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ABSTRACT

This teacher's guide was developed to assist teachers in the use of multimedia resources for the Public Broadcasting System (PBS) program, "Evolution." Each unit uses an inquiry-based approach to meet the National Science Education Standards. Units include: (1) "What is the Nature of Science?"; (2) "Who Was Charles Darwin?"; (3) "What is the Evidence for Evolution?"; (4) "How Does Evolution Work?"; (5) "How Did Humans Evolve?"; (6) "Why Does Evolution Matter Now?"; and (7) "Dealing with Controversy." (YDS)

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ED 460 020

Teacher's Guide

evolution

a journey into where we're from and where we're going

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Premiering fall 2001 on PBS

clear blue sky PRODUCTIONS

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www.janegoodall.org

the Jane Goodall Institute

Dear Teacher,

As a naturalist, conservationist, and scientist, I am deeply committed to fostering an appreciation for both the natural world and science, particularly among young people. That's one of the reasons I founded "Roots & Shoots," a global environmental and humanitarian program for young people that combines classroom learning with local projects that benefit people, animals, and the environment.

That's also why I am delighted to lend my support to the *Evolution* project, one of the most comprehensive public television science initiatives ever undertaken. In addition to an outstanding eight-hour broadcast series, the *Evolution* team has put together an extraordinary set of multimedia resources for high school teachers across the country to help them expand and strengthen students' understanding of evolution.

I believe that teaching evolution is critical to nurturing a community that is not only scientifically literate, but also compassionate and caring and that values the natural world. I hope you'll take advantage of the *Evolution* project's many resources for years to come.

Sincerely,

Jane Goodall

Dr. Jane Goodall, CBE

P.O. Box 14890 Silver Spring, Maryland 20911-4890

evolution

a journey into where we're from and where we're going

Dear Teacher,

Evolution is one of the most powerful ideas ever to emerge from science. It is the very foundation of biology and the key to understanding our own human origins. The mechanism of evolution helps determine who lives, who dies, and who gets the opportunity to pass on traits to the next generation. At the same time, evolution ranks as one of the most widely misunderstood scientific principles in America today.

To address this, leading public broadcaster WGBH Boston (producer of the award-winning science series *NOVA™*) and acclaimed documentary and feature film production company Clear Blue Sky Productions have joined together to bring you *Evolution*. This groundbreaking project includes a PBS series, content-rich Web site, and extensive educational resources—including this teacher's guide—for classrooms nationwide. The guide is packed with activities to help you enhance and deepen your students' understanding of evolution and its relevance today.

We salute you, America's high school biology teachers, for your dedication and commitment to teaching evolution. We hope you'll use this guide and all our *Evolution* resources to illuminate what many regard as the single greatest scientific idea ever conceived.

Sincerely,

Richard Hutton
Executive Producer, *Evolution*
WGBH

Jody Patton
Executive-in-Charge
Clear Blue Sky Productio

Evolution is a co-production of the WGBH and Clear Blue Sky Productions.

WGBH
125 Western Avenue
Boston, MA 02134
617.300.2000

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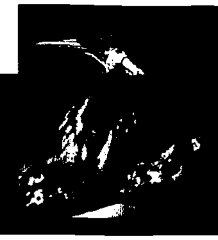
Contents



About the *Evolution* Project

> "If I were to give an award for the single best idea anyone has ever had, I'd give it to Darwin, ahead of Newton and Einstein and everyone else. In a single stroke, the idea of evolution by natural selection unifies the realm of life, meaning, and purpose with the realm of space and time, cause and effect, mechanism and physical law. But it is not just a wonderful idea. It is a dangerous idea."
>
> —Daniel Dennett,
> *Darwin's Dangerous Idea*, p. 21

Programs can be videotaped and used for up to one year after broadcast. Check your TV listings or call your local public television station to confirm broadcast dates and times.

The *Evolution* project—a groundbreaking public television series, content-rich and easy-to-navigate Web site, and extensive educational resources—explores a simple yet remarkable theory that ranks as one of the greatest breakthroughs in the annals of science, and one of the most misunderstood scientific principles in America today.

Produced by public broadcaster WGBH Boston and documentary and feature film producer Clear Blue Sky Productions, the *Evolution* project aims to help biology teachers nationwide enhance and deepen their students' understanding of evolution and the nature of science.

Television Series

This seven-part, eight-hour PBS series premiering fall 2001 travels around the world to examine evolutionary science and its profound effect on our lives and our planet.

Darwin's Dangerous Idea (two hours)
Why does Charles Darwin's "dangerous idea" matter more today than ever, and how does it explain the past and predict the future of life on Earth? This show combines drama and documentary filmmaking to explore Darwin's life and the key concepts of evolution.

Great Transformations (one hour)
What underlies the incredible diversity of life on Earth? How have complex organisms evolved? The journey from water to land, the return of marine mammals to the sea, and the emergence of humans suggest that species, past and present, are all members of a single tree of life.

