Looking at the Evidence

What we know. How certain are we?

Here's a simple true or false quiz:

1. Science is a static body of facts.
2. Science is a dynamic, evolving process that tests questions and makes conclusions.

By Amy Pallant

Amy Pallant (apallant@concord.org) directs the High-Adventure Science project.

Scientists and science teachers talk a lot about things they know, things that have been established in the scientific community beyond a doubt. DNA carries hereditary information. The Earth's surface is made up of many constantly shifting plates. Gravity is the force of attraction between two objects.

But everything that is known began as a question. Through the gradual accumulation of experimental data, model building, and the discussions (and disagreements) among scientists, scientific explanations and theories were proposed, tested, and ultimately accepted by the scientific community.

Scientists—and, indeed, the field of science—move from the unknown to certainty, gathering and analyzing data, making observations, and drawing and testing conclusions. Some of these conclusions hold up for a very long time as continued experimentation verifies original theories. Other times, contradictory evidence or results force a revision of what was previously "known."

So, referring back to the true or false quiz that introduced this article, science is clearly a dynamic, evolving process, not a collection of static facts. And we should teach it that way.

The Concord Consortium's High-Adventure Science project, funded by the National Science Foundation, is bringing the excitement of scientific discovery to students by letting them explore pressing unanswered questions using the same methods that practicing scientists use. The goal of our research is to determine whether the active exploration of these questions helps students come to view science as a dynamic, evolving process.

Uncertainty in science is a feature

Although there is a very large body of agreed-upon scientific explanations of the way the natural world works, scientists continue to explore new areas. This doesn't mean past experimental results are wrong. It simply means there is more to discover, more to learn, more to articulate. Through careful consideration of the evidence and examination of the process of science, students can sort out what scientists are certain about and where they are looking for more evidence.

The High-Adventure Science project is creating three investigations for middle and high school students that focus on current, compelling, unanswered questions in Earth and Space Science:

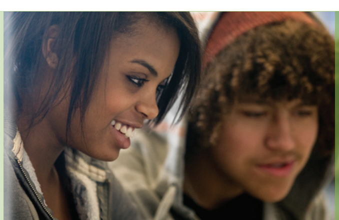
- **What will Earth's climate be in the future?** Students investigate past climate changes and learn how mechanisms for positive and negative feedback can affect global temperature. They think about how scientists use this information to make climate change predictions.
- **Is there life in space?** Students learn how scientists use modern tools to find planets around distant stars as they consider the probability of finding extraterrestrial life.
- **Will there be enough fresh water?** Students evaluate whether the vast underground stores of water will be sufficient to support a growing human population.

Each investigation incorporates interactive computer models combined with real-world data, plus video of scientists who are currently working on the same unanswered question. Students use the models, interpret the data, and draw conclusions just as scientists would. What makes these investigations unique is the way in which students begin to develop scientific argumentation skills and explore the issues of certainty with the models and data. Throughout the investigations, students are prompted to define their levels of uncertainty about the science, the data, and the models.

Developing scientific analysis and argumentation skills

Our investigations present a unique challenge to teachers: helping students embrace the idea that all cutting-edge scientific research is characterized by uncertainty, but at the same time instilling confidence that widely accepted scientific knowledge based on multiple sources of evidence is reliable and not likely to be overturned.

Those engaged in scientific research understand that science is a continual quest for knowledge. Understanding in science is an incremental increase in confidence as conjectures become hypotheses and ultimately scientific theories. Our goal is to help students to interpret data and scientific evidence while explicitly considering three questions: a) what is known? b) how do scientists know that it



is known? and c) what is still unknown?

To develop students' skills—in particular, to develop their ability to interpret data, models, and experimental results—we include in our investigations a set of tools called "explanation-uncertainty item sets" that couple students' explanations with certainty rationale items (see below). When students draw conclusions, they are consistently asked to justify their claims, rate their uncertainty levels, and explain what influenced their uncertainty.

An explanation-uncertainty item set about finding life in outer space

[Claim] 1. There are many billions of stars in the Milky Way galaxy. One of those stars is our Sun, which has eight planets orbiting around it. Scientists have just started to identify planets outside our solar system. So far they have discovered nearly 500 planets outside of the solar system. To date, scientists have not found proof of life outside of Earth.

Based on the information, is it probable that life exists outside of Earth?

☐ yes
☐ no

[Explanation] 2. Explain your choice in question #1.

[Uncertainty] 3. How certain are you of your answer about the probability of life outside of Earth?

☐ 1 Not at all certain
☐ 2
☐ 3
☐ 4
☐ 5 Very certain

[Uncertainty rationale] 4. Explain what influenced your certainty in question #3.

These item sets are designed to reveal a more complete picture of student understanding. Following a scientific claim, students must answer a question and explain their reasoning; their explanations help us understand how they think about both the evidence and the claim. The uncertainty rationale items measure whether or not students recognize the uncertainty of claims.

Students are encouraged to use this tool set throughout the curriculum. Through repeated exposure, we hope to encourage them to reflect on both the evidence they generated from using the models and the real-world data, and to evaluate how certain they are about their own claims, as well as the claims of scientists.

The following are examples of students' uncertainty rationales from pilot tests of the items with non-High-Adventure Science students.

One student who was very certain (level 5) said:

"Due to the fact that there are billions of stars within one galaxy, and there are many planets orbiting each star, and there are thousands of galaxies, the odds of Earth being the only planet capable of sustaining life are incredibly small."

Another student chose level 3 (exactly halfway on the certainty scale, between "not at all certain" and "very certain") said:

"I always believed there were other life forms on different planets, but it has not been proved that there are other life forms."

Our initial work shows that students were more likely to be uncertain about their claims and justifications when they cited personal reasons on the uncertainty rationale, while students were more likely to be certain when they cited scientific reasons. Our research will look at how their uncertainty rationales change after using the curriculum.

The High-Adventure Science project is attempting to bring frontier science to the classroom. We hope that when students hear something in the news—or in their science class—they will weigh the evidence. Students should no longer look for "answers," but begin to distinguish between what is known, what is suspected, and what is still being researched.

High-Adventure Science's Latest Investigation

In the "Is there life in space?" investigation, students learn the techniques scientists use to look for planets outside our solar system. These "planet hunters" use powerful telescopes in their search.

With the wobble method, scientists have located hundreds of planets. Students explore how a planet's diameter and mass might cause a star to wobble or move. Students also observe how the movement of a star affects the wavelength of light observed. Finally, students discover the importance of angle of orbit as it relates to scientists' ability to locate planets orbiting stars.

Using another technique—the transit method—scientists look for the dimming of stars caused by planets moving between the star and our telescopes. These eclipses, however, are rare. Students look at graphs of light intensity as planets pass in front of stars (Figure 1) and again explore how the angle of orbit affects the perceived dimming a scientist would observe through a telescope.

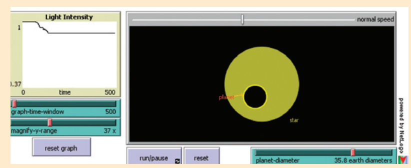


Figure 1. NetLogo model of the transit method.

In this investigation, students use both models and real-world data, and are asked to weigh in on the certainty of finding life "out there."

Follow our blog

The High-Adventure Science project is focusing on some of the current unanswered questions in Earth and Space Science. This frontier science is in the news all the time. Visit the High-Adventure Science blog at our website for easy-to-read articles that connect to our investigations—and share your thoughts, too.

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