 (Our Search for Understanding). That last one is a very helpful graphic that gives an overview of many of the terms and concepts used in this booklet. It would be helpful to share it when you review the unit with your class.

Implementation Options
1. Teach Science Surprises as a single 2-3 week NOS unit at the beginning of the school year or course semester. This is a fairly tight package, especially in 2 weeks, but with careful scheduling, with average kids, it’s doable. You do need to be very selective of lessons, and possibly do a shorter investigative study (instead of the Oat Seed Lab). To help with selecting lessons, see Teacher Appendices TA-3, 4, 5a and 5b.

2. Teach the first 2-3 chapters of Science Surprises in the first week or so, then insert subsequent chapters (with appropriate ENSI lessons) later in the course, between other units. Chapters 4 and 5 deal mostly with how the quality of science is often compromised, and how critical thinking skills helps to recognize poor science and pseudoscience when we meet them. Opportunities to practice those skills are provided. Those chapters could be easily inserted at other points in your curriculum. Allow for about 1 week to do each chapter, including the recommended ENSI lab/lessons.
The treatment here will focus on option #1, so if your schedule allows for only a week or so at the beginning, you will need to select option #2, selectively reduce the materials used, and parse the material (lessons and chapters) appropriately through your course. The lessons and chapters selected could be based on the pre-test results.

Sample Schedules
To help you plan your unit, three sample schedules are provided in this Teacher Guide (Appendix TA-6, a-d). The three-week schedule is preferred for maximum impact. If your curriculum does not allow 3 weeks for this, the two-week plan should suffice, but it will be tight. In either case, but especially if you use the 2-week plan, be sure to integrate at least a few lessons not used in your NOS unit into other places in your curriculum later on where appropriate. Perhaps one or two can even be inserted into a day or two “break” between units, just to remind your students of some key elements of the nature of science.

The following details for presentation will follow the 3-week schedule. The Student Info Sheet (SIS) mentioned for the first day is suggested so that you can get to know your students as soon as possible, take quick roll, and target useful interests. A sample form is available from the author. If you would like to have Word/docx files of any items mentioned here, to make it easier to modify so it fits your class better, just e-mail the author.

Distributing the Science Surprises Student Booklet
There are five ways that you can provide the booklet for your students:
1. Upload PDF file of Science Surprises to your teacher/school website with student access;
2. Transfer PDF files of Science Surprises to individual student USB memory sticks;
3. Transfer PDF files of Science Surprises to individual student e-books or tablets;
4. Have your district print hard copies from a PDF file;
5. Obtain class sets of printed copies of Science Surprises from the publisher.

If they all have ready access to a computer or certain e-readers, (certain e-books, or tablets) you could simply post the Science Surprises material on your school website with access restricted to your students Or (more work), you could provide each student with a digital copy of the entire booklet. To do either of these, you can request from the author that a PDF version of Science Surprises be e-mailed to you as an attachment. Then you can upload that PDF file to your school site, or attach that file to emails addressed to of all your students. Or, if preferred, students can get digital copies from you on their USB thumb drives, which they can transfer to their computer, pad, or e-book. Not all pads or e-books may accept PDF format, so that’s something you would need to check. If you prefer to have hard copies for each student, you should order class sets from the publisher. The author would appreciate hearing from you about how you distributed the text, and what special instructions or cautions were necessary.
Part 4. Getting Started

Engage

**Day 1:** The most important day of the year! Every teacher does this differently, but time management is very critical for this NOS unit. You have three priorities: roll call, pre-testing, and getting student information for making a seating chart. You also want to engage your students, and give them a sense of excited anticipation for your course and your teaching. Therefore, I have provided here an example of how I might handle the first day. See below, and see the Teacher Appendix TA-6b for a detailed day-by-day suggested treatment. Feel free to modify according to your particular style and/or needs. Be sure you have numbered your pre-test quiz sheets to be sure *all* are returned before the end of the period, so you can use them for your next period (and none get out the door to be shared with other students!).

As soon as students are seated and you welcome them to your class, share some kind of surprising illusion or discrepant event. You could use the T-illusion in some dramatic way (from the “Perception is Not Always Reality” lesson), or perhaps some other illusion [Search online for “discrepant events,” especially on YouTube; be creative]. This usually gets their attention. If someone doesn’t ask (“How does that work?” or “Why is that?”), then you ask, followed by “Do your eyes play tricks on you? Can you depend on what you see?” If answers are yes or no or both, say “Can anyone think of an illusion in *nature*?” Accept a few examples, then say “Well, that’s why we have science. Science can help us to understand what’s really going on. And this year, we’re going to take a close look at just how science does that. There may be some surprises! But first, …” [Here, you can do your usual first day routine, taking roll, etc., or try the following].

“I’d like to get acquainted with each of you as soon as I can. This *Information Sheet* [hold it up] will help me do that. Where you are sitting will be your assigned seat for now, and that will probably change later. See the ‘Desk Number’ on your desk? Please put that in the upper right corner [show them] of your Student Information Sheet. That will help me to set up a seating chart. While you work quietly on this, I’ll take roll, then I’ll hand out a little pre-test answer sheet and quiz to see what you already know about science. Please go to the quiz as soon as you get it, then when you finish, continue working on your Information Sheet. I’ll collect those items as you finish, before you leave today.”

Once all Student Information Sheets are all out, ask “Did you put your Desk Number in the upper right corner? [Show this again]. If not, please do it now.”

Do your oral roll call. Then walk around handing out all the quiz *answer* sheets, then all the *numbered* quiz *question* sheets. When all quiz sheets are out, say “Would you please put your *Desk Number* at the end of your name on your quiz answer sheet?” Look around to see that they are all doing that.
As they work, walk around, collect Student Info Sheets, making sure each has name and Desk Number on it. Then, as they finish the quiz, walk around collecting answer sheets, making sure each has name and Desk Number on it. Finally, collect all question sheets and sequence them by number. If any numbers are missing, track them down and collect them before letting class go. The collected Student Information Sheets makes an excellent source for building your seating chart, and the collected quiz answer sheets can serve as a check on that.

As time allows, try one or two “False Assumptions” (see ENSI NOS lessons). Before the bell rings, be sure to announce “No homework tonight! Please take these same seats when you come tomorrow.”

Latter that day, be sure to score the pre-tests, and do an item analysis for each period. You will want to use that information later.

Read the Teacher Prep at the end of Day 1 details, especially re: the Oat Seed Lab (TA-6b)

**Day 2:** Start the Oat Seed lab. See other Day 2 details (TA-6b)

**Processes of Science**

In most science textbooks (and therefore in many science classes), “The Scientific Method” (TSM) is usually presented as THE process of science, often required by teachers to memorize as a strict sequence of steps, almost a mantra, that somehow magically makes any study into good science. Unfortunately, this gives the mistaken impression that this is essentially all there is to science. Many students never come to realize that there’s a lot of excellent science that does not rigorously follow that process (TSM). Processes of inquiry tend to follow different protocols in different fields of science. There’s more about that below (also see Student Appendix SA-1.1). In any case, there are many important aspects of science that go beyond those processes—and that’s what this booklet is about. See “How Science Works” in the Understanding Science website listed in the Useful Websites following the Teacher References. Also see Firestein, 2012.

**Experimental Science:** However, to the extent that TSM may reflect the essence of most experimental science, and that state and/or national standards expect experience with this, students should still have the opportunity to work with at least one simple investigative study, starting as early as possible, even in the first few days. There are many such studies you could do. As an example (for Biology or Life Science), you can use the Oat Seed Lab in ENSI’s Nature of Science collection. It’s a useful, guided and modeled introductory investigation (see Direct Links). It’s an example of what is technically called the “hypothetico-deductive process” (HDP), but students don’t need to know that. The lab runs about two weeks, with a few minutes spent each day of the second week recording oat seedling lengths, while other lessons and assignments are carried out concurrently. Upon completion, the lab data are processed (graphed and analyzed statistically), the results are discussed, and the entire study is presented in a formal report, following a modeled style and format. All directions, forms, and examples are provided. This experience provides a model that students can use for selected investigations during the course, either as complete inquiries, or for practicing parts of the inquiry process, as appropriate.
and as time allows. Students also have a model to follow for doing any special projects for extra credit or science fair competition. This lab works best in the 3-week unit.

If you are teaching a physical science or earth science course, just do an alternative inquiry. For example, consider a simple pendulum inquiry, where students can test the effects of a variable (mass, pendulum length, or starting position) on the time taken for 10 swings (for example). See TA-8: A Pendulum Experiment.

Perhaps you can find another simple inquiry that relates more closely to your course, and could be done in a day or so. Another ENSI inquiry to consider would be the Perception is Not Always Reality lesson, where students analyze why a simple illusion is an illusion. The value of this one is that it’s not quite as “biological” as the Oat Seed Lab, it’s engaging, and it introduces students to natural illusions, a productive target for many scientific investigations.

Historical Science: To get a broader perspective of how science operates, students must also experience the general approach used in the historical sciences. This kind of science is used for studying non-witnessed past events that cannot be repeated or studied directly, so they don’t lend themselves directly to the process of repeated experimentation. Instead, scientists seek and analyze clues to those past events. Such studies are typical in the fields of geology, paleontology, astronomy, evolutionary biology, paleoclimate science, and forensic science. In such studies, scientists look for clues of past events, and develop strategies for testing those clues and the events inferred from them. Some people have the mistaken impression that any science that does not involve TSM is poor science. They assume that, to be good science, it must deal directly with observable and repeatable phenomena. There must be an experiment, with independent and dependent variables. This, of course, is completely false, which is why students must have experiences with the effective methods of “historical” investigations and other strategies for doing excellent science. This is a most important part of their introduction to science. At some point in your course, your students should work with at least one or two such lessons. They should at least recognize an example of historical science when they see it.

With the popularity of TV crime scene investigations, one of the most engaging approaches to historical science is to have your class do a forensic lab. There are many available, but you can find a couple on the ENSI site. One of these is fairly straightforward, and could easily be done during this NOS unit: Crime Scene: Case of the Missing Microchip. You can find this in the Nature of Science section of the ENSI site.

Making testable predictions, based on hypotheses formed from observations of evidence (clues), is an important part of these lessons. The Checks Lab is a very popular lesson that also nicely simulates this kind of science, using easily prepared materials from the ENSI site. The lab also models several other important elements of the nature of science, including its tentativeness, degrees of tentativeness, its social context, and its biases or assumptions. It also provides an excellent opportunity to practice scientific argumentation. Another “historical science” lesson to consider would be The Great Fossil Find; it’s engaging and easily done in one period. And like the Checks Lab, this, too, models other elements of the nature of science.
If your course is biology or life science, there are additional ENSI lessons that reflect the procedures of historical science. You should do these later, in your introduction to evolution, or chromosomal genetics units. When studying fossils and/or evolution, check the **Footsteps in Time**, and **Laetoli Puzzle** lessons. They are in the Human Evolution section of the *ENSI* Evolution index. When teaching DNA or genetics units, try the **Mystery of the Matching Marks** lesson (on chromosome fusion) for an additional “historical science” example. When studying macroevolution, showing how the speciation process accumulates over time to produce what we see as major groupings of organisms, do the **Becoming Whales** lesson, where students can predict an expected body plan between two sets of fossil lines, then “discover” a new real fossil that fits perfectly into that time and morphology slot! Further work can provide evidence that confirms whale genealogy, and also illustrates a prime example of how **multiple lines of evidence** make for **stronger science**. (See the **Whale Ankles and DNA** lesson.) However, remember that your introductory unit on the nature of science should probably not even touch on evolution, for reasons explained elsewhere in this *Teacher’s Guide*.

For physical or earth sciences, perhaps you can find a simple inquiry (or simulation) that explores a problem in astronomy, geology, paleontology, or forensics investigations.

When you can, make some time available (10-15 minutes) at the end of a period early in your unit to introduce or continue the **False Assumptions** lesson. This alerts the class to the fact that we commonly do make false assumptions. We accumulate biases based on experience, “common sense,” common word usage or other influences. But we seldom realize it. False Assumptions get students to think critically “outside the box” about this common human tendency. Afterwards, whenever there are 5-10 minutes at the end of a period, display (or say) one of the False Assumptions and get the class to solve the puzzle. This makes for a productive and engaging “sponge” activity.

**Explore**

**The Realm of Science**

Once your processes-of-science lessons are underway, do some more magic! Engage your students again with some illusions. If you can, do a little sleight-of-hand, or use some easy-to-use gimmick from a magic store, or show a discrepant event, where something unexpected happens, raising the questions “Why?” and “How?” Whatever you do, be sure to practice in front of a mirror or “personal audience” (spouse, kids, friend). And be sure to make a convincing effort to attribute the magical event to your “magical powers!” This should segue nicely into doing the **Magic Hooey Stick** lesson, or the **Great Volume Exchanger** demonstration. All of this, of course, is to get your students to ultimately recognize that science cannot deal with magical or mystical problems as such. This is one of the most important realizations that your students must learn. The reason for this is explained in the lessons and in the *Science Surprises* booklet.

You should definitely do the popular **Sunsets, Souls & Senses** lesson to help your students realize the limited realm of science, showing that science can only deal with natural phenomena. It also brings up a number of misconceptions about science.
Part 5. Introducing The *Science Surprises* Text

**Chapter 1: Engage: Why Science In Your Life? and What Is Science?**

**Reading Assignment:** After the first 3-5 days of interactive lessons, the *Science Surprises* booklet can now be distributed (or made available online) and homework assigned to learn *why* we should all know about science, *what* science IS, and *how* it works (Chapter 1 and **Self-Check A**, which should be discussed the next day). Two useful teacher resources (see **Useful Websites** below): Mike Brotherton blog (The Importance of Science: Ten Reasons) and **Science Learning** (Reasons for teaching features of the nature of science). You’ll find lots of material here for discussion.

Here’s a truly off-the-wall engaging experience that is guaranteed to grab the attention of your students: On the first day following your assignment to read chapter 1, open the period with the dramatic experience of **Deep Ignorance**. See the **Direct Links** following the **Teacher References**. If you can, get a copy of Stuart Firestein’s little book *Ignorance: How It Drives Science* (2012) and read about how ignorance does that. It’s a novel, yet meaningful way to see just what really motivates scientists. Author Firestein also presents a delightful TED talk on this concept (see **Useful Websites: Pursuit of Ignorance**); you might want to show this to your students. If you don’t do **Deep Ignorance** now, do it later, or even earlier. It’s a great motivator to encourage creative students to explore science as a possible career. As you will learn in the last chapter of *Ignorance*, author/scientist Firestein started out doing various jobs in theater productions, and only later discovered the deep satisfactions of doing science.

Chapter one opens with several figures illustrating a number of examples showing some key elements of the nature of science. For example, its *tentativeness*, new ideas replacing old ideas (with evidence), scientific knowledge is always getting better, new evidence disproving earlier understanding, and science can only use natural explanations, never supernatural or magical explanations. This is followed with a list of these and other elements of the nature of science. The logic here is that students should first recognize important realities about science, with impressive graphics, not its misconceptions. Then, when particular misconceptions are encountered, they will be warned about then. Then they will get experiences with the real elements of science (in the ENSI lessons), and learn why those misconceptions are misconceptions. This all reflects the recommendations in the *Debunking Handbook* (Cook & Lewandowsky 2011) This approach has been critically studied, and found to be effective. See the summary of these tips in **Effective Debunking** under **Dealing With Misconceptions** in Section 2 of this **Teacher’s Guide**.

Note about Earth: Information about flat earth to spherical Earth views (people and dates) are not important here. Interested students might want to search those names for more information. Also note that the flat-Earth view was not really scientific. And note that the spherical-Earth view (and evidence for that) long-preceded Columbus’ voyage across the Atlantic. It is also clear that Columbus, contrary to popular myth, was well-aware of our spherical Earth. Actually, the idea of continental drift and plate tectonics is a much better example of an earlier assumption by scientists (static continents) being changed by new scientific evidence. That situation is used in Chapter 2. If you know of a good example in your field, use it! Especially if it’s dramatic.
When you discuss the **reasons why science is important**, have your students identify examples that relate to themselves. In “What Do Scientists Do?” ask if they remember when they were really curious about the world, and what kinds of questions they asked when they were young children – even silly questions. Also ask how those questions were answered. Were they just ignored, or were they given the desired answer, or were they encouraged, with a few questions and hints, to figure out the answer? Who did that? Was it a parent, a teacher, a friend of the family? Were any of your students surprised about what scientists actually do? Were any surprised that there is NO **one Scientific Method**?

In your class discussion, be sure to read the **Rules of Science** to your class, commenting that each rule will be explored in some detail in the following pages. You might also want to point out that these “Rules of Science” are based on certain **assumptions** and **limitations** of science (Nickels 1998). In high school classes, you might want to display the list of **Basic Assumptions and Limitations of Science** that serves as the basis for those **Rules of Science**, which you might also display as a big list on a wall of the room (**Teacher Appendix TA-2**). To reinforce and provide additional experiences, refer to the **Magic Hooey Stick**, or **The Great Volume Exchanger** experiences if you did either one. Or do one of them now if you haven’t. These lessons provide vivid opportunities to further drive home the fact that science can only deal with **natural** issues, not supernatural (as such), and can only use **natural explanations**. Be sure that your students understand **why** this is: it’s not just somebody’s opinion or assertion. Supernatural or magical explanations **cannot** be **reliably tested**. Any outcome to such a test could be due to the unpredictable mystical forces in play. But scientific understanding requires that potential explanations be subjected to tests that must have definitive, predictable outcomes if the explanation is a valid one, and different outcomes if it’s **not** valid.

Discussing the **“windows” metaphor for different ways of knowing** (Moore 1984) can be a big help, as can the **“sports” metaphor with different rules for different games** (McCain 1988). If you have the time, you could even do the **Palpating Pachyderms** lesson, providing an opportunity to discuss the several different “windows” to understanding, of which science is one (a very powerful one, as they will learn in **Science Surprises**).

When you discuss **Why Science is Not Always Logical**, and how things may not always be as they seem, share another discrepant event or contrived illusion. Then give an example of a natural illusion, e.g., “sunset” and “sunrise.” This idea of natural illusions was hinted at in Figure 1.1 at the beginning of this chapter (spherical Earth, not a flat earth). Be sure to show the **video** taken by astronauts from the International Space Station as it orbited around the Earth: <www.wimp.com/stunningearth/>. They will see our atmosphere edge on, the aurora borealis, lightning, lights from cities, stars, and the Russian shuttle attached. They will also clearly see that our Earth is clearly a ball. You might ask for other natural illusions they have experienced and taken for granted, but were later, under careful observation and critical testing, found to be incorrect. They might mention the old beliefs that lightning and floods were caused by the gods to punish people; diseases were supposedly caused by “bad deeds” or “evil spirits.” They may cite again the ancient belief that the Earth was flat, and fixed, while the Sun revolved around the Earth. Help out with a cue or two, and make a short list of these. **The Flat Earth ENSI** lesson offers an interesting example to explore, and it could lead to other examples, e.g., the more
recently corrected misconception in science that our continents were fixed in place, never moving. If you are aware of similar examples from the topics of your course, you might at least mention those. These ideas are further treated in Chapter 3. Also, see Student Appendix SA-3.2

Some Old Theories Replaced.

All of these examples provide the clear message that scientific knowledge is tentative, but it’s also important to point out that some ideas are more tentative than others. This fact is seldom presented in science textbooks or classes. Put another way, some understandings in science are much more reliable (closer to reality) and long-lasting (durable) than others, depending on the volume and quality of critical study that has been done on them. It also depends on the number of independent lines of evidence that point to the same understanding. Finally, the level of credibility of a scientific understanding depends on how well it works in its applications in the real world. Students should recognize the relative reliability and durability of different kinds of scientific knowledge. These points are treated more deeply in chapter 3, so you don’t need to spend lots of time on them here, or give them labels, yet.

This is also a good time for students to recognize that most engineers and medical doctors are really not scientists – one of the most common misconceptions about science. Ask your students why they aren’t scientists. What would they have to do to be practicing scientists? You should also distinguish between the natural sciences, the social sciences, and the applied sciences.

At this point, students should have some experience with interactive lessons in which they discover that they are thinking of possible explanations (which some students may recognize as “hypothesizing”) and testing those explanations as a process for problem-solving. This requires some “meta-thinking” about what our minds often do subconsciously, and the Mystery Boxes lesson is perfect for this. But so are several of the others, including Find the Washer, Three-Hole Bottle, and the Checks Lab (which you can refer back to if they’ve already done it). In addition, any of these lessons provide opportunities to practice scientific argumentation (giving evidence for claims made). An excellent resource for scientific argumentation is in the “Direct Links on the ENSI Website” (following the Teacher References).

If not already assigned, ask students to do the Self Check Questions Set A. Next day, have them discuss their responses within teams, then each team with the entire class (class discussion guided by the teacher).