Extinction! (one hour)
Five mass extinctions have occurred over the life of the planet. Are we humans causing the next one? And what does evolutionary theory predict for the world we will leave to our descendants?

The Evolutionary Arms Race (one hour)
"Survival of the fittest" —is raw competition or a level of cooperation indispensable to life? Interactions between species are among the most powerful evolutionary forces on Earth, and understanding them may well be the key t our own survival.

Why Sex? (one hour)
In evolutionary terms, sex is more important than life itself. Sex fuels evolutionary change by adding variation to the gene pool. The drive to pass on our genes has shaped not only our bodies, minds, and lives, but the rich and complex fabric of human culture.

The Mind's Big Bang (one hour)
Fifty thousand years ago, something happened—the modern human mind emerged, triggering a creative, technological, and social explosion. What forces contributed to this breakthrough and where might the power of the human mind ultimately lead us?

What About God? (one hour)
Of all species on Earth, humans alone attempt to explain who we are and how we came to be. This final show explores the struggle between science and religion. The personal stories of scientists, teachers, and students support the view that the two are compatible.

Evolution Web Site

Visit **pbs.org/evolution** for an engaging, comprehensive educational experience. The site is packed with interactive features that allow users to test evolutionary principles in action.

Resources for Teachers and Students

Evolution Library
Direct Web access to hundreds of multimedia evolution resources, including video, photographs, interviews, articles, and annotated Web links. Available at **pbs.org/evolution**.

Online Lessons for Students: Learning Evolution
Produced in tandem with the *Evolution Teacher's Guide*, these inquiry-based, teacher-assigned lessons provide students with online activities to enhance their understanding of the nature of science and evolution. Available at **pbs.org/evolution**.

Videos for Students: Evolving Ideas
Seven short videos (streamed online at **pbs.org/evolution** and available for purchase through WGBH Boston Video) combine storytelling and science to explore the concepts of evolution and spark students' interest.

Teaching Evolution Case Studies
Four 15-minute videos (streamed online at **pbs.org/evolution** and available for purchase through WGBH Boston Video) highlight a range of strategies for teaching evolution in classrooms across the country.

Online Course for Teachers: Teaching Evolution
This eight-session course for high school teachers draws on the broadcast series, Web features, case study videos, and the *Evolution* Library to provide a vibrant learning experience. The course will deepen your understanding of evolutionary concepts and help you address obstacles to teaching evolution. Available at **pbs.org/evolution**. Explore the sessions for your own enrichment or take the whole course for credit through a local college (contact local institutions for availability).

Companion Book
Award-winning journalist Carl Zimmer tells the compelling story of the theory of evolution—from Charles Darwin to 21st century science—in *Evolution: The Triumph of an Idea*. Published by HarperCollins, this companion book to the *Evolution* series features an introduction by renowned paleontologist Stephen Jay Gould and a forward by *Evolution* Executive Producer Richard Hutton.

Order Today

Free *Evolution Teacher's Guide*
WGBH
Educational Programming & Outreach
125 Western Avenue
Boston, MA 02134
Order online at **pbs.org/evolution**

Series Videos, Videos for Students, Case Study Videos

1. The entire seven-part *Evolution* series is available for $99.95 (WG1158)
2. Single program videos are available for $19.95
   - "Darwin's Dangerous Idea" (WG1219)
   - "Great Transformations" (WG1220)
   - "Extinction!" (WG1221)
   - "The Evolutionary Arms Race" (WG1222)
   - "Why Sex?" (WG1223)
   - "The Mind's Big Bang" (WG1224)
   - "What About God?" (WG1225)
3. *Learning and Teaching Evolution*, a compilation of the videos for students and case study videos, is available for $19.95 (WG1302)

Contact WGBH Boston Video at 1-800-949-8670 to place an order, or to request more information about other videos and DVDs.

Using This Guide

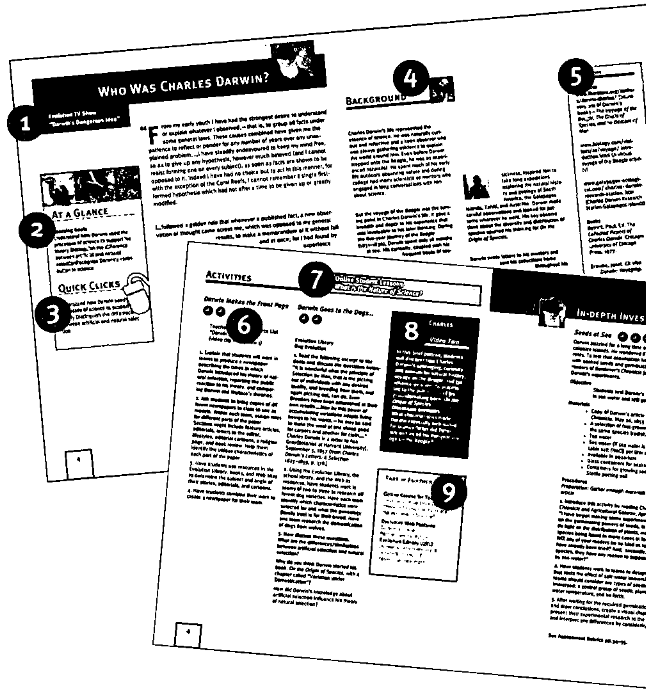
This guide is designed to help you take full advantage of the *Evolution* project's vast multimedia resources. Many of the lessons and activities are built around dynamic video segments, *Evolution* Web features, articles, images, and more...all easily accessible by going to **pbs.org/evolution** and clicking on Teachers and Students. Then go to the *Evolution Teacher's Guide,* where you'll find the Teacher's Guide Web Resources organized by unit. Teaching high school biology will never be the same!

