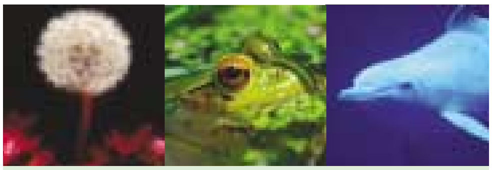
UNIT 1 WHAT IS THE NATURE OF SCIENCE?

Evolution TV show
"The Evolutionary Arms Race"



AT A GLANCE

Learning Goals

Understand the processes of science

Distinguish between scientific and everyday meanings of key words—theory, hypothesis, law, fact—and use in context

Recognize the variables that affect observation, data collection, and interpretation

Recognize the importance of inference and interpretation

Understand that explanations often change as new evidence is found

QUICK CLICKS

Teacher's Guide Web Resources

Access the Web resources referenced in this guide—from handouts to video segments to Web features—by going to **pbs.org/evolution** and clicking on Teachers and Students, and then going to the *Evolution Teacher's Guide,* where the material is presented by unit.

For a hundred years, scientists have studied the **symbiosis** between tropical leafcutter ants and the fungi they cultivate for food. But it took the fresh eyes of a young graduate student, Cameron Currie, to make an astounding discovery. Currie had questioned how leafcutter ants could grow their fungal gardens free of pests. Seasoned scientists had concluded that ants maintained their gardens pest-free, probably by meticulous weeding. Currie decided to delve deeper. To test his hypothesis that there were parasites in the ants' gardens, he collected 1,500 ant colonies and isolated the fungal gardens to search for invaders. There he found a common culprit—the *Escovopsis* fungus. Curious about why this parasitic fungus didn't overtake the gardens, he experimented by removing the worker ants. Within days, sometimes even overnight, the parasitic fungus overran the ants' gardens.

This phenomenon raised a new question for Currie: What did the ants do that kept the parasitic mold in check? Currie began to focus on a white substance on the worker ants' exoskeleton. Earlier researchers had assumed this white, waxy substance was inert and lifeless. Currie scraped off the white bloom and examined it under a microscope. To his surprise, he found a tangled mass of Streptomyces—the same kind of bacteria that produces half of the antibiotics used in medicine. With further tests, Currie found that the ants' Streptomyces bacteria specifically targeted the pathogenic fungus in the ants' garden. The simple evolutionary partnership of two organisms, the ants and the fungus—had become a complex party of four—ant, fungus, parasitic fungus, and bacteria.

KEY TERMS

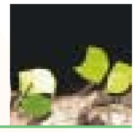
science: a way of knowing about the natural world
Scientific explanations are based on observations and facts that can be confirmed or disproved by other scientists using accepted scientific techniques.

law: a description of how a natural phenomenon will occur under certain circumstances
Kepler's Law of Planetary Motion describes the relationship between the time it takes a planet to go around the Sun and the planet's distance from the Sun.

fact: a natural phenomenon repeatedly confirmed by observation
It takes Venus 225 days to go around the Sun.

hypothesis: a possible and testable statement about a natural phenomenon
Newton proposed that the force of gravity between two objects depends on the distance between the objects.

theory: a well-substantiated explanation of some aspect of the natural world that typically incorporates many confirmed observations, laws, and successfully verified hypotheses
Heliocentricism: the Sun is the center of our solar system.



Background

Cameron Currie's story of leafcutter ants is an example of science at its best. Currie looked at the findings of veteran researchers and asked important new questions. With healthy skepticism, careful observations, and persistence, Currie discovered a complex symbiosis of four organisms.

Science is an equal opportunity venture with clearly defined processes. It also is a human endeavor, and the assumptions that scientists make can influence the questions they ask and the observations and interpretations they make. Currie used the following scientific processes in his search for answers: asking a question; making careful observations and collecting precise data; creating a testable hypothesis; doing experiments and collecting evidence to test the hypothesis; analyzing and interpreting data to accept or reject a hypothesis; revising a hypothesis based on new evidence and retesting; creating explanations that describe patterns and interrelationships and link evidence to pre-existing knowledge; and presenting research for review by scientific peers.

Scientific inquiry often begins with an observation that leads to a question. Careful observations are the foundation of scientific inquiry. But, science is far more than a collection of observations and evidence. The ultimate goal of scientists is to develop a deeper understanding of the natural world. Scientists make connections between disparate facts, find patterns, and determine cause and effect to create the most logical explanations. Scientific explanations must be consistent with the available observational and experimental evidence, use only natural forces and processes (never supernatural), and allow scientists to make accurate predictions about the natural world. Since not all phenomena are directly observable, science also relies on inference and interpretation. This has been true in understanding the nature of atoms as well as in determining the mechanism for evolution.