Chapter 2: Explain & Elaborate: What Science Is Not: The Limitations Of Science. This would probably be a good place to more formally introduce students to some of the main assumptions and rules of science. Science Surprises does this nicely, bringing terminology to the concepts learned in their prior lab experiences. If they have done 2 or 3 of the NOS labs suggested, they should be ready to read What Science is NOT, so you can assign them to read the material in Chapter 2 and doing Self-Check Set B. Be sure to reinforce the concept that science is not democratic (and why that is). By the way, Figure 2.1 was taken by the author on the west (Kona) coast of the Big Island (Hawaii) when he was there with a group of students. This rich mix of reds, yellows and purples was also notable for its longevity – it just kept getting better!
Also, reinforce the fact that testing (or challenging) ideas is the most important part of science, and that this is largely a process of trying to disprove possible explanations, not “prove” them, as commonly assumed. (Avoid using “hypotheses” for these tentative explanations for now. It’s the concept that’s most important – labeling comes later.) Dramatize the picture of “testing” cars for safety by crashing them. Ask students why insurance companies would be interested in crash-testing cars (the photo comes from a company that does this for insurance companies). This costs a lot of money, so there must be a cost-benefit here. Do they discover cars that survive best cost less to insure? These experiences should help students to begin developing the skills for proper critical thinking.

When you discuss the Self Check Questions (SCQs), include some discussion of the last two figures (Figures 2.5 and 2.6) used in this section. This is where deeper discussion can focus on another key rule (introduced in chapter 1) that supernatural forces cannot be used for scientific explanations, and why this is so. Failure to clearly understand this most basic rule of science lies at the core of much of the common misunderstanding about what science can and cannot do. That confusion makes us vulnerable to those who distort science for their own purposes. Students must be able to explain why supernatural explanations cannot be used in science.

Science and Religion: While making a strong case for supernatural explanations not being used in science, it’s also important to remind your students that science does not say that religious or supernatural explanations are wrong. Rather, in science, we just cannot use such explanations because we cannot test (try to disprove) them scientifically, so science must remain neutral on all such issues. Nevertheless, don’t bypass the opportunity here to point out how science has figured out the natural explanations for many phenomena formerly thought to be supernatural, providing tested alternatives to those traditional views, consistent with observations. Some people view this power of science as a threat to their deepest traditional beliefs, which may explain why they resist science so passionately. Reference to Figure 2.6 with the lightning strike would be a good example for discussing this.

In any case, students must be assured that they can still believe what they want to believe, and should respect the beliefs of others, but they must also recognize that faith-based beliefs cannot be a part of science—science is not based on mere belief or authority, but on the critical testing and analysis of observations. If the conclusions of science and religion seem to conflict with each other, there might be a flaw in one’s understanding of their beliefs. Or there might be a flaw in the science, or in their understanding of the science, or in their understanding of how science works in general. And that’s what this unit is about. This should encourage students to dig deeper to improve their understanding of all perspectives, hopefully as a goal for a lifetime of learning.

A critical difference between traditional beliefs and scientific understanding is that science is open to change, if the evidence warrants it. But beliefs, based on faith and authority, generally resist change, regardless of the observed and tested evidence. In the end, it may all come down to what is most convincing or important to a person. Still, many are open to both views: going with their religious beliefs in certain circumstances, and with the scientific consensus in others, as appropriate.
You may want to tell your students that most scientists hold religious or spiritual beliefs, and that none of the world’s major religions have any problem with science, so one world-view doesn’t automatically exclude the other (Matsumura 1995). Part of this compatibility depends on how we interpret our beliefs and the nature of the authority for those beliefs, as compared with our confidence in tested observations. But an important part of this equation to many is what they see as the frightening consequence of opposing a traditional authority or belief, and that can be very powerful. Read Nelson (2000) for his “rusty hand grenade” metaphor for dealing with this.

Nevertheless, as science teachers we are obligated to teach the nature of science, and reject all efforts to distort them with misinformation or misconceptions. Appealing to honesty and accuracy could be a worthwhile approach here. It might be helpful to remind students about how many showed several misunderstandings about science in the pre-unit Science Surprises Quiz. Again, looking at religion and science as different “games” with different rules, or different “windows” to understanding (as described in the student booklet) are useful metaphorical ways to help students see them as different ways of knowing about the world, and that they need not be mutually exclusive. If you haven’t done the Palpating Pachyderms lesson, consider doing it here—or refer to it if done earlier. The mutual goal of this unit, and the course, should be to help students to accurately understand how science works. Assure your students that many seeming conflicts will disappear once they fully understand key NOS aspects, and knowing what science is NOT sharpens their understanding of what it IS.

For the last word, one of the basic National Science Education Standards (high school content standard G) succinctly states: Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific. (NRC 1995).

As you anticipate chapter 3: Words of Science, and you have the time, do another one of the “historical” science lessons that you haven’t done, e.g., the Checks Lab, The Great Fossil Find, or the Crime Scene: The Case of the Missing Computer Chip lesson. As you move into chapter 3, students will have that lesson to apply those labels of science to the concepts experienced and discussed. The lesson will also remind students that lots of good science is done without doing “experiments.”

Assign to read as homework: Chapter 3. Words of Science: Observation and Explanation, and Problems With Words, and do the Self Check Set C.

Chapter 3: Words Of Science – Observation And Explanation
After discussing the material (Self Check Questions in set C), have them read Appendix SA-3.3: Hypothesis EXPLAINED. They should also practice reading and writing hypotheses, so be prepared to hand out one or more of the practice sheets provided (Teacher Appendix TA-9, 4 sets of practice sheets). Every student should have his/her own practice sheet(s) to work on (perhaps as homework). Students (in teams) should share and discuss their efforts while you circulate around and monitor the teams. If they are still having trouble with one Hypothesis Practice Sheet, hand out the next one (to do for homework). They should then discuss that one in teams the next day.
In the paragraph beginning with “Natural Illusions,” students are asked how fast the Earth travels in its orbital path around the Sun. See if they have found (or calculated) the circumference of our orbit around the Sun (about $940 \times 10^6$ km, or $583 \times 10^6$ miles), then divided that by 8765 hours ($365.2$ days x 24 hours per day). They should get about 107,300 km/hr (66,500 mi/hr). This is a good chance to show students how to do this kind of problem. (If you’re rusty, have a chemistry or physics teacher help you with this. See details below.)

Keep in mind that Earth’s orbit around the Sun is a nearly circular ellipse, so, for general calculations, it is treated as a circle. Numbers from different sources will vary mainly to rounding errors. Most of the figures below were taken from the Curious Astronomer site: <http://curious.astro.cornell.edu/question.php?number=356>.

To calculate the velocity of Earth in its orbit around the Sun, start with Earth’s average distance from the Sun - the radius ($r$) of our orbit around the Sun: $149.6 \times 10^6$ kilometers ($92.75 \times 10^6$ miles). The circumference ($C$) of our orbit around the Sun would be:

$$C = 2 \pi r \quad \text{or} \quad C = 2 \cdot \left(\frac{22}{7}\right) \cdot 149.6 \times 10^6 \text{ km} = 940 \times 10^6 \text{ km per year} \quad \text{OR…}$$

$$C = 2 \cdot \left(\frac{22}{7}\right) \cdot 92.75 \times 10^6 \text{ mi} = 582.8 \times 10^6 \text{ mi per year}$$

Time ($T$) in hours, for one year is $T = \left(\frac{365.2 \text{ days}}{1 \text{ yr}}\right) \cdot \left(\frac{24 \text{ hrs}}{\text{ day}}\right) = 8765 \text{ hours / year}$

Velocity ($V$) = $C/T$, so $V = \left(\frac{940 \times 10^6 \text{ km}}{8765 \text{ hrs}}\right) \approx 107,300 \text{ km/hr} \quad \text{OR…}$

$$V = \left(\frac{582.8 \times 10^6 \text{ mi}}{8765 \text{ hrs}}\right) \approx 66,500 \text{ mi/hr}$$

Students should get results that at least approximate those numbers. Then, when they add the velocity of our spinning Earth near the equator (about 1000 mph, or 1600 kph), we get: 107,300 km per hr + 1,667 km per hr $\approx$ 108,967 km per hour, and…

66,500 mph + 1000 mph $\approx$ 67,500 mph

The “Big Moon Illusion” is another natural illusion presented with a diagram (Figure 3.2). A possible explanation is given, but students are asked how that idea might be tested, and asked to consult the teacher. If asked, see Teacher References for Kaufman and Kaufman (1999). The full article, testing that illusion, is available at <http://www.pnas.org/content/97/1/500.full>.

Science as a powerful tool: A useful reference for the fact that eyewitnesses to crimes are often wrong: see Bridge & Voss 2014.

Notice that terms for Scientific Explanations (where we use our brain to infer, or make sense of observations) are introduced as distinct from terms for Scientific Observations (where we just get sensory information). Help students to see those distinctions.

Have students make a concept map or mind map after showing them how (Do This #3.1). You might also have them make a list that prioritizes those terms (Do This #3.2). See Teacher Appendix TA-10 for a Sample Concept Map of Science Terms, and TA-11 for a Sequence of Terms of Science. Discuss both maps with your students. After showing and discussing the #3.2 sequence that scientists would choose, ask your students where they think “observation” would fit in, and why they think that. [My sense is that it would go on the bottom, below facts. Reason?
Simple observations have not been analyzed, correlated or processed. By themselves they are not as useful or informative as facts, hypotheses, laws or theories. Read Scott (2004), p. 11-14 for an explanation of the sequence.

A Deeper Study of Words:
A key part of this introduction to the terminology of science is the clear distinction between theory, hypothesis, fact, and natural law. In addition to the distinctive definitions for each of those terms, it’s also very helpful for students to become aware of some of the more common misuses of those terms—even by scientists, and by some teachers—and the possible reasons why this happens. This can help sharpen their understanding.

The main body of Chapter 3 touches on a few important points that are often confused. If you want your students to have a more in-depth experience with these and other common problems and confusions with those words of science, you should have them read their Appendix SA-3.4: More Problems with the Words of Science, and do the Self Check for that Appendix. This would probably be more appropriate for high school science classes, but read it, then try it with your students if you think they can handle it, and you have the time. If you do this, it might be most appropriate to assign Appendix SA-3.4 after you have discussed this chapter on The Words of Science, and follow that with further discussion of the Self Check items found in SA-3.4.

In addition, because of the widespread popular use of theory as a tentative or speculative idea, even by scientists at times, you might consider David Morrison’s suggestion to drop the word (theory) from the titles of long-established, fully supported theories, e.g., atomic theory, germ theory, plate tectonics theory, cell theory, and evolution theory. If “theory” is used, it tends to reinforce the vernacular meaning of the word as being only tentative and not well-established. As a matter of fact, what was once called “The Big Bang Theory” for the origin of the universe is now just called “The Big Bang.” This is because there is such an abundance of evidence that supports it. All of those other concepts are also clearly much better established and well supported by evidence than the popular use of “theory” would suggest. Future references to those concepts should simply convey the matter-of-fact acceptance they actually have in science, using, perhaps, the word “principle” instead of “theory” if necessary.

You may want to explain briefly why you will henceforth avoid using “theory” with those concepts, and will expect your students to do likewise (Morrison 2005). However, if you think that any mention of “evolution” might raise passionate opposition in your class, then be sure to avoid any such mention of the word here. As discussed earlier, a major purpose of this extensive treatment of the nature of science at the beginning of the course is that students can come to recognize (and accept) that there are certain rules to science, and can do this in the relatively neutral context of NOS elements, without the influence of what could be emotionally charged issues to cause distractions, defensiveness and divisiveness.

On the other hand, course standards may expect students to know and use the word “theory” properly. So that’s a case for teaching and using “theory” only in its “well supported” scientific sense, never in its popular sense as speculation. Instead of using “theory” in its vernacular sense, use words like “idea” or “hunch” or “model.” Instead of saying “What’s your theory about
that?”—say “What’s your idea about that?” Try to get your students to raise their hands whenever someone (even you) says something like “I’ve got a theory about that.” They can make a pre-agreed-upon “T” with their hands, for “Time out” (or “Theory?”), so everyone will know that the speaker needs to back up and use a proper term (e.g., “model,” “idea” or “hypothesis”). In any case, never accept (or use) the phrase “It’s only a theory.” Use the big T sign. Let students know this, and ask them why that’s a totally wrong phrase. By now, they should know that. You might even introduce that phrase as an example of an “oxymoron”: an expression with self-contradictory words. Instead, they should say something like “It’s only an idea.”

Tentativeness & Uncertainty: Degree and Durability
Throughout this unit, most of the lessons demonstrate and emphasize uncertainty. This is another feature of science that is often misunderstood. It’s the way science gets better; it’s one of the important strengths of science, giving it great flexibility and usefulness, and leading to an increasingly accurate understanding of our world. Firestein (2012) says we should celebrate a tolerance for uncertainty. In addition to the lessons already suggested, especially the “Checks Lab,” seriously consider doing the “Mystery Boxes” lesson to provide vivid experiences with the uncertainty in science. This is especially important for understanding how scientists use clues to study currently inaccessible phenomena, like atomic structure, extinct animals, the Earth’s core, or distant stars. Mystery Boxes also helps to distinguish “inferences” from “observations,” and it includes a kind of “peer-reviewed publication” component as well.

At the same time, students need to realize that established scientific knowledge is generally durable—it survives well over the long haul, and gets better (more accurate) over time. This seeming paradox could be confusing to students, so be sure to point out that the degrees of uncertainty are relative, and depend on how well-tested the concept is, and how well it has worked in its practical applications over time. There are many concepts in science that have survived very well over the years, and are widely considered quite real—virtually “certain” for all practical purposes, and very useful. Students should think of the “uncertainty” feature of science as its openness to improvement when new facts require it.

You may be asked for examples of established scientific theories that have been replaced by better ones. Several have been listed in their Appendix SA-3.2. If they want more, this might be a good topic for students to search for, if time allows, then can be shared in class. They can use key words like “replaced theories.” I wouldn’t dwell on this topic, but you can mention a few, if you like, as they pertain to your course. For example, there was the conviction that all the continents were fixed in place, and this was gradually replaced in the mid 1950s (as new evidence became more compelling) with the theory of Plate Tectonics. This nicely explains many geological events and conditions we find: earthquakes, volcanoes, mountain building, mid-oceanic ridges, etc. Another established set of concepts, Newton’s Laws of Motion, have not really been replaced, but rather added to by Albert Einstein to deal with the near-light-speeds and other conditions of relativity. Then even some of Einstein’s insights were replaced with quantum mechanics. Again, the point is that even established theories of the past have been replaced or refined when new information became available.

Under Atomic Structure, if your students are not familiar with the fact that an atom is mostly empty space, you might want to do the Demo in Teacher Appendix TA-12. You should do this
before assigning the reading of this chapter. It’s an opportunity for students to apply the use of conversion factors and do a little bit of scaling math to answer a question in science.

Be sure that students clearly understand what models are in science, and how they relate to hypotheses and theories. Also, you might want to clarify the use of “truth” in science, as discussed in this chapter. To really get more deeply into various ways these terms of science are sometimes used (or misused), especially in high school classes, have your students read in their Appendix SA-3.4 about More Problems With the Words of Science.

Assign to read as homework Chapter 4: The Quality of Science. During this assignment time they should do (and discuss) the Appendix SA-4.3 activity “Good Science vs Poor Science.” If there is time, students may find the Therapeutic Touch inquiry very interesting. You should also consider using one or more of the climate change items in their appendix (SA-4.4, 5.1, and/or 5.2. There are discussion sheets for those items in the Teacher Appendix TA-13-16). Consider doing the CONPTT lesson. High school students could do the Women’s Brains lesson (Stephen Jay Gould’s literary style here could be challenging for middle school). Answer and discuss the Self Check Set D questions.

Chapter 4: The Quality Of Science—Good Science vs Poor Science
A topic seldom addressed in science classes is the fact that even science, like any other human endeavor, can be done poorly. Everything from poor experimental design, to sloppy technique, to intentional fraud occurs in science. The point here is that students should realize that just because something was done “scientifically” doesn’t necessarily mean that its conclusions are completely reliable. Furthermore, it’s good for all of us to know that we can be skeptical of scientific findings… especially if the evidence is minimal, or there is an indication of fraud or bias.

Fortunately, the policy of peer review for all studies published in academic journals of natural science, and open discussions at science conferences, minimizes the number of faulty studies. And the conclusions of faulty studies usually don’t survive. Furthermore, the scientists responsible for poor science suffer damage to their reputations, and will find it harder to get funding or get future studies published unless they improve their work. Students should learn that integrity is highly regarded in science, where it is constantly monitored. At the same time, far from being closed to new ideas (as sometimes wrongly portrayed by science cynics), science actually attracts evidence-based critical review of established knowledge as well as new perspectives. Many scientists are actually looking for evidence that could change long-held views. Such breakthroughs can bring rewards of great fame and funding for further work. But there has to be material evidence to support it.

Bias in Science
Be sure to have your students read the article on Confirmation Bias – Examples (SA-4.1, part A). You can provide the discussion questions to help focus this reading, then discuss in class. The Discussion handouts master and Key are in TA-13. An alternative, especially for high school level (higher reading level) could be the popular “Women’s Brains” lesson on the ENSI site.
In spite of the reputation of science for being very objective, we need to be reminded that even scientists, as normal human beings, still have biases, including biases of politics, economics, race, or gender. This can be a humbling experience, reminding us to always be vigilant in our search for objective reality. To do this, we need to recognize our biases, and consciously work to neutralize them. The rules and protocols of science are critical precisely because they tend to reduce and neutralize bias. Doing science as a team effort also tends to neutralize bias. The “Checks Lab” works well here, because students can recognize their biases and experiences in the different interpretations they propose.

Another kind of bias that scientists may encounter is the influence from those who pay for their research, where conflict of interest and economic or political pressure can be applied. Reports by scientists working for commercial interests, e.g., tobacco, fossil fuel, or pharmaceutical companies, should be especially suspect. The “Good Science vs Poor Science” activity suggests the possibility of such bias in the cyclamate ban imposed by the FDA some years ago. If you can, be sure to read the article in Discover magazine by investigative reporter Jeanne Lenzer (2009). A quote from this article is included in the student booklet (Chapter 4 under “publishing”). The quotation comes from the last section of the article. It’s scary. You might even want to share another excerpt or two with your class. This is another reason why all citizens should try to be vigilant and skeptical.

Another area where it seems that conflict of interest is playing a role, is the plastics industry. We are reading now that plastics containing BPA (bisphenol A) have been replaced in food containers by "safe" plastic, but the "safe" plastic also leaches an estrogen-like chemical which can cause serious health damage, especially in babies and children (Blake 2014). Frequently noted is the widely-used plastic "Tritan," made by Eastman Chemical. It’s marketed as being free of estrogenic activity, but independent labs have found this to be untrue. Apparently many of the scientists working for Eastman Chemical claim (from their testing) that Tritan is safe. It turns out that many of those scientists were also involved in the efforts of the tobacco industry to claim that tobacco is safe. You might suggest that students critically explore this issue, looking at both sides of the argument. A good place to start would be the article by Mariah Blake (2014).

“Alternative medicine” (e.g., homeopathy) is one of the commonest areas where one finds poor science. This topic can be a sensitive one, since many students (and/or members of their families) may lean heavily on such treatments. This is often a cultural feature, and some students may resent what they see as an attack on their beliefs or customs. Again, you may need to tactfully assure them that there may be nothing wrong with a particular “alternative treatment.” But they do need to know that such treatments have generally not survived scientific testing, in spite of the “scientific aura” that sometimes accompanies these treatments. In fact, their very nature makes such testing very difficult. Apparent successes of such treatments can often be attributed to the placebo effect (discussed in this chapter). But if it helps a person to feel better, that’s good. As long as the treatment doesn’t obscure the reality of a serious or life-threatening medical problem, and delay a medical treatment that is scientifically known to be effective.

“Good Science – Poor Science”
This activity is in the Student Appendix SA-4.3. Be sure that your students do this activity so they get at least a brief glimpse of the relative transparency of science—of scientists critiquing
other scientists. If you prefer, perhaps with high school students, you might want to have your students actually read the full-page letter from two scientists to the editor of the journal *Science* that criticizes many aspects of the cyclamate research that led to its (unwarranted?) banning. This is the letter that was the basis for the much-abbreviated version in SA-4.3. If you would like a copy of that article and accompanying worksheet to help in that experience, contact the *Science Surprises* author. Find the key to SA-4.3: Good Science vs Poor Science in TA-14.

**How Can We Tell If It’s Good Science, Or Not?**

Be sure to clarify that being a skeptic is not just a negative attitude about everything. That’s what a cynic would be, and many people confuse those two terms. A skeptic is one who tends to critically challenge assertions that seem to have no solid basis, or good supportive evidence. Skeptics are people who seek honesty, openness and accuracy about all important claims.

When anyone claims that something is “scientific” or is “proven by science,” a skeptic’s ears perk up. Experience has shown that such claims are very often not scientifically supported. In fact there are a number of clues that we can look for to determine if certain claims are good science – or not. There are a number of checklists that list those features to look for. Just do an online search for “pseudoscience checklist.” This section discusses some of those clues.

**Publishing**

Have students read the excellent article by scientist Chris Lee on *Avoiding Confirmation Bias* (SA-4.2 part B). He describes a typical path to publishing for one of his research projects, with examples. Provide the Discussion Questions for part B (10-24). The handout master and key are in TA-13. And discuss the article with your students.