Do You Avoid the "E" Word?

Are you committed to teaching evolution, but nervous about the controversy that might arise? Did you know that nearly every major religion doctrinally supports the teaching of evolution? Turn to p. 30 for "Dealing with Controversy," a special section created to help you successfully and respectfully address the controversy surrounding the teaching of evolution.

Overview

The guide is divided into six four-page units, each one framed by an essential question designed to spur inquiry-based learning and to meet National Science Education Standards (see p. 40). Each unit includes:



1. *Evolution* TV show
2. "At a Glance" learning goals
3. **Quick Clicks: Teacher's Guide Web Resources**

   Access all the Web resources referenced in this guide...
   - Handouts
   - Video resources
   - *Evolution* Web features
   - Online Lessons for Students: Learning Evolution
   - Online Course for Teachers: Teaching Evolution
   - Videos for Students: Evolving Ideas
   - Teaching Evolution Case Studies
   - External Web links

   ...by going to pbs.org/evolution, clicking on Teachers and Students, and then going to the *Evolution Teacher's Guide*, where you'll find the resources organized by unit.
4. "Background" content to help build your knowledge of evolution
5. "Know More" offering Web, video, and print-based resources outside the *Evolution* project universe
6. "Activities" to support students' exploration of the subject
7. "Online Lessons for Students: Learning Evolution"
8. "Videos for Students: Evolving Ideas," short videos for students, each one focusing on a core question that serves as a springboard for discussion
9. "Take It Further" box with *Evolution* project resources/Web features and "Extensions" (activities outside the *Evolution* project universe) to deepen your students' learning experience
10. "In-depth Investigation" for students, providing detailed learning objective, materials, and procedures (Assessment Rubrics on pp. 34–35)

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Curriculum Links

Evolution is the cornerstone of biology and we hope you'll use this guide to fortify and amplify your evolution lessons. But there also are many ways you can creatively integrate the units in this guide into your yearlong curriculum. Here are a few suggestions.

- Use "Unit 1: What Is the Nature of Science?" at the beginning of your course to introduce the processes of science.
- Use "Unit 2: Who Was Charles Darwin?" to enhance your lessons focusing on scientists and how they do their work.
- Use "Unit 3: What Is the Evidence for Evolution?" to fortify your lessons on how scientists seek multiple lines of evidence to support or refute hypotheses.
- Use "Unit 4: How Does Evolution Work?" when you're covering genetics as well as biodiversity.
- Use "Unit 5: How Did Humans Evolve?" as part of your lessons on human biology.
- Use "Unit 6: Why Does Evolution Matter Now?" in your lessons on microbes, antibiotic resistance, biodiversity, and ecology.

Guide Tips

Time to Learn!
Each clock represents approximately one 45-minute classroom session. Use these clock icons as a guide to the amount of classroom time (not homework time!) needed to complete the activity or in-depth lesson.

SciLinks
SciLinks allow you to access activities, news articles, and other Web resources collected and annotated by NSTA (National Science Teachers Association). Simply go to **www.scilinks.org** and enter the keyword number referenced in the SciLinks boxes included in each unit of this guide.

It's in the Glossary
This guide includes a glossary of key terms on pp. 36–37. Glossary terms appear in **bold** within the units for easy reference.

Activity Planning Grid

Follow the units in this guide sequentially or choose those activities that complement your lesson plans and match your students' interests, aptitudes, and learning styles.

Our Activity Planning Grid offers you several ways to navigate the material. Whatever path you choose *or* create, we suggest you review the background section of the particular unit before presenting the activity, and that you use the unit's introductory vignette to engage your students.

