New Paths to Engaging Science

with National Geographic Explorer Nalini Nadkarni

Nalini Nadkarni has all the academic credentials anyone could ask for. She's a Ph.D. biologist and forest ecologist at the University of Utah, where she's also Director of the Center for Science and Mathematics Education. She's accrued an impressive record of fieldwork, using mountain-climbing techniques, construction cranes, walkways, and hot air balloons to explore the canopies of rain forests on four continents.

But Dr. Nadkarni's real passion is finding ways to bring that important work to people outside the scientific community. She suggests that "if you want to go beyond that small percentage of people who are already environmentally and scientifically aware, you have to make your work somehow link with a passion, interest, or profession of someone who isn't interested in science or nature."

Nadkarni has found some very creative ways to reach new audiences. She invited George "Duke" Brady, a California rap singer, to join her on a tree-climbing expedition. Nadkarni believes Brady's resulting rap about his experience appealed to students in a way that more traditional approaches may not have. That's just one example. Here's another: Treetop Barbie. Combining science and fashion, this popular doll wears the clothing of a forest ecologist and comes with a field guide to canopy plants and animals.

Nalini Nadkarni's most ambitious effort has involved one of the last places you might expect—the prisons of the Washington State Department of Corrections. The Sustainability in Prisons Project helps incarcerated men and women contribute to conservation and ecological research. The benefits go both ways, Nadkarni insists. The prisoners have a purpose and learn useful skills on the job as they do scientific work, and the scientific community benefits from their projects and the data they gather.

Some of those projects involve time-consuming and meticulous procedures. For example, inmates raise frogs, rear butterflies, catalog moss species, and practice beekeeping. Inmates volunteer for such projects, Nadkarni explains, because they can contribute to society despite being confined. In turn, the inmates hear guest lectures and acquire job skills.

The prisons participating in the Sustainability project often begin to follow more sustainable practices, such as recycling, composting, and organic gardening. Nadkarni covered the walls of an exercise room in one prison with a picture of trees. To everyone's surprise, violence in that unit decreased. Nadkarni's conclusion? "There isn't a person on Earth who couldn't use a connection with nature."

Nadkarni has found some unique ways to bring science to communities that need it. She shows us that all the content knowledge in the world isn't worth much without critical thinking and creativity.

Thinking Critically

Evaluate What factors do you think would be involved in implementing programs similar to the Sustainability in Prisons Project? List some possible pros and cons.

CASE STUDY
Experimenting with a Forest

Suppose a logging company plans to cut down all of the trees on a hillside near your home. You are very concerned and want to know about the possible harmful environmental effects.

One way to learn about such effects is to conduct a controlled experiment. To conduct an experiment, scientists begin by identifying key variables, such as water loss and soil nutrient content. Then, they set up two groups. One is the experimental group, in which a chosen variable is changed in a known way. The other is the control group, in which the chosen variable is not changed. Then they compare the results from the two groups.

In 1963, botanist F. Herbert Bormann, forest ecologist Gene Likens, and their colleagues began carrying out such a controlled experiment. Their goal was to compare the loss of water and soil nutrients from an area of uncut forest (the control site) with one that had been stripped of its trees (the experimental site).

The researchers built V-shaped concrete dams across the creeks at the bottoms of several forested valleys in the Hubbard Brook Experimental Forest in New Hampshire. The dams were designed so that all surface water leaving each valley had to flow across an area where scientists could measure its volume and dissolved nutrient content.

First, the researchers measured the amounts of water and dissolved soil nutrients flowing from an undisturbed forested area in one of the valleys (the control site) (Figure 2-1, left). These measurements showed that an undisturbed mature forest is very efficient at storing water and retaining nutrients in its soils.

Next, they set up an experimental site (Figure 2-1, right). One winter, they cut down all the trees and shrubs in that valley, left them where they fell, and sprayed the area with herbicides to prevent the regrowth of vegetation.