If possible, provide opportunities for your students to apply skeptical inquiry into published articles (magazines, newspapers, etc.). The CONPTT lesson provides a useful vehicle for doing this. Newspaper articles can come from local papers or the *NY Times* Tuesday Science section. Magazine articles can come from *Discover* magazine, *Science News*, and many others. Encourage skeptical use of the internet, as well. It would also be helpful to share copies of *Consumer Reports* (or find it online). Have them see how they critique various kinds of products. If you do this, students should be told that *Consumer Reports* does not use any advertising for products that they study and report on. Then ask your students “Why is this?”

If you have time, provide your students with Carl Sagan’s “Baloney Detection Kit” and/or a list of *Logical Fallacies*” (both available online). See the Logical Fallacies Note under Chapter 5 below, and the Useful Websites at the end of this booklet. And take a look at the excellent “Science Toolkit” at the Understanding Science site, with examples for untangling media messages. Some teachers have posted those lists in large print on their walls, so students could easily refer to them whenever they read claims and assertions in magazine or newspaper articles, or in popular books. Practice, practice, practice!

For examples of consilience, students can consider age-of-earth studies, and evidence for continental drift (plate tectonics) from climate science, geology, seismology, paleontology, and geo-magnetic studies. If your course is Earth Science, be sure to have students search for the
excellent and overwhelming scientific evidence from different fields showing climate change and its human causes. And don’t forget the two Climate Change items (SA-5.1 and 5.2).

The pie chart in Figure 4.5 is inserted following the consilience paragraph for a couple of reasons. For one, it vividly illustrates the massive consilience of climate scientists on the issue of human-caused climate change. For another, in Student Appendix SA-4.4: Climate Change is Real, But…, this same graphic is used to give students an opportunity to consider why the authors of those 24 papers rejected human-caused climate change. Access to those 24 papers (abbreviated) is available at <http://www.jamespowell.org/Rejections/index.html> (and this URL is also provided on that appendix page). Those links also acquaint students with peer-reviewed papers. They are asked to look for clues that could suggest possible biases, e.g., confirmation bias, and conflict of interest.

If students have problems figuring out what clues to look for, here’s a list from which you can offer a few to get them started, then add to those contributed by the students during class discussion, if necessary:

1. Names of authors? (do any author any other climate studies in the set?)
2. Sources of funding? (are there any indications of grants or companies providing funds?)
3. Where scientists work? (a university, or for oil company, auto company, etc.)
4. When was study done? (early years e.g., before 2000 – when evidence was less clear)
5. Journals in which studies were published? (only 2-3 journals? Could they be less critical?)
6. Kind of evidence used for saying “no”? (and source of that evidence)
7. Ages, experience of scientists (can often search for their bios at their university, etc.)
8. What type of study? (original, or meta-study of several previous studies?)

Investigation Wrap-Up
During the second week or so of this unit, students should be making measurements and other observations for their investigative study of seed germination (or equivalent inquiry), probably daily or so. At some point, guide students through the wrap-up, data processing, statistical analysis, and formal report of the study. This will serve as a model for future inquiries or partial inquiries that the class (or students on individual or team projects) can do.

Assign to read as homework: Chapter 5: Pseudoscience, with Self Check Set E. Be sure to do the “How’s Your Horoscope?” lesson with the class (from the ENSI site), if possible, to illustrate a pseudoscience. Discuss the Sidney Harris cartoon—Do This #5.1—and discuss the Self Check Set E items. In the “Do This #5.1,” note the large space for books on Pseudoscience, and the small space allotted to Science! Ask students why they think this cartoon is supposed to be funny (could be several reasons). Explore the possibility of doing the Therapeutic Touch lesson from the ENSI site. It provides an engaging example that deals with confirmation bias, a pseudoscience, and the placebo effect. Perhaps a few students would like to repeat the study done by that 9-year old student who’s work formed the basis for this lesson, maybe for extra credit?
Chapter 5: Pseudoscience—A Major Misuse Of Science

This section speaks for itself. The key lesson on the ENSI site that directly addresses a pseudoscience is “How’s Your Horoscope?” so this brief lesson is highly recommended, preferably before doing the assigned reading of Chapter 5. In addition, notice the box: Examples of Some Pseudosciences. If possible, especially at the high school level, you may want students to select (or be assigned) one of the pseudosciences listed there. Find out what it’s about, and find out why it’s considered a pseudoscience—especially if they can find studies or discussions that point out their flaws, or where they didn’t follow the rules of science.

Be sure that your students can distinguish between pseudoscience, non-science, poor science, and science. For example, astrology can just be a belief (non-science), but it’s a pseudoscience when someone tries to “prove it” with “scientific studies.” Science has no problem with beliefs, but it has a big problem with beliefs presented as supported by science.” This is a critical point to reinforce! On the other hand, there is real science behind the discovery and development of vaccinations, but from time to time, a scientist will just do sloppy science, or (worse) purposely distort the data in a study to match desired expectations. This is poor science. Sometimes it’s hard to tell.

Spend some time with the box showing a Comparison of Pseudoscience and Science. Students may notice that many of the same indicators studied for poor science also work with identifying a pseudoscience. Often, the distinction is really just a matter of intent. In any case, those identifiers presented here provide a handy review of their use in Chapter 4. With the Figure 5.1 cartoon, discuss the “Do This #5.1” question.

Pseudoscience In The Science Classroom?

This section may seem a little hard-hitting, maybe even a bit controversial. But it’s important for students to encounter controversial issues, especially when it’s close to home, in their classroom. Be sure to discuss these issues, because ignorance of them can impact their lives, their science classrooms, or even the science classrooms of their eventual children. But be careful: Choose controversies wisely. Selecting a wrong topic can actually impair understanding. Details for selecting useful controversies can be found in TA-15b.

Originally, the topics of “Intelligent Design,” “Scientific Creationism,” and anti-evolutionism were mentioned in this section. But doing that here would probably be counterproductive. It has been shown that many of the misconceptions people have about evolution are actually due to misunderstanding about the nature of science. But if a teacher experiences an emotional anti-evolution rant by a student in class during a unit on evolution, it’s virtually impossible then to effectively point out that their beliefs about evolution are mostly due to misunderstandings about science, as well as misinformation about evolution. For that reason, it becomes more helpful to explore NOS concepts at a more neutrally receptive time: the beginning of the course. So, to even mention evolution (or the views against it) in this more neutral context of the nature of science actually defeats the purpose of doing NOS here. Therefore, it would be wise to avoid those topics at this time.

Then, when you do get to topics that might be perceived as controversial, e.g., evolution, you can simply ask them about what kinds of explanation science cannot use, and why that is. If you did
a good job with your NOS unit using Science Surprises, certainly one or more students in class will chime in with “Science can’t use supernatural explanations, because…” That may be all you need to tactfully deflect those anti-evolution confrontations.

Speaking of “controversial,” it’s vital that students come to realize that very often the suggested controversies in science are really not scientific (as may be implied), but rather they are more often political, as explained in the student booklet, Chapter 5, under Example 2: Climate Change (especially the second and third paragraphs in that section). In that context, so-called “weaknesses” of the science are also a misrepresentation of reality. The alleged “weaknesses” are made up by the anti-science or anti-climate-change people so that it seems like science is being discredited or weakened. They persist in doing this even after those so-called weaknesses have been clearly shown (with evidence) to be false. This alone is an excellent example of the power of biases.

If you teach evolution later in your course, you should apply the same warnings there (when you get there) as is done here for the science of climate change. The same anti-science strategies are being used against climate change as have been used against evolution. They are so similar that the organization dedicated to maintaining integrity in evolution education (NCSE) has now taken on the job of defending the legitimate science of climate change. Take a look at Climate Change Education (NCSE) under Useful Websites.

So, because climate change denial is probably not as risky to present as evolution might be, Science Surprises uses climate change as a good example to study. Recently, groups opposed to the human-caused climate change issue have been developing materials for teachers to present those claims in science classrooms (allegedly for “critical thinking”), and they are also trying to get laws passed to require this in schools in several states. If you teach Earth Science, this could be a useful focus for your students to practice their use of the “Baloney Detection Kit,” perhaps later, in your climate unit (see below). And be sure to check the material on Climate Change Education (at NCSE). If you don’t find answers to your questions there, just send an email with your query to NCSE. There are also the two reading assignments in the Student Appendices (SA-5.1 and 5.2) that could be nicely used to segue into a more extensive study of the climate issues. Another place to bring in these issues is when you study fossils. Why not consider the evidence for climate changes in the distant past, or “paleoclimates” clues? A web-search for “evidence of paleoclimates” could bring your students lots of useful information. In the life sciences, the environmental impacts of climate change are becoming increasingly obvious. So don’t miss those opportunities to help your students critically explore the contrived controversies that have been swirling around these issues.

By the way, try to use the phrase “climate change” rather than “global warming” in most situations, unless global warming itself is the specific point of interest. This is because the changes predicted (and becoming more evident) include not just global warming, but also more extreme forms of weather that would accompany global warming. As the oceans and atmosphere get warmer, this leads to more violent and more frequent storms (including snow storms) in some areas, and increased draughts in others. You may find it helpful to point this out to your students. Also, some teachers have found that some people may even object to being called “deniers.” If
you encounter this, just replace “denier” with “rejector,” and “denial” with “rejection.” This has already been done in Chapter 5.

If you have the time (and the passion) to help your students develop their critical thinking skills even more, give serious thought to using Carl Sagan’s “Baloney Detection Kit” (Sagan 1995) and a list of Logical Fallacies, which are available online, and could be used to expose various pseudosciences and other misuses of science. See the list of Useful Websites (end of this booklet). It may help to post on your wall, in big print, the saying often attributed to planet scientist Carl Sagan: “Extraordinary claims require extraordinary evidence.”

Another resource to consider here would be Massimo Pigliucci’s Nonsense on Stilts: How to Tell Science from Bunk. The author pleads for teachers to help kids to think critically, be objective, and be skeptical of tempting ideas. They need to learn how to make informed decisions about complex issues involving scientific claims. The book shows how to distinguish pseudoscience and non-science from near-science and “established” science.

The author discusses the science and politics of global warming (Chapter 6). He includes a lengthy list of global warming myths and why each IS a myth. He also provides suggestions and clues to look for in each case to help us to decide who’s right.

Included in that book (Ch. 12, pp. 298-300) is a “baloney detector’s guide.” It uses five kinds of evidence that a novice can use to determine whether someone is a trustworthy expert – or not:
1. How good are their arguments? Have they been critiqued by others?
2. Is there evidence of agreement by other experts?
3. Is there independent evidence that the expert IS an expert?
4. What are the biases?
5. What about their track records?

The application of those questions is made for the issue of intelligent design vs evolution. This is something you might address if you later introduce evolution, but I would not recommend it here, in your introduction to the nature of science (for reasons mentioned earlier). Also, the chapter dealing with the intelligent design controversy (Chapter 7) is available from NCSE at http://ncse.com/files/pub/evolution/Nonsenseonstilts.pdf

But consider developing the application of those 5 questions to the global warming/climate change issue. And include that in you Science Surprises unit.

An interesting and helpful plus in Pigliucci’s book is a brief history of science (ch. 8-9). It takes the reader from superstition to natural philosophy, then to modern science. Read the more extended review of this book (see Pigliucci in Teacher References).

Science Rejection:
With all of the misuse of science, and all the misinformation in the media, some people are tempted to simply reject science automatically, as just too unreliable. Be sure to caution your students against this. Whenever you have the chance, point out the many good things we have because of science (especially in your field). You should also point out how we will always face
a variety of problems in our lives, and science has repeatedly been shown to provide the most reliable information that leads to solutions of those problems. The products of science are the materials that engineers and medical doctors actually use to address those problems. Without scientists, engineers and doctors can only go so far.

**Logical Fallacies Note:**
One of the best indicators of illogical and uncritical thinking (common in pseudoscience claims) is the use of logical fallacies. If you can help your students to recognize a number of common logical fallacies, they will have an excellent tool for recognizing uncritical thinking and a great advantage for recognizing pseudoscience claims. If you do decide to do this, consider just posting one at a time. Select a common one for which you have examples from a current topic of study. Discuss it, share a few examples, and have students seek other examples. Later, maybe weeks later, repeat this with another logical fallacy, followed with a quick review of the logical fallacies already studied. If you do this from time to time during the year, your students can’t help but be sensitized to seeing logical fallacies in many places. They are truly becoming critical thinkers! What more could you ask?

**The Future Of Science—And Your Place In That Future**
Notice the comment about “deep ignorance” here. You might find it interesting to either open your unit (or insert it near the end) with the dramatic “Deep Ignorance” demonstration (see Direct Links). You might also want to query your students as to where they see themselves in their future—and the possible role of science in that future, or at least their future role as critical thinkers.
Part 6. Unit Wrap-up

Summarizing
This is critical to help students internalize, connect and reinforce all the important elements of this unit. Have your students read the Summary, then work in teams of four to build concept maps using key terms and concepts introduced in the unit. Each team can select what it thinks are the three most important points of this unit, and present its concept map to the class and discuss those points with the class, with teacher guidance as necessary. To do this, you could provide a list of the terms shown in Appendix SA-5.3, and ask them to build their concept map from those terms. Alternatively, that summary diagram provided in Science Surprises (Appendix SA-5.3: Our Search for Understanding) can be discussed with the class.

An excellent source for discussion topics would be what they answered for any one of the last two questions in each set of Self Check questions:
xx. List three (or more) ideas or words in this chapter that were hard to understand.
xx. List three items in this chapter that were surprises to you.
This might also be a good way to review each chapter of the unit as you work through the unit.

Unit Review of Surprises
If you asked your students to list the “Surprises” as they studied the text, they should have a list of about 30 items (paraphrases of those key points accentuated by “Surprise!” – information often unknown or misunderstood by the general public). It might be helpful as a review to have students report the items on their lists (1 item per student), with brief restatement, clarification, and perhaps some elaboration of each item by the teacher. A convenient key for these “surprises” is in the Teacher Appendix TA-17.

Reflection: Ask students to write a reflection on their experiences with this unit, including the most impressive new information they now have about science—how their ideas about science have changed. Clarify any points still unclear. You might also ask for suggestions for making the experience better for future students. Feel free to send samples to the author to help in revisions. If time is short, ask students to at least share and discuss their reflections within their teams, then each team can out-share and discuss the “best” reflection item from each team.

Finally, students need to know that many of the elements introduced in this unit will reappear throughout the course. It is the teacher’s job to actually do this – at least to point out those elements whenever possible, as appropriate to the current topic. Even better, encourage (and reward) students to point out those elements when they see them. With this on-going reinforcement, long-term assimilation of repaired misconceptions is most likely to succeed.

Assessment
A sample exam is provided in the Teacher Appendix TA-20. You can copy these questions to build your test. Feel free to add, remove or change items to fit your class’ experience with the material. Even easier, just email the author to request this test as a Word .docx file. Then you can modify as desired, and make different forms as desired. Be sure to include all the questions given in your pre-test (or use it as a separate post-test) so that you can document their collective growth on those items. The Science Surprises Quiz is in TA-19. You could use it as a stand-alone post test (easiest), or include it in some way with a more comprehensive exam, such that
you can easily extract the responses for that post test segment. Also be sure that you are assessing the understanding of the concepts as a top priority, rather than just testing for memory of term definitions. It may help to enter their pre- and post-test scores on a Pre-Post Test Analysis sheet, set up to calculate the numerical differences and percent change for each individual item, for each student, and averages for the entire class (see Pre/Post Test Analysis Sheet address in the Direct Links). Be sure to share those scores with your students. You can just show or tell each student how much they improved, and you can show the entire class how much the class improved (averages of individual percent improvements).

You may want to assign participation grades for doing the lessons and lab activities and discussing the material, using your own system for such grading. Students should be rewarded for exceptional involvement: asking questions, responding to questions, helping team-mates to understand, sharing good examples of critical thinking, and other significant contributions. Some teachers even have teams grade each other, or members grade each other on a team, on the quality and quantity of their mutual participation. Such team assessments can then become part of the basis for their unit grade.

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Field-Testing Information

An earlier version of this Teacher’s Guide and the student text were peer-reviewed when first submitted for publication in 2011. Subsequent suggestions resulted in many improvements. One of the best suggestions was to have the material field-tested. To do that, I appealed to the roughly 600 science teachers on the ENSI listserves. About 90 responded with their interest in the project. I sent them my “Participant Data” form for details about the classes in which they would agree to do the unit in the fall of 2012. Of those, 22 returned the form. Of those 22, five started and had their students take the pre-test (with 40 items), but never did the post-test. Eight of those 22 teachers completed the unit (booklet and NOS lessons, with both pre- and post-tests) in the fall of 2012. Most of the teachers had their students take the pre- and post-tests online, using the Google Docs venue.

Those 8 teachers who finished the unit had an average of 14 years experience (range of 1-22 years). It was used with about 760 students in 33 periods, about half in middle school (2 physical science, 2 life science) and half in high school (1 AP environmental science, 4 biology). The 8 teachers were in CA (3), OR, CO, OH (2) and CT. There was a mix of urban, suburban and rural schools. The post-test scores for the high school students averaged 79% (range: 72-83%) with an average 28% improvement. The middle school students averaged 69% (range: 65-72%) with an average 17% improvement. I got good feedback from all teachers and their students. They generally liked it, but they had useful suggestions. One was that the reading level was too high (about 11th grade) which was probably why the MS scores were lower than HS scores. So I checked and adjusted every paragraph and was able to bring the reading level down to about 8th grade. I have made a number of other changes as well. Much in the two booklets was further revised to reflect suggested improvements, along with other improvements and additions that came to mind.

All in all, the field-testing was most valuable. The quality and depth of the material has greatly improved, thanks to those brave field-testers (teachers and kids). I’m very grateful to them all.

You may notice that there is virtually no mention of evolution or “creation science” in Science Surprises. This was by design (as explained earlier in this Teacher’s Guide). Instead, in order for students to see how we might apply critical thinking to some examples of what might be considered “controversial” or “pseudoscience,” I have touched on topics like climate change, vaccinations, GM foods, homeopathic medicines, and therapeutic touch. These examples were not in the field-testing materials, but there seemed to be a desire to have something like that. They are introduced in chapters 4 and 5 of the student booklet, and a few are also in the appendices for optional student interaction.
Feedback

Please let the author know how this material worked with your classes. Was it well-received? Was it enjoyed? Was it confusing? Was it too much, too fast? Were most students actually surprised about many of the “surprise” points presented? Did most or all of your students feel that they had learned a lot of useful information in this unit? Did your classes show significant improvement in their pre/post tests? Any problems? If you have any questions or suggestions for improvement, please email the author.

Thank you for using this material with your students. Hopefully, they will, as students and citizens, become better, wiser, more critical thinkers.

Cheers,
Larry Flammer
ENSIdweb webmaster
mailto:flammer4@gmail.com

PS: For science teaching in elementary schools, see TA-21: Some Suggestions for Elementary School Science Programs.

Acknowledgments

Scientific Creationists – for providing the initial need and motivation to develop these materials;
Harry Wong for giving me a good excuse (and a nudge) to compile my NOS and critical thinking materials into my Limits of Science (1985) – the original version of Science Surprises;
The Directors of ENSI: Drs. Jean Beard, Craig Nelson and Martin Nickels, for putting together the ENSI program, with all its great NOS lessons, for all their encouragement and support for the ENSIdweb project, and for reading earlier drafts of Science Surprises and sending me constructive comments;
ENSId teacher Walter Wogee for showing me the significance of illusions in science;
The ENSI teachers who submitted, classroom-tested and revised many of the ENSI lessons, and then agreed to share those lessons to create the ENSI website.
The National Science Foundation for helping fund the initial development of ENSIdweb;
For my many students who served as “guinea pigs” using earlier versions of the Limits of Science, and letting me know where improvements were needed;
The NSTA Press for encouraging this project and providing peer reviews of the book;
The several peer-reviewers who read my Science Surprises and offered very helpful feedback;
The many teachers who have used the ENSI lessons, and offered suggestions along the way;
The special teachers who volunteered to field-test my Science Surprises unit with their classes, and followed through to give me vital feedback information needed to improve the unit:

Barbara O’Connor Coleen Swihart Jennifer Naujock Christine Evans
Kristin Rikkers Kathy Laney Katie Noonan Eliza Rayner

The 760 students of those teachers who also provided helpful feedback;
Nate Fairchild, who not only field-tested Science Surprises with his students, but also tutored me in using Google Docs for online pre- and post-testing, and introduced me to online readability checking.

My wife, Sally, who has been totally supportive throughout the whole project.
Teacher References

All internet sites last accessed 22 March 2014


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[http://www.csicop.org/si/show/only_a_theory_framing_the_evolution_creation_issue/]


[http://www.corestandards.org/the-standards]

[http://www.nextgenscience.org/next-generation-science-standards]


[http://www.indiana.edu/~ensiweb/nick.sci.html].