Path One focuses on the processes of science

Unit 1
Activity: "Scientists in Action" (p. 8)

Activity: "Observe This" or "Different Points of View" (p. 8)

In-depth Investigation: "Solving the Puzzle" (p. 9)

Unit 2 **Video 2 for Students**: "Who Was Charles Darwin?" and discussion questions (p. 12)

Unit 3 **Video 3 for Students**: "How Do We Know Evolution Happens?" and discussion questions (p. 16)

Unit 4
Video 4 for Students: "How Does Evolution Really Work?" and discussion questions (p. 20)

Online Student Lesson 4, Activity 2: "Flashy Fish"

Unit 6
Video 6 for Students: "Why Does Evolution Matter Now?" (p. 28) or watch the entire broadcast of "The Evolutionary Arms Race" (how science works with medicine)

Activity: "When an Apple a Day Isn't Enough" (p. 28)

Path Two focuses on the processes of science, evolutionary concepts/mechanisms, and evidence for evolution

Unit 1
Activity:"Scientists in Action" (p. 8)

Activity: "Observe This" or "Different Points of View" (p. 8)

Unit 2
Online Student Lesson 2, Activity 1: "Darwin's Great Voyage of Discovery"

In-depth Investigation: "Seeds at Sea" (p. 13)

Unit 3
Video 3 for Students: "How Do We Know Evolution Happens?" and discussion questions (p. 16)

Activity: "A Whale of a Change" (p. 16)

Unit 4
In-depth Investigation: Read introductory vignette, and then go to In-depth Investigation,"Birds, Beaks, and Natural Selection" (p. 21)

Activity: "Darwin's Finches" (p. 20)

Path Three focuses on humans and evolution—how humans have evolved, the evidence for it, and why it matters to us now

Unit 5
Activity: "Watch Your Step" (p. 24)

Video 5 for Students: "Did Humans Evolve?" and discussion questions (p. 24)

Online Student Lesson 5, Activity 1: "Fossil Finding" and **Activity 2**: "A Tree Full of Ancestors"

In-depth Investigation: "Fossils and Dispersal Patterns of Early Hominids" (p. 25)

Unit 6
Video 6 for Students: "Why Does Evolution Matter Now?" and discussion questions (p. 28)

In-depth Investigation: "Big Decisions" (p. 29)

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

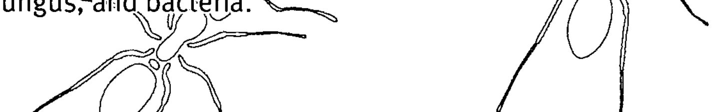
QUICK CLICKS

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

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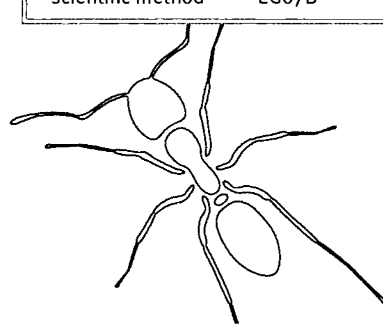
Topic	Keyword
leafcutter ants	EG07A
scientific method	EG07B



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.).

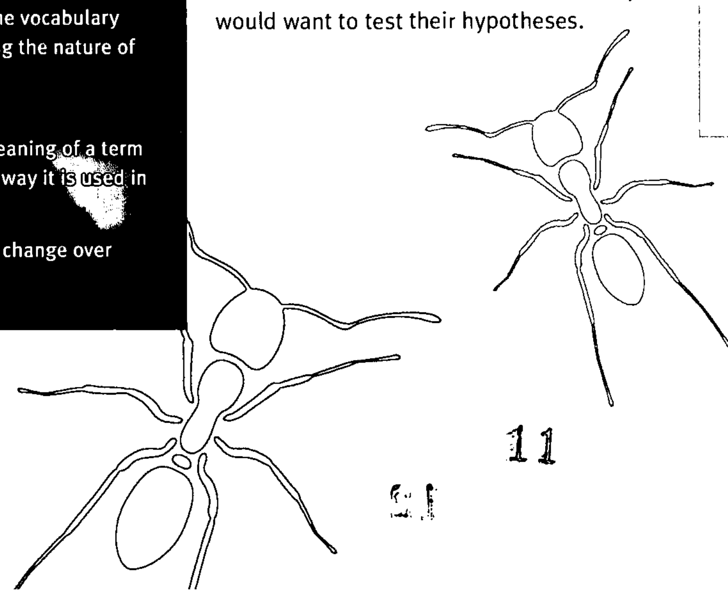
3. Ask them to write down three observations from each perspective and hypotheses for what they see. Discuss how the observations were affected by perspective and how the explanations changed with the addition of information.