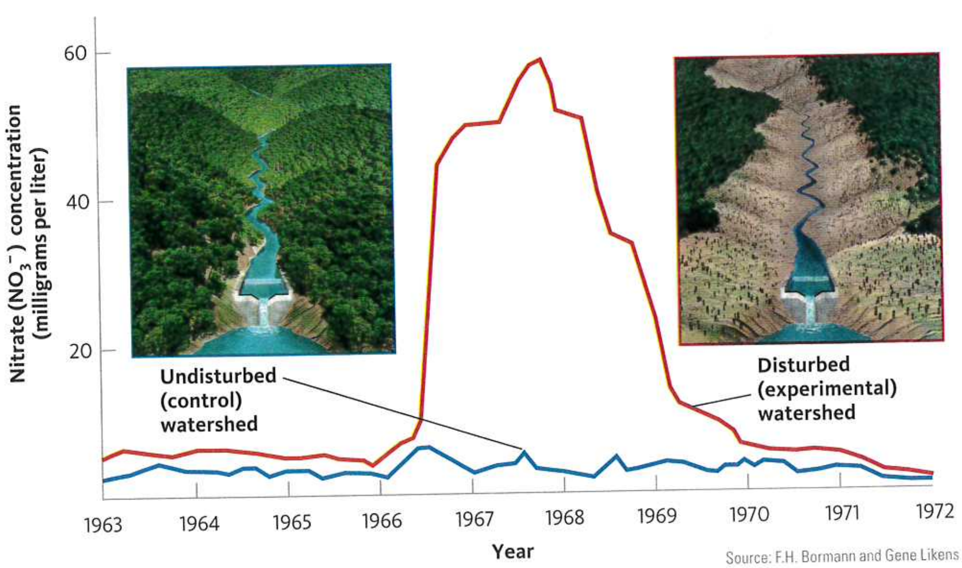
The researchers then compared the outflow of water and nutrients in this experimental site with those in the control site.

The scientists found that, with no plants to help absorb and retain water, the amount of water flowing out of the deforested valley increased by 30–40%. As this excess water ran rapidly over the ground, it eroded soil and carried dissolved nutrients, such as nitrates, out of the topsoil in the deforested site (Figure 2-1). Overall, the loss of key soil nutrients from the experimental forest was six to eight times that in the nearby uncut control forest.

In this chapter, you will learn how scientists study nature and about the matter and energy that make up the world. You will also learn about scientific laws that govern the changes to matter and energy. And you will learn the important difference between a scientific hypothesis and a scientific theory.

As You Read Think about how ecologists might use basic chemistry and the laws of matter and energy to study ecosystems.

FIGURE 2-1
Nitrate Results
This graph shows the concentrations of nitrate ions in water from the forested watershed (control site) and the deforested watershed (experimental site).



2.1 What Do Scientists Do?

CORE IDEAS AND SKILLS

- Describe the scientific methods and the importance of observation, experimentation, and models.
- Recognize the importance of evidence, hypotheses, theories, and laws in science.
- Understand the benefits and limitations of science.

KEY TERMS

science
scientific method
scientific hypothesis
data
model
scientific theory
peer review
scientific law

Scientists Use a Variety of Methods

Science is a broad field of study focused on discovering how nature works and using that knowledge to describe what is likely to happen in nature. It is based on the assumption that events in the physical world follow orderly cause-and-effect patterns that can be understood through careful observation, measurements, and experimentation.

Scientists use several **scientific methods**, or practices, to advance knowledge and understanding of how the natural world works. Figure 2-2 summarizes these practices. While the immediate goal of science is to build knowledge of the natural world, that knowledge can be applied in a number of ways. For example, engineers use scientific knowledge to design solutions that improve society and protect the planet and its resources.

In the Case Study, Bormann and Likens used scientific practices to find out how clearing a forest affects its ability to store water and retain soil nutrients. They asked questions, did research, collected information, and proposed a hypothesis. A **scientific hypothesis** is a possible and testable answer to a scientific question or explanation of what scientists observe in nature. Hypotheses can be written as *"if, then"* statements. Bormann and Likens came up with the following hypothesis: *If* land is cleared of its vegetation and exposed to rain and melting snow, *then* the land retains less water and loses nutrients.