See Sagan’s “Baloney Detection Kit”  
[http://www.xenu.net/archive/baloney_detection.html](http://www.xenu.net/archive/baloney_detection.html)


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Useful Websites: Last accessed 22 March 2013


Carl Sagan’s Baloney Detection Kit (annotated by skeptic Michael Shermer):
http://homepages.wmich.edu/~korista/baloney.html

Climate Change Education (NCSE)—http://ncse.com/climate

ENSIweb—http://www.indiana.edu/~ensiweb

NCSE (National Center for Science Education). ncse.com

See Religious organizations’ views on evolution at http://ncse.com/media/voices/religion

Pursuit of Ignorance, S. Firestein:
http://www.ted.com/talks/stuart_firestein_the_pursuit_of_ignorance.html

Sagan’s Baloney Detection Kit (outline) and Common Fallacies of Logic and Rhetoric
http://www.xenu.net/archive/baloney_detection.html

Science Learning: Reasons for Teaching NoS (from the U. of Waikato, New Zealand):

STEM Education Coalition (Science-Technology-Engineering-Math)
http://www.stemcoalition.org/

Understanding Science—How Science Really Works:
http://undsci.berkeley.edu/article/howscienceworks_01

Science Toolkit—A Scientific Approach to Life:
http://undsci.berkeley.edu/article/0_0_0/sciencetoolkit_01

Why it’s important to teach NOS and process of science (research on this issue):
Educational Research on Teaching the Nature and Process of Science:
http://undsci.berkeley.edu/teaching/educational_research.php

YouTube clips of “Breaking Magician’s Code”:
http://www.youtube.com/watch?v=oHCyNkixqs4

Direct Links On ENSI Website: Last accessed 22 March 2014

Deep Ignorance Demo: http://www.indiana.edu/~ensiweb/lessons/unt.deep.html

Engaging Activities: http://www.indiana.edu/~ensiweb/ttps.html

ENSI KEYS ONLINE: http://www.indiana.edu/~ensiweb/ws.respo.html

Index to Lessons on Evolution and Geological Patterns:
http://www.indiana.edu/~ensiweb/evol.fs.html

Index to NOS Lessons: http://www.indiana.edu/~ensiweb/natsc.fs.html

Larry’s Teaching Tips: http://www.indiana.edu/~ensiweb/lar.tip.html

Meaningful Metrics: http://www.indiana.edu/~ensiweb/connections/metrics.con.html

Oat Seed Lab: http://www.indiana.edu/~ensiweb/lessons/oat.lesson.html

Pre/Post Test Analysis Sheet: http://www.indiana.edu/~ensiweb/lessons/P_P_TestAnal.xls

Scientific Argumentation: http://www.indiana.edu/~ensiweb/Sci_Argumentation.html
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TA-5b: **ENSI NOS Lessons that fit STEM, NGSS and Common Core Standards**
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TA-1a: Key Concepts of the Nature Of Science

1. **Science deals only with natural patterns and explanations, never supernatural.**
   Only natural phenomena can be studied, and only natural explanations can be used.

2. **Scientific knowledge is different from other kinds of knowledge.**
   This is because it does *not* come from authority or by votes. It is obtained through critical *observation* and subsequent critical *testing* of proposed explanations. Published reports are critically peer-reviewed to check validity and quality of work.

3. **Good science is different from poor science, pseudoscience and non-science.**
   Not recognizing those difference can lead to uncritical thinking and poor choices.

4. **Testing of scientific ideas means trying to disprove those ideas, not to prove them.**
   If the knowledge survives repeated testing, then the knowledge is strengthened.

5. **Scientific knowledge is always open to change with compelling new evidence.**
   There are degrees of uncertainty. Some scientific knowledge is relatively new and untested, but other scientific knowledge is well established due to long term testing and successful application, and therefore unlikely to be overturned; it’s durable.

6. **Scientific knowledge can be biased.**
   All people have biases, but the rules of science are geared to minimize bias.

7. **Scientific knowledge is stronger when it has multiple lines of evidence.**
   Consilience of different, independent data-sets and analyses of those data, strengthens the knowledge. [Consilience = data and conclusions are consistent for different studies.]

8. **There is no one scientific method. For ancient events, we look for predictable clues.**
   Not all science is experimental. Some is descriptive, some is historical,

9. **Some scientific explanations are better than others.**
   This is simply because they work better and explain more observations.

10. **Collaboration leads to more reliable scientific knowledge.**
    This includes the open sharing of data and interpretations in journals and conferences.

11. **Scientific tests should be “Fair Tests.”**
    This means that results could go either way, depending on the validity of the explanation.

12. **Ignorance is a key driving force of science**
    Scientists are driven to understand the ever-increasing secrets of nature.
All the *ENSI* lessons used in this NOS unit adhere to one or more of the above concepts. Whenever you are assessing learning during this unit, be sure that you put primary focus on these concepts. It might be helpful for you to place a large poster on the wall with at least the boldfaced numbered Key Concepts displayed and easily visible throughout the room. From time to time, ask different students to indicate which (one or more) of the Key Concepts a particular lesson (or part of a lesson) illustrates. Or, at the end of the unit, take each concept, and ask which lesson (or lessons) illustrated that concept.

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See:  **TA-1d: Key Concepts of NOS for Overhead**
TA-1b: Assessable Objectives for the Science Surprises Unit

Students, in terms of the realm and limits of science, will recognize that...
- science deals only with questions about the natural world, never the supernatural, as such.
- science can only use natural explanations, never supernatural.
- science cannot answer questions involving personal judgments, opinions, or beliefs.
- scientific knowledge is always open to change (i.e., it’s tentative, to varying degrees).
- scientific knowledge can change when new facts conflict with previous knowledge.
- scientific knowledge can be biased.
- science can be done poorly; this is poor science.
- science deals with probabilities, not certainties or absolutes.
- scientific testing involves efforts to disprove, not prove, tentative explanations.
- scientific knowledge differs from non-scientific knowledge, and why that is.
- scientific knowledge is our most reliable knowledge about natural phenomena, and why.
- scientific knowledge is getting better all the time.
- scientific processes tend to reduce bias and poor science.
- scientific findings are not always logical or common sense, and why that is.

Students will recognize that the processes of science generally involve...
- critical observation of natural phenomena.
- recognizing unanswered questions about nature.
- forming plausible, testable explanations or answers (hypotheses).
- creating ways to test those explanations (by experiment, or searching for clues).
- performing those tests: experiment, search for clues, or make further observations.
- assessing the data collected, and relating those data to resolving the original question.
- reporting the work to peer-review journals for critical assessment and publication.

Students, in terms of the social context of science, will recognize that...
- scientists typically collaborate with other scientists.
- scientists must publish their work in peer-review journals.
- scientific knowledge welcomes critical assessment from peers.
- scientific conclusions can reflect personal experiences and biases.
- scientific knowledge is stronger when it has multiple lines of evidence.
- scientists face challenges in their work: ethical, financial, peer pressure.

Students, as an application of critical thinking skills, will be able to...
- understand why ignorance is the key driving force of science.
- distinguish good science from poor science and pseudoscience.
- recognize the clues that characterize good science, poor science and pseudoscience.
- recognize examples of bias in scientific work.
- use the key terms of science accurately, with clear understanding of meanings.
- identify examples of the different types of scientific inquiry.

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Most common misconceptions in the pre *Science Surprises* population

When *Science Surprises* was field-tested in the fall of 2012, 1,014 students were pre-tested on about 40 common NOS misconceptions. Those students represented a fair balance of middle school and high school science students, in urban, suburban and rural schools sampled in four states: CT, OH, OR and CA. Compiled from those tests, several of those misconceptions that were most common in that population can be listed. They include the following:

<table>
<thead>
<tr>
<th>Most Common NOS Misconceptions in the Student Population:</th>
<th>% students favoring misconception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Good scientific work tries to prove certain explanations to be correct.</td>
<td>83%</td>
</tr>
<tr>
<td>2. A hypothesis is just an educated guess about anything.</td>
<td>83%</td>
</tr>
<tr>
<td>3. Testing hypotheses means trying to prove them</td>
<td>80%</td>
</tr>
<tr>
<td>4. Hypotheses are the results expected or predicted for an experiment.</td>
<td>79%</td>
</tr>
<tr>
<td>5. Science is mainly a search for truth.</td>
<td>71%</td>
</tr>
<tr>
<td>6. Any study done carefully and based on observation is scientific.</td>
<td>67%</td>
</tr>
<tr>
<td>7. Astrology (predicting one’s future from positions of stars and planets) is a science.</td>
<td>66%</td>
</tr>
<tr>
<td>8. Science can deal with both the natural world and the supernatural, as such.</td>
<td>66%</td>
</tr>
<tr>
<td>9. Most engineers and medical doctors are actually scientists.</td>
<td>62%</td>
</tr>
<tr>
<td>10. Science is not influenced by biases of race, gender, nationality, or religion.</td>
<td>57%</td>
</tr>
<tr>
<td>11. Science can use supernatural explanations if necessary.</td>
<td>55%</td>
</tr>
<tr>
<td>12. Scientific theories are generally less useful than hypotheses, laws or facts.</td>
<td>54%</td>
</tr>
<tr>
<td>13. The real goal of science is to collect facts, not to find explanations of nature.</td>
<td>53%</td>
</tr>
<tr>
<td>14. A scientific theory is merely a guess or speculation.</td>
<td>51%</td>
</tr>
<tr>
<td>15. Criticism of scientific work by other scientists is a serious problem for science.</td>
<td>37%</td>
</tr>
<tr>
<td>16. Uncertainty in science makes science unreliable.</td>
<td>34%</td>
</tr>
</tbody>
</table>

The views represented here may (or may not) match those of the general population, but they probably do represent the student population for which *Science Surprises* is intended. (You might want to compare these results with those in your classes). One of the goals, then, of the *Science Surprises* unit is to turn those views around, or repair them.

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KEY CONCEPTS FOR THE NATURE OF SCIENCE

1. Science deals only with *natural patterns and explanations*, never supernatural.

2. Scientific knowledge is *different from other kinds of knowledge*.

3. **Good science is different** from poor science, pseudoscience and non-science.

4. Critical **testing means trying to disprove** scientific ideas, *not* to prove them.

5. Scientific **tests should be “Fair Tests”** whenever possible.

6. Scientific knowledge is stronger when it has **multiple lines of evidence**.

7. **Some scientific ideas are better** than others.

8. **Scientific knowledge can be biased**.

9. **Collaboration leads to more reliable scientific knowledge**.

10. Scientific knowledge is **always open to change** with compelling new evidence.

11. There is **NO one scientific method**. For ancient events, seek clues of past.

12. **Ignorance is a key driving force of science**.

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TA-2: Basic Assumptions and Limitations of Science

If you feel that your students are sufficiently ready (probably 10th-12th grade), you may want to share the following Basic Assumptions of Science (and possibly the Basic Limitations of Scientific Knowledge, as well). These assumptions and limitations form the basis for the several Key Concepts of Science and the “Rules of Science” presented in Science Surprises.

Basic Assumptions Of Science

- **1. The world is real.** The physical universe exists apart from our sensory experiences.
- **2. Humans can accurately perceive and understand the physical universe.**
- **3. Natural processes are sufficient for understanding the natural world.**
- **4. Nature operates uniformly throughout the universe in space and time.**

Basic Limitations Of Scientific Knowledge

- **A. Our senses have their own biological limitations.** Even technological devices for extending those limitations have their own limits of accuracy and range.
- **B. Our mental processing of sensory data is not always reliable.** We are influenced by previous experiences, biases, and degrees of attention, all contingent* on circumstances.
- **C. It’s impossible to know if we have considered all possible alternative explanations.**
- **D. Scientific knowledge is necessarily contingent knowledge** (and therefore uncertain). It is not absolute knowledge (certain and eternally true). It is dependent on available evidence, circumstances, tools and our analysis.

Nevertheless, scientific knowledge is the most reliable knowledge we can have about the natural world and how it works. This is because scientists have developed a methodology for learning based on principles of critical thinking and reducing bias.

*Contingent = depending on existing technology and current ways of thinking.


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TA-3: *ENSI NOS Lesson Matrix: Key Elements of the Nature of Science*

*The Realm and Limits of Science:* Seeking **Best Explanations**, always **Tentative** to some degree
- Its Assumptions and Rules
  - Only questions about the **natural world**, never the supernatural, as such
  - Only **natural** explanations allowed, never supernatural
  - No questions of personal judgments, opinions, beliefs, views, choices, or feelings

**Basic Processes of Science:** Forming and testing (challenging) hypotheses
- Experimental Science (e.g., physics, chemistry, physiology, genetics)
- **Historical Sciences** (e.g., astronomy, geology, paleontology, forensic and evolution)

*The Social Context of Science:*
- It’s Collaborative nature (including Publishing)
- Its **Biases** and Preconceptions

**ENSI NOS Lessons**
- Their Respective Areas of Emphasis

<table>
<thead>
<tr>
<th>Selected ENSI NOS Lessons</th>
<th>Realm &amp; Lim</th>
<th>Basic Process</th>
<th>Best Explan.</th>
<th>Tentative</th>
<th>Social Context</th>
<th>Bias</th>
<th>Historic Science</th>
<th>Other Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat Earth</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magic Hooley Stick</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUNsets, Souls, Senses</td>
<td>X</td>
<td>X</td>
<td>X*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percep. Not Always Real.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>T-illusion; Inquiry Guide</td>
</tr>
<tr>
<td>How’s your Horoscope?</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>Pseudoscience</td>
<td></td>
</tr>
<tr>
<td>CONPTT</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Find the Washer</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three-Hole Bottle</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Volume Exchanger</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>“Magic!”</td>
</tr>
<tr>
<td>Becoming Whales</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>Clues in predicted place</td>
</tr>
<tr>
<td>Great Fossil Find</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oat Seed Lab</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>A model for inquiry</td>
<td></td>
</tr>
<tr>
<td>Mystery Boxes</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palpatting Pachyderms</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sketch a Scientist</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>False Assumptions</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>Preconceptions</td>
<td></td>
</tr>
<tr>
<td>Crime Scene (Microchip)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>Forensic science</td>
</tr>
<tr>
<td>A Crime Against Plants</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Checks Lab</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laetoli Trackway Puzzle</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Therapeutic Touch (New)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>Pseudoscience; placebo</td>
<td></td>
</tr>
<tr>
<td>Women’s Brains</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good Sci vs Bad Science</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>Quality of Science</td>
<td></td>
</tr>
<tr>
<td>Theory, Theory</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>Emotional influences?</td>
<td></td>
</tr>
</tbody>
</table>

1. Lessons in **Bold Face** are most highly recommended for minimum experiences with NOS.
2. Great Fossil Find could substitute for Checks Lab (especially in lower grades, Life or Earth Science).
3. False Assumptions makes a good “sponge” activity with revealing insights about preconceptions.
4. The Oat Seed and Perception Not Always Reality labs are open-ended Inquiries
5. The Oat Seed lab has detailed instructions intended to help model an inquiry and its reporting.
6. The Mystery Boxes lesson is a useful additional lab to reinforce the Checks Lab.
7. Note the lessons that exemplify the “Historical” sciences, (e.g., geology, paleontology, astronomy) be sure to point this out when doing any of those lessons.
8. Therapeutic Touch lesson could be used instead of Women’s Brains.

9. **RETURN TO APPENDICES INDEX**
### TA-4: NOS Concepts by Chapters and Lessons

<table>
<thead>
<tr>
<th>Ch.</th>
<th>CONCEPTS</th>
<th>LESSONS (LABS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>WHY SCIENCE? WHAT IS SCIENCE? (INTRODUCTION &amp; OVERVIEW)</td>
<td>Sunsets, Souls and Senses</td>
</tr>
<tr>
<td></td>
<td>The goal of science is understanding the natural world</td>
<td>Sunsets, Souls and Senses</td>
</tr>
<tr>
<td></td>
<td>Science can only deal with the natural world</td>
<td>Sunsets, Souls and Senses</td>
</tr>
<tr>
<td></td>
<td>Scientific knowledge is different from other kinds of knowledge</td>
<td>Science can only deal with the natural world</td>
</tr>
<tr>
<td></td>
<td>Science follows certain rules</td>
<td>Scientific knowledge is different from other kinds of knowledge</td>
</tr>
<tr>
<td></td>
<td>Science can only use natural explanations, never supernatural</td>
<td>Scientific knowledge is different from other kinds of knowledge</td>
</tr>
<tr>
<td></td>
<td>Scientific answers must be based on critical observation</td>
<td>Scientific knowledge is different from other kinds of knowledge</td>
</tr>
<tr>
<td></td>
<td>Scientific answers must be testable (i.e., potentially disprovable)</td>
<td>Scientific knowledge is different from other kinds of knowledge</td>
</tr>
<tr>
<td></td>
<td>There is no one “scientific method”</td>
<td>Scientific knowledge is different from other kinds of knowledge</td>
</tr>
<tr>
<td></td>
<td>Natural illusions make “common sense” and “logic” unreliable</td>
<td>Scientific knowledge is different from other kinds of knowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scientific knowledge is different from other kinds of knowledge</td>
</tr>
<tr>
<td>2</td>
<td>WHAT SCIENCE IS NOT</td>
<td>Checks Lab</td>
</tr>
<tr>
<td></td>
<td>Science can only deal with the natural world</td>
<td>Checks Lab</td>
</tr>
<tr>
<td></td>
<td>Science cannot answer questions of judgment, opinion, beliefs or views</td>
<td>Checks Lab</td>
</tr>
<tr>
<td></td>
<td>Science can only use natural explanations, never supernatural</td>
<td>Checks Lab</td>
</tr>
<tr>
<td></td>
<td>Some scientific explanations are better than others</td>
<td>Checks Lab</td>
</tr>
<tr>
<td></td>
<td>Scientific answers must be testable (i.e., potentially disprovable)</td>
<td>Checks Lab</td>
</tr>
<tr>
<td></td>
<td>Scientific answers cannot include magical or supernatural forces</td>
<td>Checks Lab</td>
</tr>
<tr>
<td></td>
<td>Scientific answers must be based on observation, not dogma</td>
<td>Checks Lab</td>
</tr>
<tr>
<td></td>
<td>Scientific tests should be fair tests</td>
<td>Checks Lab</td>
</tr>
<tr>
<td></td>
<td>Scientific knowledge is not absolute or final; it is tentative</td>
<td>Checks Lab</td>
</tr>
<tr>
<td>3</td>
<td>THE WORDS OF SCIENCE</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td></td>
<td>The goal of science is understanding the natural world</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td></td>
<td>An observation is any information gained through our senses</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td></td>
<td>A fact is an observation that appears the same to all critical observers</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td></td>
<td>Even facts can change (with new tools and techniques)</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td></td>
<td>There are many natural illusions</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td></td>
<td>A hypothesis is a tentative testable explanation, not a prediction</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td></td>
<td>A scientific theory is a highly tested and supported explanation</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td></td>
<td>Theories are more important (more useful) than facts</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td></td>
<td>Theories are tentative, but can range from moderate to strong</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td></td>
<td>Models in science typically reveal the “structure” of explanations</td>
<td>Oat Seed Lab (or equivalent)</td>
</tr>
<tr>
<td>4</td>
<td>THE QUALITY OF SCIENCE</td>
<td>Mystery Boxes (published)</td>
</tr>
<tr>
<td></td>
<td>Science, as any human endeavor, can be done well, or done poorly</td>
<td>Mystery Boxes (published)</td>
</tr>
<tr>
<td></td>
<td>Quality results depend on how well the rules of science are followed</td>
<td>Mystery Boxes (published)</td>
</tr>
<tr>
<td></td>
<td>Scientific knowledge can be biased</td>
<td>Mystery Boxes (published)</td>
</tr>
<tr>
<td></td>
<td>Beware of conflicts of interest or anti-science agenda</td>
<td>Mystery Boxes (published)</td>
</tr>
<tr>
<td></td>
<td>Good science must be published in peer-review journals</td>
<td>Mystery Boxes (published)</td>
</tr>
<tr>
<td></td>
<td>Good science requires a skeptical approach</td>
<td>Mystery Boxes (published)</td>
</tr>
<tr>
<td></td>
<td>Good science is different from other kinds of science</td>
<td>Mystery Boxes (published)</td>
</tr>
<tr>
<td></td>
<td>Scientific knowledge from multiple lines of evidence is stronger</td>
<td>Mystery Boxes (published)</td>
</tr>
<tr>
<td>5</td>
<td>PSEUDOSCIENCE: A MAJOR MISUSE OF SCIENCE</td>
<td>How’s Your Horoscope?</td>
</tr>
<tr>
<td></td>
<td>Pseudoscience ignores some or all rules of science</td>
<td>How’s Your Horoscope?</td>
</tr>
<tr>
<td></td>
<td>Pseudoscience tries to prove its explanations</td>
<td>How’s Your Horoscope?</td>
</tr>
<tr>
<td></td>
<td>Pseudoscience may use supernatural explanations</td>
<td>How’s Your Horoscope?</td>
</tr>
<tr>
<td></td>
<td>Pseudoscience ignores or denies unsupportive studies</td>
<td>How’s Your Horoscope?</td>
</tr>
<tr>
<td></td>
<td>Pseudoscience holds authority higher than observation</td>
<td>How’s Your Horoscope?</td>
</tr>
</tbody>
</table>

General Rule: Wherever possible, do the lab before reading about it in Science Surprises.

As you can see, most of the lessons serve as good examples of several elements of the NOS. Lessons (Labs) shown in **boldface** print should provide the minimum of lessons used. Concepts in **boldface** are included in the list of Key Concepts of the Nature of Science.