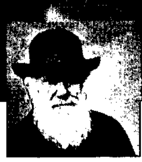
TAKE IT FURTHER

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

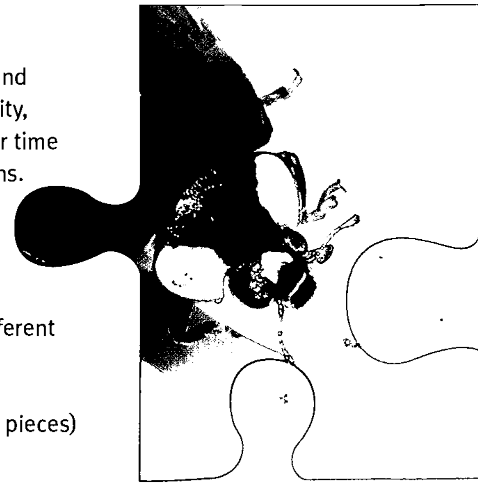
Extensions
For another observation activity, see the ENSI lesson "Palpating Pachyderms" at **www.indiana.edu/~ensiweb/lessons/palppach.html**

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/**

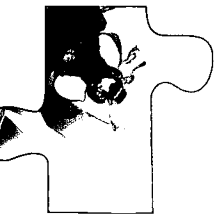




Solving the Puzzle



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.

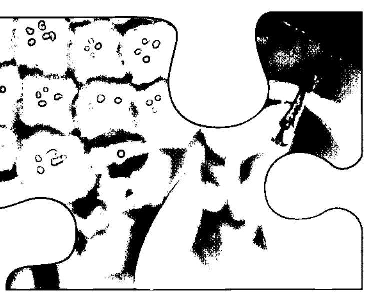


Objective
Give students practice using evidence to make inferences.

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.

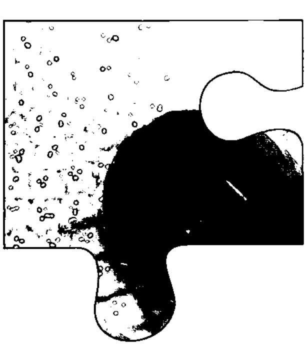
3. Give each group an envelope containing the puzzle pieces and piece of cardboard. Ask them to begin by pulling 20 puzzle pieces out of the envelope. Have each group propose a hypothesis about the complete puzzle scene based on the pieces (evidence) they have. Ask them to assemble their puzzle pieces 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.

Unit 2/ Who Was Charles Darwin?

***Evolution* TV Show**
"Darwin's Dangerous Idea"

At a Glance

Learning Goals

Understand how Darwin used the processes of science to support his theory

Distinguish between artificial and natural selection

Recognize Darwin's contribution to science

Quick Clicks

Teacher's Guide Web Resources

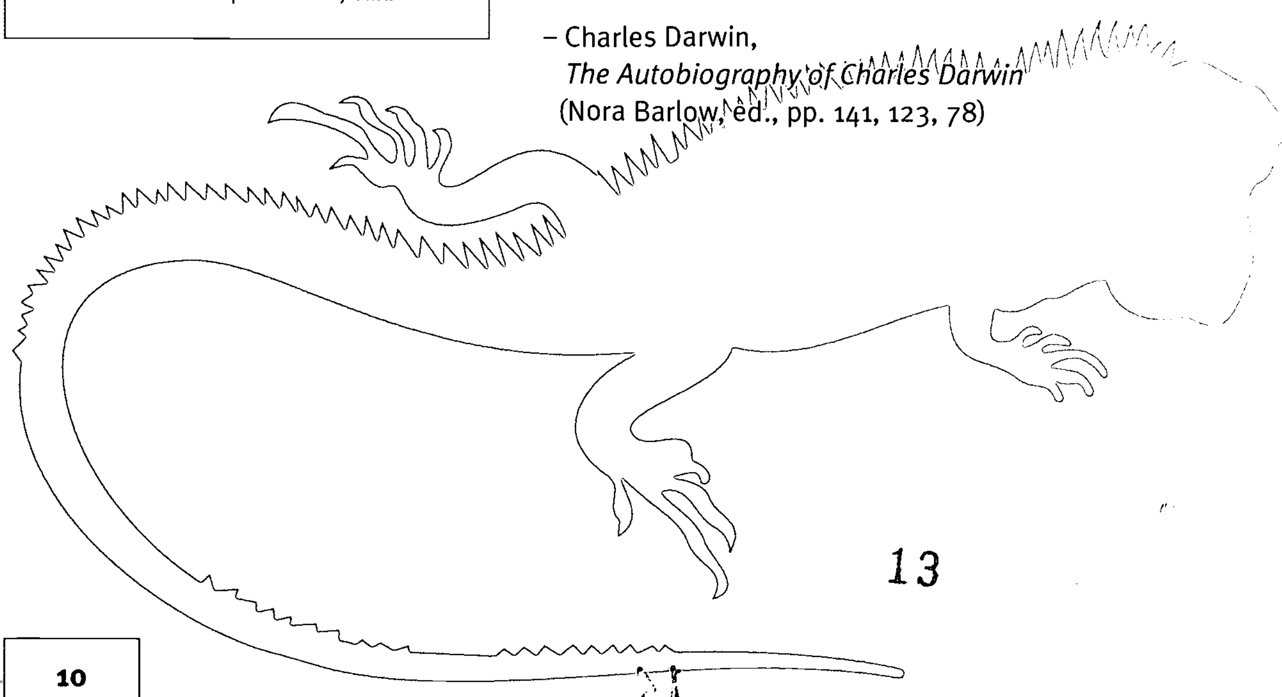
Access the Web resources referenced in this guide—from handouts to video segments to Web features—by going to **pbs.org/evolution** and clicking on Teachers and Students, and then going to the *Evolution Teacher's Guide*, where the material is presented by unit.