Next, Bormann and Likens designed experiments to collect **data**, or information, to test their hypothesis. In an experiment, researchers try to keep all variables the same between a control group and an experimental group except for the variable they are testing—in this case, deforestation. Controlled experiments are the only way to show that one variable causes another. Correlation studies, on the other hand, can show that two variables are related, but they can't show how they are related.

FIGURE 2-2
Scientific Practices This table summarizes the main practices that scientists use to advance knowledge. Scientists may use these practices in any order. Some scientists use all of the practices, while others focus on only one or a few.

THE PRACTICES OF SCIENCE
Asking questions
Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Using math
Forming explanations
Forming arguments from evidence
Obtaining, evaluating, and communicating information

Bormann and Likens tested their hypothesis twice. The first set of data recorded the amount of nitrogen in the runoff. They repeated their experiment to determine the amount of phosphorus in the water. The experimenters wrote scientific articles describing their research. Other scientists evaluated their data and conclusions. These reviews and further research supported their hypothesis.

Models are often used to conduct experiments or form explanations. A **model** is a physical or mathematical representation of a structure or system. Data from the research carried out by Bormann and Likens and others was fed into models, which also supported their hypothesis.

A well-tested and widely accepted scientific hypothesis or a group of related hypotheses is called a scientific theory. A **scientific theory** is one of the most important and certain results of science and is based on a large body of evidence. The research conducted by Bormann and Likens and other scientists led to the scientific theory that trees and other plants hold soil in place and retain water and nutrients needed to support the plants.

checkpoint What is a scientific hypothesis?

ENGINEERING FOCUS 2.1

WHAT IS ENGINEERING?

Engineering is all about defining problems and designing and testing solutions to the problems. In fact, anyone who applies science and math to solve a practical problem is using the practices of engineering (Figure 2-3).

Whereas the result of science is an advancement in human knowledge, the result of engineering is a new or improved product. A product can be a structure such as a dam, a technology such as a new software application, or even a new procedure or method.

The outputs of science and engineering feed into one another. Engineers use knowledge gained by scientists—and scientists use tools developed by engineers. New or improved tools and methods can lead to new knowledge, and new knowledge leads to the development of new tools.

Engineering's many specialties fall into different broad categories, including mechanical, electrical, civil, chemical, and biological engineering. One exciting new field of engineering is conservation technology, which uses technology to solve ecological problems (Figure 2-4).

Thinking Critically

Apply Describe an example in which a new tool or technology led to new scientific knowledge.

FIGURE 2-3

Engineering Practices These are some of the main practices that engineers use. The practices of engineering are similar to the practices of science. How do they differ?

THE PRACTICES OF ENGINEERING
Defining problems
Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Using math
Designing solutions
Forming arguments from evidence
Obtaining, evaluating, and communicating information