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TA-5a: Elements of the Nature of Science: Grouped by ENSI NOS Categories

**Realm & Limits**
- Deals only with natural phenomena, not supernatural (as such)
- Can only use natural explanations, never supernatural
- Must follow the rules of science
- Based on observable evidence
- All findings are tentative / uncertain / open to change
- Degree of tentativeness/uncertainty decreases with repeated testing and confirmation
- Fair Tests could go either way – not committed to dogma, authority or opinion
- Limited by our assumptions about what is real, that we can perceive and understand the natural world, that natural processes are sufficient for understanding natural world, and that nature operates uniformly throughout the universe
- Our senses have their own biological limitations
- Our mental processing of sensory data is not always reliable
- It’s impossible to know if we have considered all possible alternative explanations
- Scientific knowledge is necessarily contingent knowledge (and therefore uncertain)

**Basic Processes**
- **Descriptive**: Observe, look for Patterns, Organize/Categorize, Record.
- **Historical / Pre-Historical**: “What happened?”; Look for Clues, Patterns; Hypothesize (possible explanation); Predict observations if hypothesis correct, and if wrong; Search for those clues.
- **Experimental**: Observe, pose Problem, Create Hypothesis, Design Test, Predict Results, Do Test, Reach Conclusion.
- Some explanations are better than others (those that repeatedly survive testing)
- Quantitative wherever possible (for precision and to enable reliable repetition)

**Social Context**
- Mostly collaborative (therefore more reliable)
- Subject to critical review: publishing required for peer-review, repetition by other scientists
- Subject to bias

**Why Science Works (And Is the Most Reliable Form of Knowledge)**
- Based on critical observation
- Ideas subject to critical assessment / testing / attempts to disprove (not prove).
- Multiple Independent Lines of Evidence produce greater confidence.
- Mystical, magical, supernatural explanations not allowed (not denied, but simply not used)
  - Reason: such explanations cannot be disproved – *any* test outcome is possible.
- Not tied to dogma, authority or opinion.
- It works: Results are more reliable and useful than any other way of knowing.

**Problems with Science**
- Pseudoscience – alleged “science” that does NOT follow rules of science
- Poorly done science
- Conflict of interest science
- Fraudulent science
- Misuse of the word “science” (and other words used in science)
- Popular misconceptions about science

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**TA-5b: ENSI NOS Lessons for STEM, NGSS and Common Core Standards**

It may be helpful for you to know that several of the *ENSI* lessons contain elements appropriate for STEM teaching (Science, Technology, Engineering and Math). They also satisfy NOS elements for the current NGSS (Next Generation Science Standards) and Common Core Standards. They deal with scientific argumentation, scientific creativity, functional design, applications of math, and competitive engineering.

ENSI NOS lessons that illustrate *scientific argumentation from evidence*, and *scientific creativity* (mostly for hypothesizing reasonable, testable explanations, and designing tests of those hypotheses):
- Flat Earth
- Magic Hooey Stick (reverse engineering)
- Perception Not Always Reality (T-illusion, other illusions)
- The Great Volume Exchanger (reverse engineering)
- Mystery Boxes (reverse engineering)
- Sketch a Scientist (or sketch an engineer, or sketch a mathematician)
- Checks Lab (proposing plausible scenarios based on evidence)

ENSI lessons that use and apply *math* in science:
- Oat Seed Lab (statistical analysis, growth measurements, graphing)
- Perception is not always reality (rotational degrees, measurement, % error)
- How’s Your Horoscope? (calculate likely results due to chance).

**Common Core**-related material in the *ENSI* collection that require reading and interpreting scientific material (besides the math-using and argumentation lessons mentioned above):
- Flat Earth
- CONPTT
- Women’s Brains

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TA-5c: NGSS for NOS and ENSI NOS Lessons

In the final NGSS, Appendix H (Nature of Science), there are eight “basic understandings” about the nature of science” listed (page 4). The first four (1-4 below) are associated with practices; the second four (5-8) with crosscutting concepts. In the matrices they show (pp. 5-6), those “basic understandings” for the nature of science are referred to as “major themes” and listed under “Categories” in each matrix. The matrix describes specific “learning outcomes” for each Category/Theme in each grade band. They say that those learning outcomes are expressed in selected performance expectations in the foundation boxes throughout the standards.

If you search the NGSS for those NOS performance expectations, you will find that there are not many, and those are relegated to the bottoms of the foundation boxes (blue and green), where they may even go unnoticed or ignored by teachers. The new Framework (2012) strongly urges that the many aspects of NOS must be taught for students to achieve good science literacy. Furthermore, research has clearly shown that if the NOS elements are to be properly understood and remembered, they must be explicitly taught, and not just mentioned in the context of science inquiry for other topics of science. See <http://undsci.berkeley.edu/teaching/educational_research.php>. Fortunately, a selection of any three or four of the ENSI NOS lessons already meet all of the NGSS expectations with interactive, classroom-tested and engaging lessons. We urge you to use these in your introductory unit on the nature of science, and insert others where appropriate throughout your course.

The grid below shows which NGSS NOS Themes/Categories are addressed with each of several selected ENSI NOS lessons available on the ENSI site. Some of these (and others on the site) also meet the expectations of Common Core and STEM. Any of these lessons could be used in either middle school or high school. For lessons, see <http://www.indiana.edu/~ensiweb/natsc.fs.html>.

The Eight NGSS NOS Themes/Categories:

<table>
<thead>
<tr>
<th>NGSS NOS Themes/Categories</th>
<th>ENSI Key Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Scientific investigations use a variety of methods.</td>
<td>4,5,6,11</td>
</tr>
<tr>
<td>2. Scientific knowledge is based on empirical evidence.</td>
<td>2</td>
</tr>
<tr>
<td>3. Scientific knowledge is open to revision in light of new evidence.</td>
<td>7,10</td>
</tr>
<tr>
<td>4. Scientific models, laws, mechanisms and theories explain natural phenomena.</td>
<td>1</td>
</tr>
<tr>
<td>5. Science is a way of knowing.</td>
<td>2,3,7,12</td>
</tr>
<tr>
<td>6. Scientific knowledge assumes an order and consistency in natural systems.</td>
<td>1</td>
</tr>
<tr>
<td>7. Science is a human endeavor.</td>
<td>8,9</td>
</tr>
<tr>
<td>8. Science addresses only questions about the natural and material world.</td>
<td>1,2</td>
</tr>
</tbody>
</table>

| Selected ENSI NOS Lessons:                                                                                                                                                                                                                                                                                                                                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|---|---|---|---|---|---|---|
| False Assumptions                                                                                                                                                                                                                                                                                                                                                                                                    | X | X |   |   |   |   |   |
| The Oat Seed Lab                                                                                                                                                                                                                                                                                                                                           |   | X | X |   |   |   |   |   |
| Checks Lab                                                                                                                                                                                                                                                                                                                                                  | X | X | X |   |   |   |   |   |
| Sunsets, Souls & Senses                                                                                                                                                                                                                                                                                                                                    |   |   |   | X | X | X |   |   |
| Perception is Not Always Reality                                                                                                                                                                                                                                                                                                                          | X | X | X | X |   |   |   |   |
| The Magic Hooey Stick                                                                                                                                                                                                                                                                                                                                    | X | X | X |   | X | X |   |   |
| Palpating Pachyderms                                                                                                                                                                                                                                                                                                                                   | X | X |   | X |   |   |   |   |
| Mystery Boxes                                                                                                                                                                                                                                                                                                                                             | X | X | X | X |   |   |   |   |
| Crime Scene: Case of Missing Microchip                                                                                                                                                                                                                                                                                                                      | X | X | X | X | X |   |   |   |
| Therapeutic Touch                                                                                                                                                                                                                                                                                                                                       | X | X | X | X | X | X |   |   |
| How’s Your Horoscope                                                                                                                                                                                                                                                                                                                                     | X | X | X | X | X | X | X |   |

<table>
<thead>
<tr>
<th>Corresponding ENSI Key Concepts:</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,5,6,11</td>
</tr>
<tr>
<td>2,3,7,12</td>
</tr>
<tr>
<td>1,2</td>
</tr>
</tbody>
</table>
TA-5d: How the ENSI NOS Lessons and Science Surprises Meet the NGSS

In the final NGSS, Appendix H (Nature of Science), there are eight “basic understandings” about the nature of science” listed (page 4). The first four (1-4 below) are associated with practices; the second four (5-8) with crosscutting concepts. In the matrices shown on pages 5-6, those “basic understandings” for the nature of science are referred to as “major themes” and listed under “Categories” in each matrix. The matrix describes specific “learning outcomes” for each Category/Theme in each grade band. Those learning outcomes are supposedly expressed in selected performance expectations in the foundation boxes throughout the standards. Each Theme/Category is extended here in red based on its implications as reflected in the new Framework.

NGSS NOS Themes/Categories of Basic Understandings:
1. Scientific investigations use a variety of methods for gathering, analyzing, testing evidence/clues.
2. Scientific knowledge is based on empirical evidence; on observations of evidence/clues, not authority.
3. Scientific knowledge is open to revision in light of new evidence; claims are tentative to some degree.
5. Science is a way of knowing: follows rules that are empirical, logical, skeptical, critical; most reliable results.
6. Scientific knowledge assumes an order and consistency in natural systems throughout universe.
7. Science is a human endeavor, involving creativity, biases, sensory limits, and benefits of teamwork.
8. Science addresses only questions about the natural and material world. never the supernatural.

However, a search of the standards for those NOS performance expectations reveals only a few. They are relegated to the bottoms of the foundation boxes (blue and green), where they may even go unnoticed or ignored by teachers. Research has clearly shown that if the NOS elements are to be properly understood and remembered, they must be explicitly taught and frequently reinforced, not just mentioned in the context of science processes for other topics. The Science Surprises materials provide a ready-to-use unit that does, indeed, introduce those elements explicitly and repeatedly.

The grid below shows which NGSS NOS Themes/Categories are achieved with each of the ENSI NOS lessons suggested for the Science Surprises (SS) unit, and where in the Teacher’s Guide each is mentioned. In addition, all of those Categories are fully addressed in the Science Surprises student book. Ideally, the appropriate interactive lessons should be experienced before they are discussed in the student book. All of these lessons can be used in either middle school or high school. “Pre Txt” lessons can be used before using the SS text.

<table>
<thead>
<tr>
<th>Ref. in SS Unit</th>
<th>ENSI NOS Lessons:</th>
<th>1</th>
<th>2</th>
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<td>The Oat Seed Lab</td>
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<td>Palpating Pachyderms</td>
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Lessons in boldface most recommended

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TA-6a: Sample Schedule: 3-Week Plan – Abbreviated

Day 1: Grabber: Illusion or discrepant event: if you can, work in Deep Ignorance this week.
   Student Info Sheets (SIS)
   Science Surprises Quiz as Pre-Test
   False Assumptions (sponge activity)

Day 2: Start Oat Seed Lab
   Course Syllabus – Overview of Course
   False Assumptions (continued)

Day 3: Do Checks Lab (gets collaborating right away)

Day 4: Do Sunsets, Souls and Senses

Day 5: Check oat seed liquids
   Assign Chapter 1 of Science Surprises (SS): Why Science? & What IS Science?
   Reflect on Week’s Work; Do a few False Assumptions if time.

Day 6: Introduce Meaningful Metric Measurement (or measuring mm and cm).
   Check oat seeds; add water, start measuring cotyledons, record, share with partner.
   Review Ch. 1 of SS: Why Science? & What IS Science?; do Self Check Questions (finish as homework).

Day 7: Measure oats, record, share data.
   Go over SC Questions and discuss for clarification and emphasis.
   Do Magic Hooey Stick, Flat Earth, Perception Not Always Reality, Palpating Pachyderms.
   Assign Ch. 2 of Science Surprises: What Science is NOT; do SCQ – finish as HW.

Day 8: Measure oats, record, share data. Add liquids as necessary.
   Discuss Ch. 2 SCQ; Do Mystery Boxes (or alternative E: What’s in the Bag?)
   Assign Ch. 3 of Science Surprises: Words of Science; do SCQ – finish as HW.

Day 9: Measure oats, record, share data.
   Discuss Ch. 3 SCQ; Do Crime Scene: The Case of the Missing Computer Chip.
   Assign Ch. 4 of Science Surprises: The Quality of Science; do SCQ – finish as HW.

Day 10: Measure oats, record, share data; Add liquids.
   Discuss Ch. 4 SCQ. Reflect on week’s work.
   Do Good Science vs Bad Science activity (Student Appendix SA-4.3)
Day 11: Measure oats, record, share data.  
Hand out Oat Seed Lab Analysis sheets and forms. Students begin Oat Seed analysis.  
Assign SA-4.1 Part A: **Confirmation Bias in Science** to do as HW. Provide Discussion sheets.

Day 12: Discuss **Confirmation Bias** questions (bias); Encourage doing SA-4.2, if time.  
Hand out Discussion Options for **Oat Seed Report**; full report due tomorrow.  
Assign Ch. 5 of *Science Surprises*; **Pseudoscience**; do SCQ – finish as HW.

Day 13: Collect Oat Seed Reports. Suggest *ENSI* lesson **Therapeutic Touch** for extra credit.  
Discuss Ch. 5 SCQ and Sidney Harris cartoon.; **Do How’s Your Horoscope?**

Day 14: Reflect and review unit on the Nature of Science

Day 15: Unit Exam (include the pre-test items and score separately for pre/post comparison)  
Begin prep for next unit, or explore the Appendix for possible extra credit (for deep probers).
TA-6b: Sample Schedule: 3-Week Plan – Detailed (3 pages)

Week One, Day 1

Greet students at door. Channel the last trickle to fill in seats in front row, then 2nd, 3rd and 4th rows, etc. so first 3-4 rows are filled.

First Day Grabber: Do an illusion (magic trick or discrepant event); get “how?” queries; Ask if anyone can think of an illusion in nature…. e.g., flat earth, sun circles earth
Ask “How do we know this is just an illusion? (careful observations, science, math)
Announce “This is what we’re going to do – discover many of the illusions of nature.”

Hand out Student Info Sheets (SIS). Ask students to put their Desk Number on their SIS (have desk numbers on each desk before class). Contact author for sample SIS and how it’s used.

Take roll (while students quietly fill out SIS)
Hand out Scantron-type answer sheets, then the Science Surprises Quiz (15-20’); Ask students to put their Desk Number on the answer sheet (next to their name).
When finished, collect Science Surprises Quiz and answer sheets; collect Student Info Sheets when done (before end of period); Announce: “When you come in tomorrow, take these same seats.”

Last 5-10 minutes, do a False Assumption or two. Just before bell, say “Look out for your false assumptions!” Bell rings… “See you all tomorrow, in these seats!”

Teacher Prep: Score “Scantrons”, using item analysis. Sort Student Info Sheets by Desk Number (or have student assistant do this). Prepare seating chart based on Desk Numbers. Prepare materials for Oat Seed Lab (be sure to read the lesson on the ENSI site, especially the Teacher Rationales linked to from the lesson).
Prepare copies of your Syllabus (if you have one) to be distributed to students.

Day 2: Bell Ringer (e.g., “list 3 questions about what we did yesterday”—and quick attendance check (look up names for empty desk numbers; deal with new arrivals);
Begin Oat Seed Lab. Read “Rationale;” Students plant oat seeds (6/vial or cup) (~ 30’)
Introduce yourself (and experience), and the course: Topics to be covered (I like to show a series of slides reflecting engaging aspects of those topics); Share your expectations for your students. If time, hand out and go over your course syllabus – especially how grades are earned, and how they can earn extra credits for top grades, etc.
Go over a few of your key rules of the classroom.
Go over class results on the Science Surprises Quiz. Mention a few items missed by most students; point out that misconceptions about science are all too common.
If time, do another False Assumption or two. Plan to do one or two of these as a flexible “sponge” near end of period – to reinforce the fact the we all have many false assumptions about how the world works.

Teacher Prep: Prepare materials for Checks Lab

Day 3: Bell Ringer and check attendance. Assign team groups (convenient to where they sit).
Introduce and do Checks Lab. Discuss the key NOS features experienced in the lab. (team disc, then class disc.)

Day 4: Bell Ringer and quick attendance.
Introduce and do Sunsets, Souls & Senses lesson. Discuss the key NOS features experienced in the lesson (team disc, then guided class disc.)
**Teacher Prep:** Prep for watering oat seeds. Have Science Surprises ready to hand out. Remind students NOT to put name on the Science Surprises chapters, and NOT to write in them.

Day 5: Bell Ringer and quick attendance.
Add water to oat seeds (before weekend): plain tap water to controls, special water solution to the experimental vials.
Hand out Science Surprises. Assign to begin reading (Chapter 1).
Reflect on the week: ask and discuss “What did we do?” What did we learn?” What was new – different from what was assumed before we started?”
If time, go over the Science Surprises Quiz items missed by most students. “Do we have more to learn?” “Look over the Science Surprises.”
**Teacher Prep:** Get oat seed data recording sheets for next day. Prepare materials for presenting Deep Ignorance and introducing metric measurement; measure and water oat seedlings.

Week Two, Day 6: Open the period with Deep Ignorance. Then segue with the Dynamic Meaningful Metric System as a key tool in our search for understanding.
http://www.indiana.edu/~ensiweb/connections/metrics.con.html
Or just show how to make linear measurements of oat seedling lengths from rim of vial in mm

Students start measuring their oat seedlings, recording and sharing the data. Add water / solution to vials as needed. Share data within team partners.
Assign Ch. 1 to review and answer Self Check questions in notebook. Might be collected tomorrow.

**Teacher Prep:** Prepare for one of the five lessons mentioned below for day 2.

Day 7: Measure oats, and record. Add water/solution if needed. Share data with partner.
Go over the Ch. 1 Self Check questions quickly; expand on any item of confusion.
Wherever possible, ask students to recall examples related to parts of this chapter, and be prepared to point out others.
Ask “What rules or other features of science have we experienced so far?” List these on whiteboard (or equivalent). What rules or features of science have we NOT experienced yet – or not enough?”
[If “realm and limits of science” needs more experience, consider doing Flat Earth, Magic Hooey Stick, or Perception is Not Always Reality lesson.]
[If “different ways of knowing” needs more experience, consider doing the Palpating Pachyderms lesson.]
Assign Ch. 2 to read and answer SC questions to discuss tomorrow.
Day 8: Measure oats and record. Add water/solution as needed. Share data with partner. Discuss the SC Questions of chapter 2. Wherever possible, ask students to recall examples related to parts of this chapter, and be prepared to point out others.

Another excellent ENSI lesson to insert here (or on day 4) would be the Mystery Boxes. Assign Ch. 3 to read and answer SC questions to discuss tomorrow.

Teacher Prep: Possibly, run off Hypothesis Practice Sheets (TA-9).

Day 9: Measure oats and record. Add water/solution if needed. Share data with partner. Discuss the SC Questions of chapter 3. Wherever possible, ask students to recall examples related to parts of this chapter, and be prepared to point out others. Emphasize the levels of uncertainty in science. Consider assigning SA-3.3 and/or SA-3.4 to read. Run off copies of Hypothesis Practice Sheets for SA-3.3 (TA-9), and/or assign SCQs for SA-3.4

Assign Ch. 4 to read and answer SC questions to discuss tomorrow. Do one of the “forensic” lessons: Crime Scene, or Crime Against Plants, or do another forensic type of lesson (for experience with an historical type of investigation).

Teacher Prep: Possibly, run off Discussion Questions for SA-4 (Conf. Bias, see TA-13).

Day 10: Measure oats and record. Add water / solution as needed. Share data with partner. Discuss the SC Questions of chapter 4. Wherever possible, ask students to recall examples related to parts of this chapter, and be prepared to point out others. If time, have students do SA-4.1 and SA-4.2: Confirmation Bias in Science. Provide Discussion Questions for these two items (TA-13).

Do Good Science vs Bad Science activity (Student Appendix SA-4.3) (Key: TA-14).

Teacher Prep: Prepare Discussion Options for Oat seed report (to handout next). Also handout for Confirmation Bias activity (TA-13) if not done already.

Week Three, Day 11:

Measure oats and record. Add water/solution if needed. Share data with partner. Hand out the Oat Seed Lab analysis sheets and forms. Explain briefly how to process the data and begin analysis. Students begin processing the data (making graph of data and doing t-Test of significance on their data.).

Assign SA-4.1 Part A: Confirmation Bias to do as HW. Provide Disc. Sheets (TA-13).

Teacher Prep: Prepare Discussion Options for Oat seed report (to handout next).

Day 12: Discuss Confirmation Bias questions (and/or collect them). Encourage doing SA-4.2 Finish work on Oat Seed analyses. Hand out Discussion options for Oat Seed report. Full Oat Seed Report due tomorrow. Assign Ch. 5 to read and answer SC questions to discuss tomorrow.

Day 13: Collect Oat Seed Reports. Suggest ENSI lesson Therapeutic Touch for extra credit. Discuss the SC Questions of chapter 5. Wherever possible, ask students to recall examples related to parts of this chapter, and be prepared to point out others.

Do How’s Your Horoscope? Lesson. Discuss Sidney Harris cartoon

Reflect and review topics studied in this unit. See Teacher’s Guide Part 6.