"From my early youth I have had the strongest desire to understand or explain whatever I observed—that is, to group all facts under some general laws. These causes combined have given me the patience to reflect or ponder for any number of years over any unexplained problem....I have steadily endeavoured to keep my mind free, so as to give up any hypothesis, however much beloved (and I cannot resist forming one on every subject), as soon as facts are shown to be opposed to it. Indeed I have had no choice but to act in this manner, for with the exception of the Coral Reefs, I cannot remember a single first-formed hypothesis which had not after a time to be given up or greatly modified."

"I...followed a golden rule that whenever a published fact, a new observation or thought came across me, which was opposed to my general results, to make a memorandum of it without fail and at once; for I had found by experience that such facts and thoughts were far more apt to escape from memory than favorable ones."

"During some part of the day I wrote my Journal, and took much pains in describing carefully and vividly all that I had seen; and this was good practice....Everything about which I thought or read was made to bear directly on what I had seen and was likely to see; and this habit of mind was continued during the five years of the voyage. I feel sure that it was this training which has enabled me to do whatever I have done in science."

– Charles Darwin,
The Autobiography of Charles Darwin
(Nora Barlow, ed., pp. 141, 123, 78)



13

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Background

Charles Darwin's life represented the essence of science. He was naturally curious and reflective and a keen observer who was always gathering evidence to explain the world around him. Even before Darwin stepped onto the *Beagle*, he was an experienced naturalist. He spent much of his early life outdoors observing nature and during college had many scientists as mentors who engaged in long conversations with him about science.

But the voyage of the *Beagle* was the turning point in Charles Darwin's life. It gave a breadth and depth to his experience that was invaluable to his later thinking. During the five-year journey of the *Beagle* (1831–1836), Darwin spent only 18 months at sea. His curiosity, coupled with his frequent bouts of seasickness, inspired him to take long expeditions exploring the natural history and geology of South America, the Galapagos Islands, Tahiti, and Australia. Darwin made careful observations and looked for patterns wherever he went. His key observations about the diversity and distribution of **species** spurred his thinking for *On the Origin of Species by Means of Natural Selection*.

Darwin wrote letters to his mentors and sent his collections home throughout his journey. By the time Darwin stepped off the *Beagle*, he was already recognized by the scientific community for his expertise.

Upon Darwin's return, he spent eight years studying barnacles and believed that his in-depth knowledge in this one area sparked his thinking in others. In the years following his *Beagle* voyage, Darwin began to develop his revolutionary theory of **natural selection** that explained a mechanism for **evolution.** He carefully explored different lines of evidence, experimenting and gathering information to support his case for evolution.

One of Darwin's interests, pigeon breeding, played a significant role in the development of his theory of natural selection and in the way he presented his argument in *On the Origin of Species.* Darwin wanted to understand how new species could be created from a common ancestor by the accumulation of small changes over generations and believed that studying breeding by **artificial selection** of animals like pigeons would offer clues.

Darwin spent 20 years gathering evidence and writing about his theory before he published it. He anguished over the controversy it would create in Victorian England. And, if the naturalist Alfred Wallace hadn't come to similar conclusions and written to Darwin for help in presenting them, it might have been even longer before the world heard about *On the Origin of Species.*

"Even without evolution, Darwin would have been one of the great nineteenth-century biologists; even without biology, he would have gone down in history as a great geologist. It is a measure of the importance of the theory of evolution that those other achievements seem modest in comparison to it."

(From Michael White and John Gribbin, *Darwin: A Life in Science*, p. 173.)

Know More

Web Sites

www.literature.org/authors/darwin-charles/ (Online versions of Darwin's books *The Voyage of the Beagle*, *The Origin of Species*, and *The Descent of Man)*

http://www.inform.umd.edu/EdRes/Colleges/LFSC/life_sciences/.plant_biology/darwin/darwindex.html (The Darwin-Wallace paper of 1858)

Books

Barrett, Paul, ed. *The Collected Papers of Charles Darwin.* Chicago: University of Chicago Press, 1977.

Browne, Janet. *Charles Darwin: Voyaging.* Princeton, NJ: Princeton University Press, 1995.

Burkhardt, Frederick, ed. *Charles Darwin's Letters: A Selection 1825–1859.* Cambridge, UK: Cambridge University Press, 1998.

Darwin, Charles. *Voyage of the Beagle.* New York: Penguin Putnam Inc., 1839 (reprint 1989).