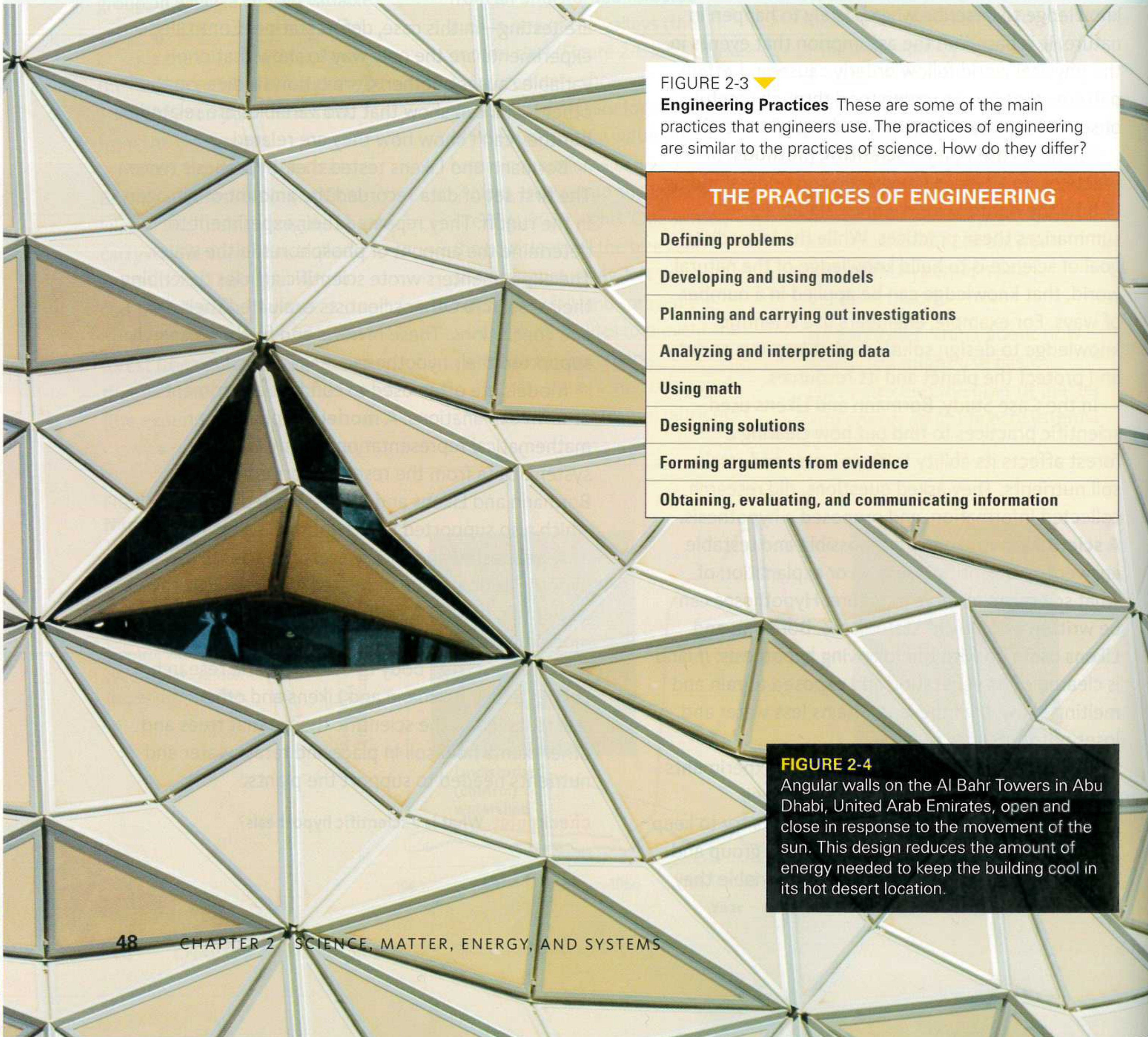


FIGURE 2-4
Angular walls on the Al Bahr Towers in Abu Dhabi, United Arab Emirates, open and close in response to the movement of the sun. This design reduces the amount of energy needed to keep the building cool in its hot desert location.

NATIONAL GEOGRAPHIC | EXPLORERS AT WORK

John Francis Marine Biologist

Virtually all environmental scientists have a deep personal connection to the natural world. How can young people establish such a connection, especially as they spend more time indoors and in front of devices? National Geographic Explorer and marine biologist John Francis is leading Americans back into the wonders of the natural world.

When he was 19, John Francis began studying marine mammals on remote islands in the Americas. After earning his Ph.D. and conducting research for the Smithsonian Institution, he was awarded two National Geographic Society grants. The grants enabled him to study and film a rare fur seal that lives only on an isolated island off Chile. Dr. Francis's passion for ecology and filmmaking led to his role as a producer of wildlife films with National Geographic Television. During his six years as a producer, he made films covering everything from chimps and tigers to whales and sharks.

Dr. Francis is now the Vice President for Research, Conservation, and Exploration at the National Geographic Society. In collaboration with the National Park Service (NPS), he developed a ten-year series of BioBlitz events held in national parks around the country, starting in 2007. During a BioBlitz, teams of volunteer scientists, families, students, teachers, and other community members work to identify as many species of organisms as possible in a particular area in a 24-hour period. The BioBlitz provides a "snapshot" of species diversity and helps bring people closer to nature.