Day 15: Unit Exam (including Science Surprises Quiz for post-test analysis).
TA-6c: Sample Schedule: 2-Week Plan – Abbreviated

Day 1: Grabber: Illusion or discrepant event
    Student Info Sheets (SIS)
    Science Knowledge Survey
    False Assumptions (sponge activity)

Day 2: Introduce Perception Not Always Reality (Illusion), or Pendulum Problem, etc.
    Course Syllabus
    False Assumptions (continued)

Day 3: Finish Investigation (PNAR, or PP or equivalent)
    Or Do Sunsets, Souls and Senses
    Assign Chapter 1 of Science Surprises: Why Science? & What IS Science?
    Homework: Read Ch. 1, answer Self Check Questions (SCQs)

Day 4: Discuss SCQ for Ch. 1
    Do Crime Scene, Checks Lab, or Great Fossil Find (similar lessons on historical science)
    Assign Ch. 2 of Science Surprises: What Science is NOT; do SCQ – finish as HW.
    Homework: Read Ch. 2, answer SCQs

Day 5: Discuss SCQ for Ch. 2
    Do Sunsets, Souls and Senses if not done earlier
    Do a few False Assumptions, if time.

Day 6: Brief recap of previous week’s work
    Do Mystery Boxes (or its alternative E: What’s in the Bag?)
    Assign Ch. 3 of Science Surprises: Words of Science; do SCQ – finish as HW.
    Homework: Read Ch. 3; Do the three “Do This” items #3.1 and 3.2; answer SCQs

Day 7: Discuss SCQ for Ch. 3
    Do Good Science vs Poor Science (Student Appendix SA-4.3)
    Assign Ch. 4 of Science Surprises: The Quality of Science; do SCQ – finish as HW.
    Homework: Read Ch. 4, answer SCQs

Day 8: Discuss SCQ for Ch. 4
    Do How’s Your Horoscope? lesson
    Assign Ch. 5 of Science Surprises; Pseudoscience; do SCQ – finish as HW.
    Homework: Read Ch. 5, answer SCQs; Answer “Do This” item #5.1 question for Fig. 7.

Day 9: Discuss SCQ for Ch. 5, and the “Do This” item #5.1
    Reflect and Review the NOS unit: What were the “surprises?” What did you learn?
    How is science different from what you thought it was when we began? Any questions?
    Read over the Summary together, and discuss any part not clearly understood.

Day 10: Unit exam (include the pre-test items and score separately for pre/post comparison)
    Begin prep for next unit, or explore the Appendix for possible extra credit (for deep probers).

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TA-6d: Sample Schedule: Block Schedule Plan (about nine 90’/periods)

Day 1: Grabber: Illusion or discrepant event: as “Why is this?” “How can we find out?”

Student Info Sheets (SIS)

Science Surprises Quiz (25 items)

Introduce inquiry problem to investigate: Introduce rationale for Oat Seed study
(Background, Problem, Hypothesis) or other investigative subject, e.g., the T- illusion
(Perception is Not Always Reality) study, or Pendulum Study, etc.

Start the study (for the Oat Seed study, prepare vials and seeds, add liquid (use water
and “plant food”).

Introduce Meaningful Metric Measurement needed for the study (at least using ruler
for mm and cm).

Course Syllabus – Hand out Overview of Course to read (finish as homework).

False Assumptions (If time, introduce this and do 1-2 examples, as an insightful “sponge”
activity. As time allows, try to do this near the end of each period, if possible, for at least
a few periods).

Day 2: Course Syllabus (Discuss as necessary)

Point out Science Surprises Quiz class results – the large number of misconceptions shown
by class, and therefore the need to repair those misconceptions. That’s what this unit’s
about!

Inquiry Study: Check water or make other progress on oat seeds, T-illusion, pendulum, etc.

Do Checks Lab, including discussion of the lab.

Introduce Sunsets, Souls, and Senses (if time), and/or do a False Assumption or two if
time.

Day 3: Inquiry Study: Check water, measure and/or or make other progress on oat seeds, T-
illusion, pendulum, etc.

Do Sunsets, Souls, and Senses (or finish, if started previous session)

Assign Chapter 1 of Science Surprises (SS): Why Science? & What IS Science? Read,
answer Self Check Questions (SCQ); finish as homework.

Day 4: Inquiry Study: Check water, measure and/or or make other progress on oat seeds, T-
ilusion, pendulum, etc.

Discuss Ch. 1 SC Questions as needed.

Do Magic Hooey Stick, Great Volume Exchanger Flat Earth, Perception Not Always
Reality OR Palpating Pachyderms lesson from ENSI site.

Assign Chapter 2 in SS: What Science is NOT; do SCQ; finish as homework.

Day 5: Inquiry Study: Check water, measure and/or or make other progress on oat seeds, T-
ilusion, pendulum, etc.

Discuss Ch. 2 SCQ.

Do Mystery Boxes (or equivalent if not done earlier, e.g., Checks Lab, or Great Fossil
Find).

Assign Ch. 3 in SS: Words of Science; do SCQ, finish as HW.
Day 6: **Inquiry Study**: Check water, measure and/or make other progress on oat seeds, T-illusion, pendulum, etc.

_Discuss Ch. 3 SCQ._

Do Crime Scene (or other quick Forensic lesson)

_Assign Ch. 4 in SS: The Quality of Science; do SCQ, finish as HW._

Day 7: **Inquiry Study**: Process data, start report on oat seeds, T-illusion, pendulum, etc.

_Discuss Ch. 4 SCQ._

Do Good Science vs Bad Science activity (Student Appendix SA-4.3)

_Assign Ch. 5 in SS: The Quality of Science; do SCQ, finish as HW._

Day 8: **Inquiry Study**: Prepare report on oat seeds, T-illusion, pendulum, etc. (Due next session).

_Discuss Ch. 5 SCQ._

Do How’s Your Horoscope? on pseudoscience (in class)

Hand out Confirmation Bias material on bias in science (SA-4.1); finish as homework

_Reflect on the Key Concepts from the unit. Prepare for test._

Day 9: Brief Discussion of Confirmation Bias as an example of bias in science.

_Take Science Surprises Quiz as Post Test. (40 items); Take any other assessment by teacher._

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Preparations For Nature Of Science Lessons (2 pages)

Lessons Requiring Extended Preparation
(Beyond duplication of handouts)

Oat Seed Lab requires oat seeds at about 10 per student, and vials (or equivalent – see lesson for details) at 1 per student. Also requires the preparation of a particular solution to be available in multiple dispensing bottles, and a series of handouts.

Checks Lab requires checks to be printed, cut apart and placed in envelopes.

Sunsets, Souls & Senses: extension of this lab (Science IS / Science is NOT) requires cutouts to be printed, cut apart and placed into envelopes.

Flat Earth requires some handouts to read and discuss. Also, there is a very good video the class should watch and discuss (source provided).

The Magic Hooey Stick requires at least one Hooey Stick, and practice in using it properly (directions provided by ENSI). A classroom set of Hooey Sticks is even better (one set for every 2-4 students. Hooey Sticks can be made by the teacher (directions provided), or purchased from commercial supplier for about $2 each (source provided). For additional information and key, contact the author (flammer4@gmail.com).

Mystery Boxes requires the preparation of enough boxes so there’s one for every two students in your largest class. Instructions provided in the lesson.

Crime Scene requires clues to be printed, cut apart and placed into envelopes.

Find the Washer requires preparing the box in which to find the washer (directions provided).

Three-Hole Bottle requires preparation and testing of the 3-hole bottle from a plastic liter soda bottle (fairly easy).

The Great Volume Exchanger requires preparation and testing of this rather elaborate contraption (instructions provided).

The Great Fossil Find requires printed “fossils” to be printed, cut apart and placed into envelopes. Especially good for elementary or MS classes.

NOTE: For Answers to Crime Against Plants or the Laetoli Puzzle lessons, or many of the Evolution lessons, go to ENSI KEYS ONLINE (See Direct Links).

Key Points For Any Nature Of Science Unit
Sample schedules are only suggestions for a first trial run. The content and timing is based on a tightly run program for high school biology students with reasonably good-to-average reading skills and daily 50 minute periods. Obviously, adjustments would be needed for different school schedules and/or the leaning skills of your students. Note especially these important features:
An engaging first day (and every day, as much as you can).
Give *Science Surprises Quiz* on the first or second day.
Do a fairly simple model investigation (e.g., the Oat Seed Lab) beginning on second day. The example used here is good for life science or biology; something different would probably be better for a physical science – something involving observations and measurements to test a particular hypothesis. The hypothesis that a pendulum’s mass affects its period might be a good one, or possibly combine this with a pendulum’s length affects its period; alternate teams of two can test each hypothesis.

Introduce metric system units as needed and used
Have students do 2-3 interactive lessons during the first week, without using any text material.
Select interactive lessons that anticipate the next assigned reading, so students gain experience and some understanding before reading about it (thereby reinforcing their understanding).
Let teams discuss Self Check (and other) questions, then engage the entire class in getting answers from one or two team representatives, subject to agreement (or not—with reasons for disagreement) and further guided discussion.
One of the lessons must provide an example of “historical” science, e.g., *Crime Scene, The Great Fossil find*, or the *Checks Lab*, as compared with an “experimental” science.
One of the lessons must provide experiences to recognize the realm of science — that only *natural* explanations can be used in science, and that only *natural* phenomena can be studied. To study supposed supernatural events, one must assume that there are *natural* explanations.
One of the lessons must provide an experience with the tentativeness of science, the related idea that different explanations can have *different degrees* of strength and durability (and why that is), and that some explanations in science *are* better than others.
One of the lessons must provide experience with the reality of *biases* in science, what they can be, and how they are reduced by the rules of science.
One of the lessons must provide experience with *pseudoscience* as well as the fact that science can be done well, or poorly, like any human endeavor.
One of the lessons must provide experience with *illusions*—leading to awareness of natural illusions, and how they can be critically examined. This includes an awareness of our common assumptions (as exposed in *False Assumptions*).
One of the lessons must provide experience with distinguishing between *reality* (what is being observed), *observations* (what our senses detect), *inferences* (our assumptions), and our *explanations* (why we observe what we observe).

If more time is available, do an additional *ENSI NOS* lesson or two, or explore one or more of the items presented in the Appendix of the student booklet. These might also be used for individual students who are motivated to explore them on their own, perhaps for extra credit.

Some of the Nature of Science lessons (not used in your NOS introductory unit) can be used at different points during your course, where appropriate, and thereby reinforce those elements of the Nature of Science, in context.

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TA-8: A Simple Pendulum Experiment

If you are teaching a physical, earth, or general science class, a simple pendulum experiment should work well for an investigative study. Below are links to a couple of versions available online. It would be especially useful to get your students to come up with at least three reasonable variables that might influence the period (time for one complete swing to and fro) or the number of seconds for 10 such periods. Variables might include different weights, different string lengths, different swing-starting positions or angles, etc.

Then you could have 2-3 groups testing one of those variables, another 2-3 groups testing the second variable, and the remaining 2-3 groups testing the third. You can use your own ideas as for setting up, recording data and reporting the study. Or, you could use the Oat Seed lab as a model, if you like. If you don't have ring stands from which to swing the pendulums, you could just have them swing them from the edge of their table or desk. You will need meter sticks for measuring and some items for weights (e.g., different sized washers) to hang--using bent paperclip--on a loop at the end of a string.

Try this link: <http://www.worsleyschool.net/science/files/pendulum/experiment.html>
This gives some preliminary explanations. Then click “Pendulum Experiment” at the bottom of that page. This takes you to:
<http://www.worsleyschool.net/science/files/pendulum/pendulum1.html>

Another site to try: <http://www.scribd.com/doc/15685729/Simple-Pendulum-Lab>

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Hypothesis Practice 1: Problem—Hypothesis – Test—Prediction

The following describes an example for how one well known scientific discovery was made:

Observation: In 1928, Alexander Fleming was growing bacteria in laboratory petri dishes when molds invaded some of the dishes. Fleming intended to discard those dishes but left them sitting while doing some other work. Those particular bacteria (with the invading mold) were ones that caused many infections (Staphylococcus, causing “staph” infections).

Even in the midst of his other work Fleming noticed that there was a clear area close to the mold in a contaminated dish; the bacteria were no longer growing near that one mold. This puzzling observation was to become a lifesaving one [why?]. The question it raised kept distracting Fleming:

Problem: Why weren't the bacteria growing near that particular mold?

Hypothesis: The mold may produce a colorless liquid that inhibits growth of the bacteria.

Test: Remove liquid from the mold and place that fluid on bacteria starting to grow on a petri dish.

Prediction: [If we do that test,] the bacteria will die or stop reproducing [this last part, in italics, is the actual prediction]. If the hypothesis is not correct, we should see no change in bacteria growth [second prediction in italics].

Definitions:
A. Which of these phrases defines “hypothesis?” _______________________
   1. a possible solution
   2. expected to happen
   3. a suggested explanation
   4. a tentative answer
   5. a game plan
   6. a trial answer
   7. an educated guess
   8. a model
   9. all of the above

B. Which of those phrases (1-9 above) defines “prediction?” _______________________

If you were asked to figure out what that great discovery was, how would you do that?

What was that great discovery?

BE SURE TO CUT OFF THIS KEY BEFORE DUPLICATING FOR STUDENTS
KEY: A: 1, 3, 4, 6        B: 2
[“educated guess” is not acceptable; it’s is too vague; it could be about anything, like saying what’s in the gift box (a prediction), OR giving a possible reason why your car won’t start (hypothesis), or anything else.]
Hypothesis Practice 2

For each statement below (1-10), indicate (with the letter) which of the following (A-E) fits best:

A) **PROBLEM** (or question)

B) **HYPOTHESIS** (look for terms suggesting a solution, answer, or explanation, eg. "because", "caused by...", etc., AND terms of uncertainty, eg. "most likely", "probably", "I think", etc.)

C) **TEST** (look for something done to check the hypothesis)

D) **PREDICTION** (look for phrases like "if....then....", "based on....., should be able to...")

E) **NONE OF THESE**

___ 1. I am missing the ball most likely because I'm not keeping my eye on it.

___ 2. The ocean contains oxygen.

___ 3. Why doesn't your car start?

___ 4. I know for certain that my key doesn't work because the lock needs lubricant.

___ 5. I think my bike is making a scraping noise because the bearings are not lubricated.

___ 6. Based on the idea that South America and Africa were once joined as one large land mass 200 million years ago, we should now be able to find matching rocks, minerals and fossils at corresponding points across the Atlantic on both continents.

___ 7. An earthquake is probably caused by a sudden slipping of earth masses along a fault.

___ 8. What causes thunder?

___ 9. if I eat less food, then I shouldn't get stomach aches.

___10. Because I read about this in a science book, I think the air has water in it.

KEY: Cut this off before duplicating the practice sheet.  [In #6 and 9. C is implied.]


If you rearrange the items and replace certain words with comparable words, this could be used as a quiz.
Hypothesis Practice 3.1: Sample Hypotheses, Tests And Predictions
Each numbered item is a question or problem. For each lettered statement that follows,
Use H for Hypothesis, T for Test, and P for Prediction. Combinations are ok, too.

1. Why does the Earth seem flat?
   A. The Earth seems flat because it is flat.
   B. The Earth is actually round like a ball, but is so big that we can’t see its curvature easily.
   C. If we went to the Moon and looked at the Earth, we would see that Earth was like a ball.

2. Why is it that when an airplane keeps flying west (landing for gas then taking off again), it will eventually be able to land where it started?
   A. If an airplane keeps flying west, it would eventually be able to land where it started because the Earth is round like a ball.
   B. An airplane flying west would eventually be able to land where it started because the Earth is round like a ball.
   C. The Earth is round like a ball.

3. Why does the Sun seem to circle the Earth?
   A. The Sun actually does go around the Earth.
   B. The Earth actually goes around the Sun, going around once every year.
   C. The Earth spins on its axis, making one turn every 24 hours while the Sun stays in one place.

4. Why does the Magic Hooey Stick change directions?
   A. Shouting “Hooey” blows the propeller in the opposite direction.
   B. It’s the way the propeller stick is turned.
   C. If you blow on the propeller, it will reverse direction.

5. Why does the T-illusion work the way it does?
   A. Our eyes make vertical lines seem longer than they are, compared to horizontal lines.
   B. Our eyes make vertical lines seem shorter than they are, compared to horizontal lines.
   C. Our brain makes it work that way.
   D. If we turn the T on its side, then the original vertical line will actually be longer than the original horizontal line when they are adjusted to appear the same.

6. Pendulum X is 30 cm long and weighs 30 g. Pendulum Y is 35 cm long and weighs 35 g. Why does pendulum X swing faster?
   A. Pendulum X is shorter.
   B. Pendulum X is lighter.
   C. Both A and B.

7. How does a plant food (fertilizer) affect oat seed growth?
   A. If you grow an oat seed in plant food, it would make it grow faster.
   B. If you grow an oat seed in plant food, it would still grow the same.
   C. Plant food stimulates growth of plants.

8. What is inside the mystery box that makes it feel the way it does when tilted?
   A. There’s a ½ barrier across the middle, and a small cylinder rolling and sliding around.
   B. If there’s a cylinder, it should roll when tilted one way, and slide if tilted 90° the other way.
   C. If there’s a ½ barrier across the middle, the cylinder only rolls or slides a short distance along one side of the box, and the full distance along the other side of the box.
Hypothesis Practice 3.2: Sample Hypotheses, Tests And Predictions

ANSWER PAGE

Use H for Hypothesis, T for Test, and P for Prediction. Combinations are ok, too.

1. 
   A. ________
   B. ________
   C. ________

2. 
   A. ________
   B. ________
   C. ________

3. 
   A. ________
   B. ________
   C. ________

4. 
   A. ________
   B. ________
   C. ________

5. 
   A. ________
   B. ________
   C. ________
   D. ________

6. 
   A. ________
   B. ________
   C. ________

7. 
   A. ________
   B. ________
   C. ________

8. 
   A. ________
   B. ________
   C. ________
**KEY Hypothesis Practice 3.3: Sample Hypotheses, Tests & Predictions**

Use **H** for Hypothesis, **T** for Test, and **P** for Prediction. Combinations are ok, too.

1.  
   A. H  
   B. H  
   C. T & P  

2.  
   A. T, P, H  
   B. T, P, H  
   C. H  

3.  
   A. H  
   B. H  
   C. H  

4.  
   A. H  
   B. H  
   C. T & P  

5.  
   A. H  
   B. H  
   C. H  
   D. T & P  

6.  
   A. H  
   B. H  
   C. H  

7.  
   A. T & P  
   B. T & P  
   C. H  

8.  
   A. H  
   B. T & P  
   C. T & P  


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Hypothesis Practice 4: For each problem or question below, think of a reasonable hypothesis for that problem, and write it clearly in the space provided. When done, discuss the examples written by each student. Be sure to point out why each example is a good one, or why it is not a good one. Be tactful. And, remember, it doesn’t have to be the right hypothesis; it just has to be worded properly for a reasonable hypothesis.

1. Why doesn’t my smart phone turn on?
   Hypothesis: ________________________________________________________________

2. When a magician made a coin disappear, how did she do that?
   Hypothesis: ________________________________________________________________

3. Why is the Earth’s climate changing?
   Hypothesis: ________________________________________________________________

4. Why do some people get colds more easily than others do?
   Hypothesis: ________________________________________________________________

5. Why is the sky blue?
   Hypothesis: ________________________________________________________________

6. What causes our seasons?
   Hypothesis: ________________________________________________________________

7. Why are some people better at math than others are?
   Hypothesis: ________________________________________________________________

8. Why does oil float on water?
   Hypothesis: ________________________________________________________________

9. The oldest fossils of modern humans are about 200,000 years old. Why not any older ones?
   Hypothesis: ________________________________________________________________

When you discuss these, be sure to look for words of tentativeness and words of explanation. No predictions, no tests.

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RELATING THE TERMS OF SCIENCE

THEORY
Nicely explains and ties together all the relevant facts, observations, laws and tested hypotheses

HYPOTHESIS
Answers, Explains

FACTS
Observations, when critically and consistently confirmed by many observers, are called Facts

NATURAL LAW

QUESTIONS, PROBLEMS

FACTS
Facts can be tentatively explained by a testable Hypothesis

Facts can be generalized and often quantified to form a Natural Law

OBSERVATIONS

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TA-11: Sequence of Importance for Terms of Science

How most people might list these terms:

MOST IMPORTANT

Facts
Laws
Theories
Hypotheses

LEAST IMPORTANT

Scientists would probably list them like this:

MOST IMPORTANT

Theories
Laws
Hypotheses
Facts

LEAST IMPORTANT

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From Scott 2004, page 11.
TA-12: Demo: Atom is mostly Empty Space

Here’s an exercise in math scaling and using conversion factors. See Conversion Factors sites below for helping to teach students how to do this. Do it before they read chapter 5.

An atom is about 100,000 times the size of its nucleus!

You might have your students calculate the size of an atom scaled up to where the diameter of the nucleus is about the size of a sand grain – about 1mm. Show them how to set up the use of conversion factors, but let them do the calculations.

\[
\begin{align*}
1\text{mm} \times 100,000 &= 100,000 \text{ mm} \\
100,000 \text{ mm} \times (1 \text{ meter}/1000 \text{ mm}) &= 100 \text{ meters} \\
100 \text{ m} \times (1 \text{ yard}/0.9 \text{ m}) &= 111 \text{ yards}
\end{align*}
\]

Ask your class “what's something that's about this big?” This is about the size of a football field!