Science is built on the principle that the same natural laws we observe today have been operating over space and time. We know that the planets orbit the Sun today, as they did in Copernicus's time, and we assume that they did before that. What changes is the depth of our understanding of the natural world. Each discovery leads to new questions, new experiments, and eventually, new discoveries. One way we can add to our knowledge is by developing tools and techniques that will extend this frontier. For instance, the scanning electron microscope enabled Currie to identify Streptomyces bacteria. As we learn more, we can challenge previous assumptions, as Curry challenged the idea that ants were just very careful gardeners. While scientific ideas are always open to challenge, some ideas withstand the test of time, are supported by an increasing amount of evidence, and become well-grounded theories.

Currie and other scientists are pursuing new questions that have been raised by his research. If leafcutters are part of a four-way symbiotic relationship, how many other organisms are part of more complex systems? How have leafcutter ants used antibiotics to check the pests in their gardens for 50 million years without antibiotic resistance developing? And what can we learn from this to reduce antibiotic resistance in human pathogens? In the time-honored tradition of science, each new discovery paves the way for new research and revelation.

Know More

Web Sites

www.botany.utoronto.ca/H-paper_2/index.htm
(Cameron Currie's article on leafcutter ants)

www.nap.edu/readingroom/books/evolution98/
(Online version of NAP publication, *Teaching about Evolution and the Nature of Science*)

www.indiana.edu/~ensiweb/lessons/chec.ins.html (Includes many lesson ideas on the nature of science and evolution)

Books

Aicken, Frederick. *The Nature of Science.* Portsmouth, NH: Heinemann Educational Books, Inc., 1991.

Gardner, Martin. *Science: Good, Bad, Bogus.* Prometheus Books, 1990.

Moore, John. *Science As a Way of Knowing: The Foundations of Modern Biology.* Cambridge, MA: Harvard University Press, 1993.

National Academy of Sciences. *Teaching about Evolution and the Nature of Science.* Washington, DC: National Academy Press, 1998.

Videos

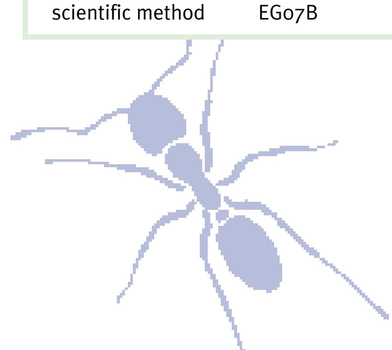
"Creatures in Crime," 1995. (Available from Carolina Biological)

"Galileo: The Challenge of Reason" (Available from Phoenix Learning Group, 1-314-569-0211)

pbs.org/evolution

SciLINKS **www.scilinks.org**

Topic	Keyword
leafcutter ants	EG07A
scientific method	EG07B



Activities

Online Student Lesson 1: ***What Is the Nature of Science?***
Students explore the capabilities and limits of scientific processes and discover how science helps develop our understanding of the natural world.

Scientists in Action

Teacher's Guide Web Resources

Video Resources
"Red Queen," Bob Vrijenhoeck's minnows

"Tale of the Peacock," Peacock study with Marion Petrie

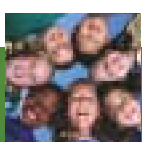
"Ancient Farmers of the Amazon," Leafcutter ant studies with Mueller, Schultz, and Currie

1. Before showing the three video clips, have students brainstorm a list of scientific processes.

2. Show students the video clips of scientists at work and ask them to notice the scientific processes used.

3. Ask students to write a paragraph describing the scientific processes used by each scientist. Then ask:
How do the processes of science used by each scientist compare?

What are the scientists' assumptions and how do they affect their observations and experiments?



Video 1 for Students

Isn't Evolution Just a Theory?
When we use the word *theory* in everyday life, we usually mean an idea or a guess, but the word has a much different meaning in science. Have your students watch this short video to learn the vocabulary essential for understanding the nature of science and evolution.

Discussion questions:
How does the scientific meaning of a term like *theory* differ from the way it is used in everyday life?

Can the "facts" of science change over time? If so, how?

Observe This

1. Discuss why observations, as demonstrated by Cameron Currie's leafcutter research, are the foundation of science. What we observe and how we observe it determines the questions we ask. Provide a soupspoon and invite students to describe the difference in reflections in the inner and outer side of the curved surfaces. How many students noticed this difference before?

2. Now ask students to keep a five-day log of observations about one aspect of their daily life (e.g., classmates' attire, the temperature at different times of day, the behavior of a pet, etc.). Have them choose one thing to observe before they leave class. Discuss different ways to record observations, including detailed descriptions, measurements, and sketches.

3. After the first day, ask students to review each other's observations to determine if they are making specific enough observations, and then provide feedback to encourage careful descriptions.