Darwin, Charles. *The Origin of Species.* New York: The Modern Library, 1993.

Darwin, Charles. *The Autobiography of Charles Darwin.* New York: W.W. Norton and Company, Inc., 1958.

Desmond, Adrian, and James Moore. *Darwin: The Life of a Tormented Evolutionist.* New York: W.W. Norton and Company, Inc., 1994.

Jones, Steve. *Darwin's Ghost: The Origin of Species Updated.* New York: Random House, 2000.

Mayr, Ernst. *The Growth of Biological Thought: Diversity, Evolution, and Inheritance.* Cambridge, MA: Harvard University Press, 1982.

Ridley, Mark, ed. *The Darwin Reader.* New York: W.W. Norton and Company, Inc., 1996.

White, Michael, and John Gribbin. *Darwin: A Life in Science.* New York: Penguin Books USA, 1997.

pbs.org/evolution

SCILINKS THE WORLD'S A CLICK AWAY **www.scilinks.org**

Topic	**Keyword**
Charles Darwin	EG11A

ONLINE STUDENT LESSON 2: *Who Was Charles Darwin?*
Students meet the man behind the theory, chart his voyage, and learn how his observations led to his theory of natural selection.

Darwin Makes the Front Page

TEACHER'S GUIDE WEB RESOURCES

Video Resources
"Darwin: Reluctant Rebel"

Reading Resources
"Depart Indefinitely from the Original Type" by Alfred Russel Wallace

Introduction to *On the Origin of Species*

Audio Resources
"James Moore: Darwin and Victorian Culture"

BOOKS

The Autobiography of Charles Darwin

Charles Darwin's Letters: A Selection 1825–1859

The Collected Papers of Charles Darwin

1. Explain that students will work in teams to produce a newspaper describing the times in which Darwin introduced his theory of natural selection, reporting the public reaction to his theory, and comparing Darwin and Wallace's theories.

2. Ask students to bring copies of different newspapers to class to use as models. Within each team, assign roles for different parts of the paper. Sections might include feature articles, editorials, letters to the editor, lifestyles, editorial cartoons, a religion page, and book review. Help them identify the unique characteristics of each part of the paper.

3. Have students use resources in the *Evolution* Library, books, and Web sites to determine the subject and angle of their stories, editorials, and cartoons.

4. Have students combine their work to create a newspaper for their team.

Darwin Goes to the Dogs...

TEACHER'S GUIDE WEB RESOURCES

Image Resource
"Dog Evolution"

1. Read the following excerpt to students and discuss the questions below:

> *It is wonderful what the principle of Selection by Man, that is the picking out of individuals with any desired quality, and breeding from them, and again picking out, can do. Even Breeders have been astonished at their own results....Man by this power of accumulating variations adapts living beings to his wants—he may be said to make the wool of one sheep good for carpets and another for cloth....*
>
> – Charles Darwin in a letter to Asa Gray (Botanist at Harvard University), September 5, 1857 (From *Charles Darwin's Letters: A Selection* 1825–1859, p. 178.)

What kinds of animals have been domestically bred?

What characteristics have been selected in different animals?

2. Using the *Evolution* Library, the school library, and the Web as resources, have students work in teams of two to three to research different dog varieties. Have each team identify which characteristics were selected for and what the genealogy (family tree) is for their breed. Have one team research the domestication of dogs from wolves.

3. Now discuss these questions:
What are the differences/similarities between artificial selection and natural selection?

Why do you think Darwin started *On the Origin of Species* with a chapter called "Variation under Domestication"?

How did Darwin's knowledge about artificial selection influence his theory of natural selection?

VIDEO 2 FOR STUDENTS

Who Was Charles Darwin?
In this brief portrait, students will discover how Charles Darwin's upbringing, curiosity and passion for natural history, voyage on the *Beagle*, and his reliance on scientific process led to the publication of his groundbreaking book, *On the Origin of Species by Means of Natural Selection*.

Discussion questions:
What characteristics made Darwin especially well-suited for science?

What did Darwin see and do on his five-year voyage on the *Beagle?*

Why was the publication of *On the Origin of Species* a courageous act?

Why was it simply good science?

TAKE IT FURTHER

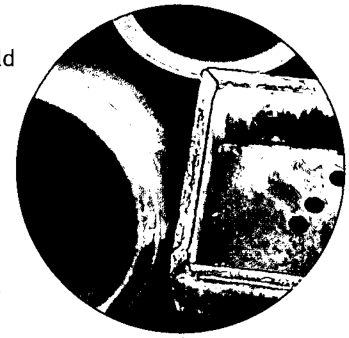
Online Course for Teachers
Session 2: "How Does Darwin's Theory of Evolution Illustrate the Process of Science?"