“Now, close your eyes and visualize: Imagine a huge ball about a football field’s length in all directions – 100 yards in diameter. And the nucleus is a grain of sand in the middle of this ball. Each electron is not much bigger than one of the protons or neutrons in the nucleus, so they take up very little space. They are flying all around the nucleus at very high speeds. So what is an atom's volume composed of, mostly? Nothing! Talk about an illusion! We are made of atoms, and each atom is mostly nothing! So we are mostly nothing! But each of you is so very precious - to your folks, and to me.”

At this point, I palm a quarter, make it seem to pass from my right hand to my left hand (it’s still secretly in my right hand, but my eyes follow my left hand). I slap my left hand (closed around the imaginary quarter, but opening just as I hit the desk) on top of a student’s desk, and at the same time, I reach under the desk with my right hand (still secretly holding the quarter), and slap it up against the underside of the desk, so students hear that slap at the same time that I slap my right hand down on top of the desk. Then I pull my right hand out and show the quarter that I “clearly forced through all that empty space in the atoms of the desk!” Then I do the same thing through my head – even more empty space! All of this drama makes the point: an atom’s volume is mostly nothing.

CONVERSION FACTORS

In mathematics, specifically algebra, a conversion factor is used to convert a measured quantity to a different unit of measure without changing the relative amount. To accomplish this, a ratio (fraction) is established that equals one (1). In the ratio, the conversion factor is a multiplier that, when applied to the larger unit, converts the larger unit into the smaller unit, by multiplication with the measured amount.

How to Convert Units of Measurement (the Big Secret) printed out.

http://oakroadsystems.com/math/convert.htm - Secret

Khan Academy: search for “Unit Conversion “ (videos show how to do it).

https://www.khanacademy.org/math/arithmetic/rates-and-ratios/unit_conversion/v/unit-conversion

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TA-13: Confirmation Bias: Discussion and Key for Student Appendices 4.1 and 4.2

Name_____________________________________________ Period_____  

Confirmation Bias in Science
Read the article by scientist Chris Lee about “Confirmation Bias in Science: How to Avoid It.” Note Glossary at the end of that article for some terms that might be unfamiliar.

Discussion

Confirmation Bias Part A

1. What is “confirmation bias?”

N-Rays

2. Why do you suppose Blondlot announced his discovery of “N-rays” so quickly, without looking for weaknesses in that discovery first?

3. Explain why this “N-ray” discovery is a good example of “confirmation bias.”

4. Explain briefly how the “N-ray” was shown to be a false phenomenon.

Water Memories

5. What did Beneveniste report in the scientific journal Nature?

6. Why was Benveniste’s paper published though his conclusions were illogical?

7. What was the flaw in Beneveniste’s procedures?

8. Why do you suppose that the researchers involved Beneveniste’s work still perform this research on other homeopathic “remedies?”

9. What happens to scientists who refuse to acknowledge their confirmation bias?
**Practice of Avoiding Confirmation Bias**

10. How was most of the time spent during the two years that the author (scientist Chris Lee) and his team worked on his method to “see the impossible” in the new microscope?

11. The author says that the first step in science is to: Get an idea, discuss it with colleagues, then …?

12. What’s the word we use for this effort to destroy a hypothesis? ________________ it.

13. Therefore, instead of trying to prove a hypothesis, scientists actually try to __________ it.

14. What’s the next step, if the idea survives this intense testing? ________________________

**Risk and its Rewards**

15. Once the paper is published, where do scientists share their studies and conclusions?

16. Why do scientists do this?

17. How did the author react to a serious criticism of the work?

18. What do global warming skeptics and homeopathic workers do when faced with objections?

19. What does the author say that “is true of every field of science”? 

20. How does this help the science?

**Science as a Contact Sport**

21. When scientists attack each others’ ideas, is this good for science, or not? Why?

22. What happens to scientists who keep seeking support for their ideas and try to publish their work, even after it’s been shown to have confirmation bias?

23. Have climate scientists carefully and seriously considered the objections of climate change deniers, and pointed out why the statements of those deniers are false? _______________

24. Why do you suppose climate deniers keep insisting they are right, even though nearly all working climate scientists have shown that those objections are completely wrong?
Confirmation Bias in Science  

Read the article by scientist Chris Lee about “Confirmation Bias in Science: How to Avoid It.”
Note Glossary at the end of that article for some terms that might be unfamiliar.

Discussion  

Confirmation Bias  
Part A

1. What is “confirmation bias?”
   When scientists only look for data that confirm (support) a desired conclusion.

N-Rays

2. Why do you suppose Blondlot announced his discovery of “N-rays” so quickly, without looking for weaknesses in that discovery first?
   There was a very strong motivation for having a French discovery; national pride; competition.

3. Explain why this “N-ray” discovery is a good example of “confirmation bias.”
   Strong desire to discover something for national pride. His desire to get confirmation led to his bias in reporting the results before testing them further.

4. Explain briefly how the “N-ray” was shown to be a false phenomenon.
   Crystal was secretly removed in the test, but Blondlot didn’t notice the absence of N-rays.

Water Memories

5. What did Beneveniste report in the scientific journal Nature?
   The anti-histamine reaction got stronger as the histamine solution was diluted.

6. Why was Benveniste’s paper published though his conclusions were illogical?
   Reviewers of paper couldn’t see an obvious flaw in the methods.

7. What was the flaw in Beneveniste’s procedures?
   He failed to do the experiment as a double-blind study. Results involved judgment, so when scientists knew which sample was being used, their subtle behavior gave it away.

8. Why do you suppose that the researchers involved Beneveniste’s work still perform this research on other homeopathic “remedies?”
   Because they believe strongly in homeopathy, so they want it to work. Possible financial bias?

9. What happens to scientists who refuse to acknowledge their confirmation bias?
   The become isolated from their peers (no longer accepted amongst good scientists)
Practice of Avoiding Confirmation Bias

10. How was most of the time spent during the two years that the author (scientist Chris Lee) and his team worked on his method to “see the impossible” in the new microscope?
   Trying to anticipate every possible objection to their approach. In summary, they tried to prove themselves wrong.

11. The author says that the first step in science is to: Get an idea, discuss it with colleagues, then ...
   try to destroy it.

12. What’s the word we use for this effort to destroy a hypothesis? Testing it.
13. Therefore, instead of trying to prove a hypothesis, scientists actually try to disprove it.
14. What’s the next step, if the idea survives this intense testing? Publishing

Risk and its Rewards

15. Once the paper is published, where do scientists share their studies and conclusions? Conference

16. Why do scientists do this? Their science becomes stronger as more scientists interact with it. Possible holes in the work might be found.
17. How did the author react to a serious criticism of the work? Tried to understand the objection, and resolve the problem if possible.
18. What do global warming skeptics and homeopathic researchers do when faced with such objections?
   They ignore the objections and continue with their work as if there was no problem.
19. What does the author say that “is true of every field of science”?
   the skepticism of other scientists

Science as a Contact Sport

20. How does this help the science? They get to their goal faster, results are more accurate

21. When scientists attack each others’ ideas, is this good for science, or not? Why?
   This is good for science, because problems are exposed so ideas can be improved. It’s a very effective way to remove confirmation bias [and other biases as well].
22. What happens to scientists who keep seeking support for their ideas and try to publish their work, even after it’s been shown to have confirmation bias?
   They are quickly isolated [by scientists who follow the rules].
23. Have climate scientists carefully and seriously considered the objections of climate change deniers, and pointed out why those statements of deniers are false? Yes

24. Why do you suppose climate deniers keep insisting they are right, even though nearly all working climate scientists have shown that those objections are completely wrong?
   [Various responses here, e.g., the climate deniers are still so strongly influenced by their own biases that they just can’t accept the conclusions of most other climate scientists. They refuse to see the errors in their own views, and just ignore efforts of other scientists to explain why those views are wrong.]

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TA-14: Good Science vs Bad Science

Activity: Examples of Poor Science

1. POOR—“controlled experiment” (should be only one variable at a time)

2. POOR—“Dose—Effect” (for causation, each effect should be proportional to dose)

3. POOR—“Published” (resources should be published) AND/OR
   “Species—Specific” (different species may react differently—and often do)

4. Good

5. POOR—“Species—Specific” (different species may react differently; also, based on poorly done studies)

F. DISCUSSION:

1. Was the cyclamate ban justified? Why/Why not?
   NO—Poorly done research (see flaws above)

2. What industry might be hurt if cyclamates were found to be harmless?
   Sugar processor—or another artificial sweetener (e.g., saccharin) manufacturer

3. Who might have paid the scientists that did the research described here?
   Sugar processor—or other artificial sweetener manufacturers (could have been a conflict of interest)

4. Why did the scientists conclude that cyclamates should be banned?
   Based on their poorly done research! They might also have been “influenced” by sugar companies.

[This “Research Sample” was adapted from a letter published in the AAAS Journal Science 167:1436 (13 March 1970): “Irresponsibility of Cyclamate Ban” by Stanley L. Inhorn and Loarraine F. Meisner, State Laboratory of Hygiene, Univ. of Wisconsin, Madison, WI. The letter pointed out, point by point, several weaknesses in the research that led to the cyclamate ban]

Something interesting you might want to read to your students after they do the discussion: Cyclamate is now used legally in more than 100 countries, including most countries in Europe and South America, in Canada and the UK. In Canada, their “Sugar-Twin” and “Sweet ’N Low” brands of sweeteners contain cyclamate. Cyclamate has less after-taste, and is cheaper than saccharin. Although the FDA has stated that a review of all available evidence does not implicate cyclamate as a carcinogen [cause of cancer], cyclamate remains banned from food products in the United States. The question is “why?” (Strong sugar lobby? Might be interesting to look into this…)

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TA-15: The Climate Change Issue

Student Appendix SA-5.1: The Climate Change Issue: Discussion Questions
Feel free to search the internet for help in answering these

1. When you see that studies clearly point to humans causing global warming, what questions do you think of?

2. There are about 1370 working climate scientists in the world today. Nearly all of these scientists (97%) – that’s nearly 1330 scientists – agree that global warming is happening and caused mostly by humans. If so, why are there even 3% (about 40) climate scientists that do not agree with this? List three possible reasons.

3. When climate-change deniers say that 31,000 scientists disagree with scientific consensus on global warming (without pointing out that these are mostly engineers, doctors, and non-climate scientists, and only about 0.1% working climate scientists), what does this tell you about the integrity of those climate-change deniers?

4. What is 0.1% of the 31,000 climate-change denying “scientists?” _______________________

5. What are the climate-change scientists saying we should do to reduce global warming?

6. What do they say will likely happen if we don’t do those things? (List three things).

7. Are we seeing any examples of those predictions happening now? __________

8. Would you rather live in a world with those changes (to the extreme), or make the sacrifices to reduce global warming now?

9. How did this article affect your views about climate change and global warming? ______
   A. Strengthened my views that climate change predictions are real.
   B. No change in my views that climate change predictions are real.
   C. No change in my views that climate change predictions are not real.
   D. Strengthened my views that climate change predictions are not real.

ANOTHER RESOURCE:
Converted Global Warming Skeptic (see Appendix SA-5.2):
Climate Physicist Richard Muller, now says humans almost entirely the cause!
Student Appendix SA-5.1: The Climate Change Issue: Discussion Questions KEY

Feel free to search the internet for help in answering these

1. When you see that studies clearly point to humans causing global warming, what questions do you think of?
   How reliable are they? Why are some people saying that people are not the cause? Why do some say that we’re only going through a normal climate change cycle? Why aren’t the world’s nations working together aggressively to cut greenhouse gases? How will global warming affect the world? How will this affect my life?

2. There are about 1370 working climate scientists in the world today. If nearly all of these scientists (97%) – that’s nearly 1330 scientists – agree that global warming is happening and caused mostly by humans, why are there even 3% (about 40) climate scientists that do not agree with this? List three possible reasons.
   a) they have biases favoring fossil fuels
   b) they work for a fossil fuel company
   c) their politics are opposed to changing to alternative (non-polluting) energy sources.

3. When climate-change deniers say that 31,000 scientists disagree with scientific consensus on global warming (without pointing out that these are mostly engineers, doctors, and non-climate scientists, and only about 0.1% working climate scientists), what does this tell you about the integrity of those climate-change deniers?
   Those climate-change deniers are being dishonest, disingenuous, or misleading.

4. What is 0.1% of the 31,000 climate-change denying “scientists?” _____ About 40 people____

5. What are the climate-change scientists saying we should do to reduce global warming?
   Greatly reduce greenhouse gas emissions (CO₂ and methane). This requires major reduction in the use of fossil fuels (coal, gasoline, natural gas), and quickly phase in alternative energy sources (solar, wind, biofuels, possibly nuclear).

6. What do they say will likely happen if we don’t do those things? (List three things).
   Sea levels will rise, inundating all coastal towns, lowlands, and low islands.
   We will see increasing extremes of weather (tornadoes, hurricanes, draught).
   Tropical diseases will spread into more temperate zones.
   Many species of plants and animals will become extinct.

7. Are we seeing any examples of those predictions happening now? ____________ YES!

8. Would you rather live in a world with those changes (to the extreme), or make the sacrifices to reduce global warming now?
   Probably make the sacrifices now.

9. How did this article affect your views about climate change and global warming? ______
   A. Strengthened my views that climate change predictions are real.
   B. No change in my views that climate change predictions are real.
   C. No change in my views that climate change predictions are not real.
   D. Strengthened my views that climate change predictions are not real.

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TA-15b: Choose Controversies Wisely:
Be sure students recognize differences between socio-political controversies and valid scientific controversies.

"When teaching scientific argumentation, selecting the wrong topic can impair -- rather than increase -- student understanding. " That was the message of four members of NCSE's staff, Minda Berbeco, Mark McCaffrey, Eric Meikle, and Glenn Branch, in their commentary "Choose Controversies Wisely," published in the April/May 2014 issue of The Science Teacher.

Because interest in teaching scientific argumentation is burgeoning, the commentary observed, "It's tempting to choose controversial topics to teach the skill of arguing from evidence. Controversies, after all, are what people argue about." But they also pose a risk: "Choosing the wrong controversial topic can result in a net loss ... in student understanding."

**Five criteria** for assessing whether a controversy is appropriate for a science classroom were presented. Among them: "If a controversy is presented as a scientific controversy, it should be a genuine scientific controversy," with climate change and evolution identified as two topics that are socially controversial but not scientifically controversial.

The commentary then addressed the question of whether to discuss non-scientific controversies in a science class at all. Without offering a definitive answer, Berbeco and her colleagues urged the importance of explicitly contrasting scientific argumentation "with the freewheeling, undisciplined, and often antagonistic argumentation of ordinary life."

Finally, a few further pitfalls in introducing students to scientific argumentation were mentioned, warning not only of counterproductive approaches like staging debates but also of attempts to exploit the increasing interest in teaching scientific argumentation in the service of undermining the teaching of evolution and climate change.

For the article in The Science Teacher, visit: http://digital.nsta.org/publication/?i=202138&p=10

This posting was from NCSE Deputy Director Glenn Branch, with emphases added.
A Converted Climate-Change Skeptic

Discussion Questions:
1. What did Richard Muller think about climate about “3 years ago” (in 2009)?

2. What changed his mind about that?

3. What kind of scientist is Richard Muller? ________________________________

4. In addition to concluding that global warming is real, what other important conclusion did Dr. Muller make?

5. How did Dr. Muller say humans are causing global warming?

6. How long have scientists been reasonably sure that people have been causing global warming?

7. What was courageous about Dr. Muller announcing the conclusions of their study?

8. Why is it ironic that Dr. Muller’s research was partly funded by the Charles G. Koch Foundation?

9. What did Dr. Muller’s work tell you about the nature of science?

10. How did this article affect your views about climate change and global warming? ________
    A. Strengthened my views that climate change predictions are real.
    B. No change in my views that climate change predictions are real.
    C. No change in my views that climate change predictions are not real.
    D. Strengthened my views that climate change predictions are not real.
Student Appendix SA-5.2: A Converted Climate Change Skeptic

**Discussion KEY**

1. What did Richard Muller think about climate change about 3 years ago?
   He was skeptical about climate change.

2. What changed his mind about that?
   He led a team of a dozen scientists in an intensive research effort. Their findings showed that global warming is indeed a reality.

3. What kind of scientist is Richard Muller? **A climate scientist and physicist.**

4. In addition to concluding that global warming is real, what other important conclusion did Dr. Muller make?
   He said that humans are almost entirely the cause [of the current global warming].

5. How did Dr. Muller say humans are causing global warming?
   By their emissions of greenhouse gases.

6. How long have scientists been reasonably sure that people have been causing global warming?
   Nearly two decades (about 20 years).

7. What was courageous about Dr. Muller announcing the conclusions of their study?
   His findings are certain to be attacked by climate change deniers.

8. Why is it ironic that Dr. Muller’s research was partly funded by the Charles G. Koch Foundation?
   The Koch Foundation financially supports various efforts to promote climate change denial!

9. What did Dr. Muller’s work tell you about the nature of science?
   Careful scientific studies can be compelling enough to reverse one’s opinions.
   Scientific integrity (honesty) is an important part of science.
   The study is being peer-reviewed for publishing in a scientific journal.

10. How did this article affect your views about climate change and global warming? ______
    A. Strengthened my views that climate change predictions are real.
    B. No change in my views that climate change predictions are real.
    C. No change in my views that climate change predictions are not real.
    D. Strengthened my views that climate change predictions are not real.
UNIT REVIEW: List of (Possible) Surprises

The word “Surprise” has been inserted 30 times, usually following a statement about the nature of science that would probably be surprising to most people—a reflection of the poor science literacy in our country. The following are largely paraphrases of those statements. If students were asked to list the “Surprises” as they found them, they should have a list something like this. It would be interesting to ask them to check-mark each item in their list that was, indeed, surprising to them, then count the check marks, and put that number at the top. You might also ask if there are any items (checked or otherwise) that might still be a little unclear. This would make a useful kind of unit review. [Double lines ===: separate Surprises into chapters]

Chapter 1:

p. 1. All these statements are false: Science can be used to solve any problem. Good scientists try to prove their explanations. Scientists can use supernatural explanations if they need to. A scientific theory is just a guess. The main goal of science is to produce facts. A hypothesis is just an educated guess. The Scientific Method is necessary for doing good science.

p. 2. Science is a powerful and effective tool for understanding the natural world. The goal of science is to understand the natural world.

p. 2. There is no ONE “Scientific Method”

p. 3. Science is not always common sense or logical (problems with natural illusions)

p. 3. Most engineers and medical doctors are not scientists.

Chapter 2:

p. 4. Science can only deal with the natural world (never the supernatural)

p. 4. Scientists cannot use an explanation just because some famous scientist said it was so.

p. 4. There are better answers: the simplest explanation that fits all observed facts is better than those that don’t. Science is not democratic.

p. 5. Scientists don’t try to “prove” their ideas (with that sense of finality). Rather, they actually try to disprove their ideas, as a way of testing them for their durability.

p. 6. Supernatural explanations cannot be part of any scientific explanation.

Chapter 3:

p. 8. Explanations are the real goal of science, not facts as such.

p. 8. Scientific facts are only assumed to be real.

p. 9. Even scientific facts can change.
p. 9. Hypotheses do not necessarily become theories, and theories don’t become laws.

p. 10. Scientific theories are more important (and useful) than hypotheses, laws, or facts.

p. 11. Science is not about absolutes and certainties. All science is uncertain, but it does deal with all degrees of probability. So some scientific ideas, e.g., theories, are better supported than others, e.g., hypotheses.

p.11. Hypotheses are generally tentative (not just guesses).

p. 11. Most scientific theories are well-supported by evidence and many studies. They generally reflect something close to what we would consider reality. They are not just guesses.

p. 12. Scientific knowledge is always getting better and more reliable.

p. 12. Science is not about seeking “truth.”

================= Chapter 4:

p. 13. Science is not always reliable, for a variety of reasons.

p. 14. Scientific work is often criticized by other scientists in scientific journals. This is a major strength of science. Criticism and conflicts are normal for science.

p. 15. The fact that scientists publish their work in peer-review journals increases the reliability of scientific knowledge. This is more reliable than their publications in magazines or books.

p. 16. Wikipedia can be a good place to begin a search for reliable information.

p. 16. When different studies in different fields give similar results, supporting the same conclusions, we call this consilience. Those conclusions are greatly strengthened.

================= Chapter 5:

p. 17. Scientific claims without publication in peer-review journals may not be science; it’s more likely pseudoscience.

p. 18. Science is essentially a process of critical and analytical thinking.

p. 19. Science is the most powerful and effective tool we have for probing the natural world and solving many of the problems that it raises.

p. 20. Being skeptical does not mean being negative. “Extraordinary claims require extraordinary evidence.”

p. 21. All that we know now about the natural world is just a tiny fraction of all we could know.

RETURN TO APPENDICES INDEX
TA-18: Self Check Questions: **KEY** to Reasonable Responses

**SELF CHECK A:** Without looking back, answer these items briefly in your notebook. Then re-read the appropriate section, and make appropriate changes or additions:

1. List three ways that science can help you.
   1) Recognize when it’s not being used properly
   2) Required or helpful for nearly all jobs/careers
   3) Helps with critical and skeptical thinking.