The ninth NGS-NPS BioBlitz was held in the Hawai´i Volcanoes National Park and involved more than a thousand participants. The event included a celebration of local culture to acknowledge the connections among land, history, and culture. The resulting inventory from the Hawai´i blitz included observations of 22 species never before recorded in Volcanoes National Park. These events have served as models for BioBlitzes around the world.

FIGURE 2-5
An i'iwi bird perches on a Hawaiian raspberry branch. The scientific practice of obtaining information was the focus of the 2014 BioBlitz in Hawai'i Volcanoes National Park.

Scientific Inquiry Advances Human Knowledge

Scientific inquiry is based on values that help advance scientific knowledge. Some of the values that support good science are logic, critical thinking, objectivity, open-mindedness, and honest reporting. Science is a worldwide effort conducted by people from many nations and cultures. Many scientists work collaboratively on teams. They almost always build from an existing body of scientific research and knowledge. For example, Bormann and Likens likely consulted many prior studies and used existing nutrient-testing methods and dam designs.

Scientists also review each other's work in a process called peer review. **Peer review** involves scientists publishing details of the methods they used, the results of their experiments, and the reasoning for their interpretations. Other scientists in the same field (their peers) evaluate their work. Scientific knowledge advances in this self-correcting way, with scientists questioning and confirming the data and hypotheses of their peers. Scientific findings that are repeatable are considered *reliable*.

checkpoint What is the purpose of peer review?

Theories and Laws Are the Most Certain Results of Science

Scientific theories have been tested widely, are supported by extensive evidence, and are accepted as useful explanations of phenomena by most scientists in a field of study. So when you hear someone say about a theory in science, "Oh, that's just a theory," you will know that he or she does not have a clear understanding of what a scientific theory is.

Another important and reliable outcome of science is a **scientific law**—a well-tested and widely accepted description of observations that have been repeated many times in a variety of conditions. One example is the law of gravity. After making many thousands of observations and measurements of objects falling from different heights, scientists developed the following scientific law: All objects fall to Earth's surface at predictable speeds.

You can break a society's law, for example, by driving faster than the speed limit. But you cannot break a scientific law such as the law of gravity.

checkpoint What is the difference between a scientific theory and a scientific law?

Science Has Limitations

Scientific inquiry has limitations in explaining and predicting natural phenomena. For example, scientific research cannot prove anything absolutely. Some degree of uncertainty in scientific measurements, observations, and models will always exist—even if that uncertainty is very small. Uncertainty also results from the fact that science requires the use of statistical tools. For example, there is no way to measure accurately how many metric tons of soil are eroded annually worldwide. Instead, scientists use statistical sampling and mathematical methods to estimate such numbers.

Scientists don't use the word *proof* in the same way as many nonscientists because it can falsely imply "absolute proof." For example, most scientists would not say, "Science has proven that cigarettes cause lung cancer." Instead they might say, "Overwhelming evidence from thousands of studies indicates that people who smoke regularly for many years have a greatly increased chance of developing lung cancer."

Another limitation of science is that of the scientists themselves. Like all humans, they are not totally free of bias about their own results and hypotheses. The self-imposed standards of evidence required through peer review help protect against personal bias and falsifying scientific results.

Despite these limitations, science is the most useful way of learning about how nature works and predicting how it might behave in the future.

checkpoint What are two limitations of science?

2.1 Assessment

1. **Identify** Describe one example of each of the scientific practices (Figure 2-2) in the Hubbard Brook experiment.
2. **Explain** What are the benefits and limitations of scientific models?
3. **Synthesize** Describe how engineering was used in the Hubbard Brook experiment.
4. **Contrast** How does a scientific hypothesis differ from a scientific theory?

CROSSCUTTING CONCEPTS

5. **Cause and Effect** Do the results of the Hubbard Brook experiment show a cause-and-effect relationship? Explain.