4. When they have finished their observations, students should create at least two hypotheses about why the things they observed are the way they are. (You could create a log handout for students with a place for them to describe their daily observations and write the two hypotheses.)

5. At the end of the observation period, have students share their logs and hypotheses. Discuss what factors and assumptions influenced the kind of information they collected and what other information they would want to test their hypotheses.

Different Points of View

"A scientist, however gifted, can be compared with a fly crawling on the inside wall of a cathedral; if it could draw what it sees, the fly's picture of the cathedral would be as crude as early maps of the world; if it could voice its speculations about the size, appearance and purpose of the cathedral, the fly's opinions would be received even more guardedly."

—Frederick Aicken,
The Nature of Science, pp. 29–30.

1. Read the above quote to students.

2. Have students carefully observe a natural object in their environment from at least three different perspectives (e.g. up close, a few feet away, etc.).

3. Ask them to write down three observations from each perspective and hypotheses for what they see. Discuss how the observations were affected by perspective and how the explanations changed with the addition of information.

Take It Further

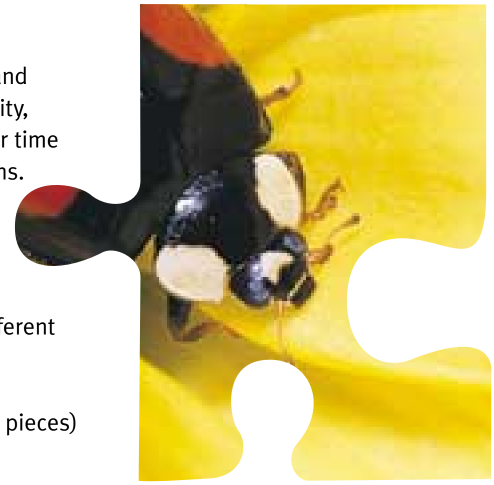
Online Course for Teachers
Session 1: "What Is the Nature of Science?"

Extensions
For another observation activity, see the ENSI lesson "Palpating Pachyderms" at **www.indiana.edu/~ensiweb/lessons/palppach.html**

To further explore the ability to form predictions based on evidence, see: "Activity 1: Introducing Inquiry and the Nature of Science" in *Teaching about Evolution and the Nature of Science,* pp. 66–73. You can print the activity from **www.nap.edu/readingroom/books/evolution98/**

In-depth Investigation

Solving the Puzzle



Darwin formulated his theory of evolution by observing nature and analyzing evidence—or using the scientific process. In this activity, student teams use evidence (jigsaw puzzle pieces) revealed over time to experience the nature of science and understand its limitations.

Objective
Give students practice using evidence to make inferences.

Materials
- One 300–500 piece jigsaw puzzle (interesting picture with different scenes in different parts of puzzle)
- 6 large envelopes
- 6 pieces of cardboard (large enough to support team's puzzle pieces)

Procedures

Preparation: Remove all edge pieces from the puzzle. Divide the remaining pieces of the jigsaw puzzle evenly into the six envelopes. Be sure to put the puzzle box out of students' sight.

1. Group students into six teams.

2. Introduce the activity by telling students they will explore the nature of science, using evidence (jigsaw puzzle pieces) to develop a series of tentative hypotheses to explain the scene represented by the puzzle pieces.

3. Give each group an envelope containing the puzzle pieces and piece of cardboard. Ask them to begin by pulling 20 puzzle pieces out of the envelope. Have each group propose a hypothesis about the complete puzzle scene based on the pieces (evidence) they have. Ask them to assemble their puzzle pieces in the order they think they belong on the cardboard, as they will need to move it later. Have them write down their puzzle scene idea as Tentative Hypothesis #1.

4. Then ask groups to pick out 20 more puzzle pieces from the envelope. Ask them to refine their first hypothesis or to create Tentative Hypothesis #2. (Note that their hypothesis may remain the same.)

5. Have the groups draw five more puzzle pieces from the envelope and proceed as before.

6. After a couple of minutes, have them share their partially completed puzzle with other groups. Tell them any unused pieces must remain in the envelope. After about five minutes of group visits, have each team choose a representative to report their final hypothesis to the class.

7. After each group has reported, use the following questions to lead a discussion:
- What kinds of information from the pieces were valuable to your team in formulating a hypothesis?
- How did the personal biases of people in your group affect your hypotheses?
- How did your initial hypothesis compare to your final hypothesis and how did collaboration with other teams affect your final hypothesis?
- Did different groups have different hypotheses based on similar evidence? How is this possible?
- Is your final hypothesis "correct"? Explain. What degree of certainty do you have about your hypothesis?
- How does this simulation compare to the process of science in the real world?
- How does not having the "edges" of the puzzle relate to the nature of science?

See Assessment Rubric on p. 34.