2. Write a brief definition of science (from memory!)
   Science is a powerful tool (or process) for understanding the natural world.

3. What is a key driving force of science? Curiosity, and Ignorance of nature’s secrets.

4. What are five things that scientists generally DO?
   1) **observe** nature and natural processes, and **ask** questions about nature.
   2) think of **possible explanations** and answers to those questions.
   3) **test** those possible explanations to eliminate those that don’t work.
   4) **peer-review:** critically examine studies of other scientists.
   5) **publish** their studies in peer-review professional science journals.

5. Why do we not use “The Scientific Method” here?
   There is no ONE “Scientific Method.” There are many ways to do science.

6. What are six of the Rules of Science? [accept all that express the sense of these]:
   1) Science can only answer questions about the natural world.
   2) Scientific answers must be based on observation, not authority.
   3) Scientific answers can only use natural forces, never supernatural.
   4) Scientific answers must be testable.
   5) Scientific answers can change with new data or new methods.
   6) Scientific answers having different lines of evidence are stronger.

7. In what way is science like a special game?
   Science has special rules. If those rules are not followed, poor science can result.
   Likewise, if the rules of a game are not followed, could be chaos.

8. List three ideas or words in this chapter that were hard to understand.

9. List three things that were surprises (new) to you.

**SELF CHECK B:**

1. List five limits of science. [sequence not important]:
   1) can only answer certain kinds of questions
   2) can only use certain kinds of answers
   3) scientific answers can vary in strength
   4) can be done poorly
   5) can be misused
2. List three questions science can *not* explain?
   1) “What is good?” 2) “What is right?” 3) “Why do I love you?” [and so forth]

3. Explain in one sentence why science cannot base an explanation on opinions or views.
   Science can only base explanations on **critical observations**; opinions and views are not nearly as reliable as **critical observations** (as done in scientific studies).

4. List five kinds of answers science can *not* use? [sequence not important]:
   1) answers from authority
   2) answers based on opinions, feelings, beliefs, logic, common sense
   3) answers based on logic or common sense
   4) answers that cannot be tested, e.g., supernatural or mystical powers
   5) answers that do not survive testing

5. What is probably the strongest and most unique feature of scientific studies?
   **Testing** possible explanations – trying to disprove them, (not prove them).

6. Explain in one sentence why science cannot use supernatural explanations.
   Supernatural causes cannot be properly tested because results can’t be predicted.

7. How could science study what *seems* to be a supernatural event?
   Make the working assumption that it does *not* have a supernatural cause.

8. List three ideas or words in this chapter that were hard to understand.
9. List three things that were surprises (new) to you.

**SELF CHECK C:**
1. What is the main goal of science?
   To understand nature (or the natural world).

2. Use a diagram to show how these terms are related to each other:
   *fact, theory, law, model, observation, hypothesis*
   See Teacher Appendix TA-10 for a sample Mind Map or Concept Map.

3. What do **theories, laws, hypotheses** and **models** all have in common?
   They are all terms used for **explanations**, each with different levels of uncertainty.

4. Why is a scientific explanation not really a scientific fact?
   Because it’s *formed in the brain, based* on critically observed facts.

5. Can facts change? If so, when?
   Yes, with new observations and/or techniques.

6. What’s wrong with the idea that a theory is a mature hypothesis?
   Most scientific theories consist of several hypotheses, observations and laws.
7. What’s wrong with saying that science seeks the truth?
   Truth has different meanings, with some that don’t fit science.

8. Why is uncertainty and tentativeness a strength of science?
   Uncertainty encourages more study to get better answers. It is a driving force of science.

9. Give two reasons why scientific theories are the most useful and successful explanations.
   They are well supported by many tests in many studies; they work reliably.

10. Give one example of a strong theory that was replaced with a new, better scientific theory.
    Atomic Theory (has gone through several stages of change),
    Spontaneous Generation Theory (replaced by Biogenesis Theory)
    [See other examples in Student Appendix SA-3.2: Some Old Theories Replaced]

11. List three (or more) ideas or words in this chapter that were hard to understand.

12. List three things in this chapter that were surprises to you.

SELF CHECK D:
1. What are two clues that an ad claiming scientific support may not be true? [any two…]:
   “Science has proven…” and “Doctors say…” or “Shown by scientific studies…”

2. List three reasons why poor science happens? [any 3]:
   To sell a product or spread a personal belief;
   The influence of biases and prejudices;
   Failure to follow all the rules of good science.
   Carelessness in doing the science; it’s just poorly done.

3. What is the one feature of good science that is different from poor science?
   Follows all the rules of science, closely and carefully

4. List two ways that personal bias can influence science?
   It can influence how we observe and how we analyze what we observe.

5. What are three features of good science that tend to make it stronger.
   Clearly tries to critically test (disprove) its hypothesis;
   Published in peer-review journals;
   Results agree with other studies in different fields (consilience).

6. What is one clue that a published scientific claim may not be good science? (any 1):
   It’s not published in a peer-review journal, just a trade book or magazine article.
   The study was funded by a company that benefits from positive results of study.
   The journal tends not to publish negative results for medicines.
   Conflict of interest is not admitted in report (when it might well exist).
7. You want to use the internet to see if a health product does what it claims. What two things would you look for to get the most reliable information? (any 2):
   Avoid blogs or sites promoting sales of the tested product.
   Seek report on university or medical institute site not funded by the product’s makers.
   Seek unbiased critical sites, like Consumer Reports.

8. What is **consilience**? How does it affect our confidence in the explanation produced?
   Consilience is when different studies in different fields all fit the same conclusion. It greatly strengthens the validity or reliability of the conclusions.

9. List three ideas or words in this chapter that were hard to understand.
10. List three things that were surprises to you.

**SELF CHECK E:**
1. List three characteristics of well-done science. (any 3):
   1) attempts to follow all the rules of science
   2) tries to disprove its own explanations
   3) excludes mystical (or supernatural) explanations
   4) considers all research on topic
   5) observed data provides main support

2. What are three typical features of a pseudoscience (any 3):
   1) ignores some or all rules of science
   2) tries to prove its own explanations
   3) includes mystical explanations
   4) ignores or denies unsupportive studies
   5) authority provides main support

3. Name three examples of pseudoscience that you have heard about before.
   [any 3 of examples listed in box on page 38 – first page of Chapter 5]

4. List two reasons why it is important to know how to recognize a pseudoscience? (any 2):
   If not wary, it can fool you into making false assumptions, e.g., vaccinations can cause autism;
   good science produced some new medicine:
   climate change is not caused by people;
   some “alternative” medical treatment is supported by good science;
   all science is not reliable, so you become a “science rejector or denier”

5. Name three of those other “windows of knowledge” (besides science). (any 3):
   Philosophy, direct observation, pure logic, religion, legal rules

6. List three ideas in this section that you found difficult to understand.
7. List three items in this section that were surprising to you.

**RETURN TO APPENDICES INDEX**
### TA-19: Science Surprises Quiz and Key: Pre/Post Test—2 pages

<table>
<thead>
<tr>
<th>Ch</th>
<th>key</th>
<th>Science Surprises Quiz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>1. Science can only deal with the natural world, never the supernatural, as such.</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>2. Most engineers and medical doctors are actually scientists.</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>3. Science can solve any problem or answer any question.</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>4. Good science can be done in several different ways.</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>5. Good science is based heavily on the views of established science experts.</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>6. Testing hypotheses means trying to disprove them.</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>7. Science can only work with answers that can be tested.</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>8. In science, one explanation is as good as any other.</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>9. Science can use supernatural explanations if necessary.</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>10. Explanations are the real goal of science, not facts as such.</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>11. A scientific theory is a very well-tested explanation.</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>12. Hypotheses are possible explanations with little or no testing.</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>13. Science is mainly a search for truth.</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>14. Established scientific theories will never change.</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>15. Uncertainty in science makes science unreliable.</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>17. All science is based on critical observation.</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>18. Scientists criticizing other scientists in science journals is bad for the science.</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>19. Good scientific work tries to disprove its explanations.</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>20. You should be suspicious of any scientific claim not published in a science journal.</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>21. Scientific claims can be influenced by the race, sex or religion of a scientist.</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>22. Astrology (how the stars and planets affect our futures) is good science.</td>
</tr>
<tr>
<td>5</td>
<td>A</td>
<td>23. A pseudoscience does not follow the rules of science.</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>24. Any study done carefully and based on observation is scientific.</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>25. Science has discovered nearly all there is to know about the natural world.</td>
</tr>
</tbody>
</table>

12 A’s, 13 B’s
Science Surprises Quiz
This quiz is given to check your understanding about the nature of science. Please agree, or disagree, with each item, then mark your answer sheet as you think a working scientist would. When done, please turn this survey AND your answer sheet face down on your desk.

PLEASE DO NOT WRITE ON THIS SHEET; USE YOUR SPECIAL ANSWER SHEET

MARKING CODE:    A = agree, (or you lean that way)
                   B = disagree, (or you lean that way)

1. Science can only deal with the natural world, never the supernatural, as such.
2. Most engineers and medical doctors are actually scientists.
3. Science can solve any problem or answer any question.
4. Good science can be done in several different ways.
5. Good science is based heavily on the views of established science experts.
6. Testing hypotheses means trying to disprove them.
7. Science can only work with answers that can be tested.
8. In science, one explanation is as good as any other.
9. Science can use supernatural explanations if necessary.
10. Explanations are the real goal of science, not facts as such.
11. A scientific theory is a very well-tested explanation.
12. Hypotheses are possible explanations with little or no testing.
13. Science is mainly a search for truth.
14. Established scientific theories will never change.
15. Uncertainty in science makes science unreliable.
16. A hypothesis is just an “educated guess” about anything.
17. All science is based on critical observation.
18. Scientists criticizing other scientists in science journals weakens the science.
19. Good scientific work tries to disprove its explanations.
20. You should be suspicious about any scientific claim not published in a science journal.
21. Scientific claims can be influenced by the race, sex or religion of a scientist.
22. Astrology (how the stars and planets affect our futures) is good science.
23. A pseudoscience does not follow the rules of science.
24. Any study done carefully and based on observation is scientific.
25. Science has discovered nearly all there is to know about the natural world.

RETURN TO APPENDICES INDEX
TA-20: Sample NOS Exam and Key (4 pages)

IMPORTANT: FOR EVERY EXAM: On your answer sheet, be sure you place your SEAT/SCOPE number (circled) after your name. Above your name, indicate this FORM and COPY #. FOR EACH ITEM, select what you feel is the ONE BEST answer, and mark the letter for that answer on your Scantron© sheet with a soft PENCIL. Make answer marks DARK and confined to the marking "bubbles". Make NO OTHER MARKS; erase accidentals completely. If you are not sure, make a logical guess; there is no penalty for guessing.

1. Those who practice a pseudoscience (e.g. astrology, biorhythms, etc.) are those who...
   A) claim to be scientific, yet do not follow all the rules of science; B) do not claim to be scientific and do not follow the rules of science; C) attempt to follow the rules of science, but make mistakes in the process; D) none of these.

2. Any observation that appears the same to all critical observers is generally regarded by scientists as a...
   A) theory; B) fact; C) test; D) hypothesis; E) proof.

3. Which of these can influence the results of a scientific study? A) who pays the scientist; B) the scientist’s politics; C) the sex of the scientist; D) A, B, or C; E) none of these.

4. The immediate purpose of a scientific experiment is usually to...
   A) collect data; B) test a hypothesis; C) solve a problem; D) create monsters; E) raise questions.

5. Any information gained directly or indirectly through our senses is a scientific...
   A) observation; B) fact; C) data; D) idea; E) hypothesis.

6. When scientists design experiments to test their hypotheses, they are actually trying to...
   A) prove; B) disprove; C) examine; D) check

7. In attempting to understand how nature works, scientists seek ultimately for the...
   A) truth; B) facts; C) final proof; D) total control of nature; E) most likely explanation.

8. Predictions in science can be applied to problems about...
   A) the past; B) the present; C) the future; D) any of these.

9. Scientific explanations...A) must include supernatural forces; B) can include supernatural forces; C) cannot include supernatural forces; D) must show that supernatural forces do not exist.

10. A scientific theory is...A) a fact; B) a vague idea; C) a possible but untested explanation; D) a general explanation which is highly probable and well supported by testing; E) the same as a scientific law.
11. A tree was found which had broken off about 4 meters up and had fallen to the ground. A scientist, wondering how it happened, studied the tree and suggested that it might have been hit by lightning. He said "If I look around the break, I should find some burnt wood, and this would support my idea." What the scientist said is an example of...A) a hypothesis; B) a prediction; C) wild speculation; D) a conclusion; E) lumberjack talk.

12. Which of these is not a limit of science? A) studies the natural world; B) scientific answers are uncertain; C) can only use certain kinds of answers; D) can answer any kind of question.

13. In which field(s) is knowledge about how science works important? A) politics; B) medicine; C) agriculture; D) law; E) all of these

14. Scientific theories...A) can begin as hypotheses; B) are heavily supported by evidence; C) attempt to explain and relate large masses of data; D) all of the above; E) none of the above.

15. A hypothesis is best defined as... A) a clear statement of a problem; B) a predicted observation; C) the result of an experiment; D) an educated guess; E) a possible solution to a problem.

For each item listed below, indicate whether it is...
A) a typical feature of science, or...B) not typical of science


17. A process for testing possible explanations to see if they can be disproved.

18. Attempts to control all results.

19. Capable of figuring out an explanation for any type of question.

20. Built on a foundation of proven concepts which are beyond questioning.

21. The process used for building a collection of facts as the main goal.

22. A scientific prediction is always based on...
A) the problem; B) the hypothesis; C) observations; D) experience; E) intuition

23. In the “Checks Lab,” you had a series of checks, with their dates, amounts, made out to, signed by, etc. What is the preferred term for all of that recorded information together? A) observations; B) facts; C) data; D) hypotheses; E) test.

24. During the “Checks Lab,” you were asked to suggest a likely scenario—or series of events—that would explain why the first few drawn checks were written. Which of these terms would best fit that scenario, in terms of scientific problem-solving? A) observations; B) facts; C) data; D) hypothesis; E) test.
25. After suggesting that scenario (“Checks Lab”), you drew a few more checks that could either strengthen your “likely scenario,” or weaken it. In this example of scientific problem-solving, what term best fits the taking and using of those additional checks?
A) observations; B) facts; C) data; D) hypothesis; E) test.

---------------------------------------------

For each statement below, indicate whether it is characteristic of...
A) "Good Science", or  B) "Poor Science":
26. Only one chemical at a time was tested.
27. A very small number of organisms was used in the testing.
28. All available data (published and unpublished) was considered equally valid.
29. A clear change occurs only at a single high-dosage level, indicating a cause-effect relationship.

---------------------------------------------

For each of the following items, select from these choices: A) science; B) pseudoscience; C) non-science
30. Claims to be scientific, but ignores some of the rules of science
31. Tries to disprove its possible explanations
32. Often uses supernatural explanations
33. Publishes opinions about the most attractive national parks
34. Bases conclusions on established authority

---------------------------------------------

For each of the following statements written in *italics*, choose the term it best represents:
A) problem; B) hypothesis; C) prediction; D) educated guess; E) none of these
35. I think my stomach is upset because *I ate too much dinner.*
36. *What causes cancer?*
37. If my headache is caused by tension, then relaxation *should reduce my headaches.*
38. *I know for certain that the great diversity of life is due to evolution.*
39. It has been suggested that South America and Africa were once joined 200 million years ago.
   If we look in the right places, we *should be able to find fossils of the same species of that age on both continents today.*

---------------------------------------------

40. Disagreement among scientists is considered to be... A) a weakness of science; B) a strength of science; C) very uncommon; D) poor practice; E) none of these.

41. So far, we have learned that the basic laws of nature...
   A) are the same everywhere in the universe;
   B) apply only on the Earth;
   C) are the same in our solar system, but are somewhat different around other stars;
   D) are the same in our galaxy, but are different in other galaxies;
   E) actually, we have no way of obtaining evidence about the laws of nature elsewhere in the universe.
Six numbered parts in the following paragraph are in italics. Each such italicized segment is an "item". For each numbered "item", select the term or phrase that best describes that passage, in that context.

CHOICES:  A) problem; B) hypothesis; C) observation, or result of an experiment; D) prediction based on hypothesis; E) an experiment.

42) Some animals have the remarkable ability to change color. 43) How they accomplish this has long been a mystery. When a catfish is placed in an aquarium with a black bottom and black sides, the fish became black in a few days. When that same fish is transferred to a tank with a white bottom and white sides, the fish becomes very pale, almost white. It could have some type of color receptor in its skin, or 44) the color receptor could be located in the eyes. If the sensitivity were due to stimulation of the eyes, 45) covering the eyes 46) should inhibit the ability to change color. 47) Fish with covered eyes were unable to respond to changes in the background color.

48. Which of the following statements would indicate that the person making the statement was ignorant of the nature of science? A) "It's only a theory."; B) "That's a scientifically proven fact."; C) "Facts never change." D) "One of the weaknesses of science is that scientists are always changing their minds."; E) all of these.

49. How much have we probably learned about the natural world by using science?
   A) We have discovered nearly all there is to know.
   B) We have discovered most of what there is to know.
   C) We have probably discovered about half of what there is to know.
   D) We have barely scratched the surface of what there is to know.
   E) We know absolutely nothing useful about the natural world.

50. A controlled experiment is mainly one in which...A) the scientist can change any variable at any time; B) an extra set-up is used for comparison; C) the study is under constant observation; D) only one variable is tested at a time.

51. Which one of these is not a major field of science?  
   A) engineering; B) zoology; C) botany; D) genetics; E) physiology.

52. Publishing a scientific study in a peer-review journal  A) guarantees its reliability; B) makes it very reliable; C) has no bearing on its reliability; D) just makes it available to other scientists; E) C & D
Alternates to “Checks Lab” questions:
23. You were asked to sketch a diagram and record what you saw when the Magic Matter Maker® was demonstrated. What is the preferred term for all that recorded information together?
   A) observations; B) facts; C) data; D) hypotheses; E) test.

24. When you figured out how the Magic Matter Maker® might have worked, what term would best reflect your sketch of the "insides" and your description of how it might work?
   A) observations; B) facts; C) data; D) hypothesis; E) test.

25. If you actually build your version of the Magic Matter Maker® and try to make it work, what should this be called? A) observations; B) facts; C) data; D) hypothesis; E) test.

NOTE to TEACHER: Prepare your NOS Unit Exam by selecting questions from the SAMPLE EXAM (above), and the Science Surprises Quiz. You might want to prepare a Form B version by rearranging the items (while keeping the pre/post test questions together and in same sequence for easy comparison). Hand out test so that students sitting side-by-side have alternate forms (A-B-A-B-, etc.)

Best Choices

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TA-21: Some Suggestions for Elementary School Science Programs

It’s never too early to begin helping students to understand some of the important elements of science, as long as these experiences are age-related and as long as the information is not distorted in the efforts to simplify. Here are some suggestions that should help.

Seriously consider avoiding the use of the word “hypothesis” at this level. The word is often misused (by texts and teachers). There’s noting wrong with predicting (based on logic or previous experience), or even just guessing what might happen (with their more limited experience), but this should be called a “prediction” or “expectation”—NOT a hypothesis! As properly used, a hypothesis is usually a tentative, testable, natural explanation for why something is the way it is, or happens the way it does. It’s not just an “educated guess.” In some cases, it could be a prediction of expected outcomes. However, a good hypothesis should be the basis or reason for expecting or predicting the likely outcome of any test of that hypothesis (experiment or planned observation), but usually not the prediction itself.

If you must use the word “hypothesis,” avoid defining it as the widely used “an educated guess” or any kind of guess. This is much too vague. A “guess” could be about anything, but “hypothesis” should just apply to an explanation or answer to a question about some natural event or condition. Use the definition as given above, and try to limit its use to “tentative explanations.” Students begin picking up that “educated guess” definition somewhere early in life, and it becomes another of the many misconceptions that their later teachers have to deal with. This may seem like a minor distinction, but it’s one that can be confusing later on.

Another term often used incorrectly is the word “theory.” This term, too, should be avoided in the elementary years. It’s better to use “idea” for the vernacular use of theory (as it’s commonly used by people). “Theory,” if used at all, should be clearly reserved as a “scientific theory” only for well-established, highly supported explanations of natural phenomena. Read the treatment of “theory” in the Science Surprises booklet, or this Teacher Guide.

Focusing on careful observations, with precise descriptions by everyone (so they can call it a "scientific fact"), writing careful and detailed descriptions of what they observe (with all their senses), and distinguishing between what they observe with their senses, and what they think or infer from those observations, would all be very important skills to develop during their elementary years. You can do a lot of this in the context of exploring many of the science standards content. More formal or abstract aspects (like developing and working with hypotheses) can wait until middle school.

Guiding those inferences, by the way, into discussions about how observations (data) can lead to deeper understanding, or meaningful insights not directly gained by observing—such things as the possible “reasons” why they observed what they observed, and “predictions” about what they might expect to happen if they change something in what they do. This gets into some analyses and other kinds of deeper thinking, but it can be fun to do, and gives kids a real taste of the power of logical analysis derived from what is observed. And you don’t have to get into any of the formal terminology for this, either, something that can be confusing, or, even worse, misunderstood.

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