Evolution Web Features
"Darwin's Diary"
"Evolution Revolution"

Evolution Library
Charles Darwin's Letters–excerpts
Charles Darwin's Journal of Researches –excerpts

IN-DEPTH INVESTIGATION

Seeds at Sea to



Darwin puzzled for a long time over how plant species from the mainland could colonize islands. He wondered whether seeds could survive being carried by ocean currents. To test that assumption he experimented enthusiastically, filling his home with soaked seeds and germinating plants and regularly asking for advice from readers of *Gardener's Chronicle* journal.
In this activity, students recreate Darwin's experiments.

Objective:
Students test Darwin's hypothesis that seeds could be immersed in sea water and still germinate.

Materials:

- Copy of Darwin's article "Does Sea-Water Kill Seeds?" *Gardener's Chronicle*, May 26, 1855 (see **TEACHER'S GUIDE WEB RESOURCES**)
- A selection of fast-growing seeds, including different varieties of the same species (radish, lettuce, cabbage, beans, mustard, carrot); note germination time on package
- Tap water
- Sea water (if sea water is not available, make a solution of 35 g table salt (NaCl) per liter of water; instant ocean mix may be available in aquarium/pet supply stores)
- Glass containers for soaking seeds (beakers, jars, etc.)
- Containers for growing seeds (pots, trays, paper cups, etc.)
- Sterile potting soil

Procedures

Preparation: Gather enough materials for teams and make copies of Darwin's article.

1. Introduce this activity by reading Charles Darwin's letter to the *Gardener's Chronicle* and *Agricultural Gazette*, April 14, 1855.

I have begun making some experiments on the effects of immersion in sea-water on the germinating powers of seeds, in the hope of being able to throw a very little light on the distribution of plants, more especially in regard to the same species being found in many cases in far outlying islands and on the mainland. Will any of your readers be so kind as to inform me whether such experiments have already been tried? And, secondly, what class of seeds, or particular species, they have any reason to suppose would be eminently liable to be killed by sea-water?

2. Have students work in teams to design and conduct a controlled experiment that tests the effect of saltwater immersion on seed germination. Some factors that teams should consider are types of seeds; number of days seeds will be immersed; a control group of seeds; planting and growing of seeds/watering; water temperature; and so forth.

3. After waiting for the required germination time, have teams analyze their data and draw conclusions, create a visual display explaining their experiment, and present their experimental research to the class. Have students compare data and interpret any differences by considering the following:

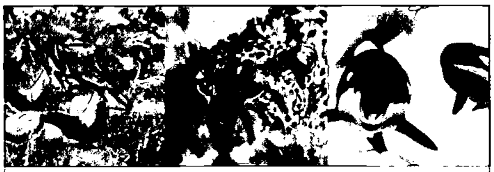
- Which plant species survived saltwater immersion the best? Did the length of time immersed affect seeds? If so, how? If you used different varieties of the same species, did all seeds respond the same?
- Does the class data help explain the colonization of islands by plant species? Why or why not?
- Is there any evidence that refutes the hypothesis that seeds are carried by ocean currents to islands?
- What other ways might seeds be dispersed to islands besides being carried by ocean currents? How might you test those hypotheses?

4. Finally, give students a copy of "Does Sea-Water Kill Seeds?" and have them compare their results with Darwin's. Ask them to identify and discuss other questions Darwin raises in his article.

See Assessment Rubric on p. 34.

Unit 3 What Is the Evidence for Evolution?

Evolution TV Shows
"Great Transformations"
and "Extinction!"



At a Glance

Learning Goals

Understand the importance of evidence in supporting Darwin's theory of evolution

Understand that the fossil record shows increasing diversity and large scale changes over time

Recognize why gaps in fossil evidence exist

Know how different lines of evidence are used to determine evolutionary relationships between different species

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.

Mammals evolved on land over 200 million years ago. So how did the world's largest mammals, whales, end up back in the water? That's the question Dr. Philip Gingerich, a **paleontologist** at the University of Michigan, would like to answer. Gingerich became intrigued when he found what looked like the **fossil** skull of an early wolf in Pakistan in 1978. But when he closely examined this wolf-like skull, he found the ear of a whale! This was the first fossil ever found that supported one of Darwin's most controversial ideas—that whales had descended from land mammals.

Whales are anatomically so different from any other mammals that they're a separate branch of mammal evolution. Had Gingerich found the beginning of that branch? The skull he found was among land mammal fossils, not in a marine layer of rock. Gingerich named the creature *Pakicetus*, whale from Pakistan. Was *Pakicetus* the land mammal whose descendants became modern whales?

Gingerich wanted to return to Pakistan to find the animal's legs. War nearby kept him from returning. Instead, he went to a place called Zeuglodon Valley, Valley of the Whales, in Egypt. Here in the middle of the Sahara Desert hundreds of whale skeletons lie buried in sandstone. Gingerich's excitement turned to disappointment when he found that most of the skeletons were *Basilosaurus*, an already known aquatic whale ancestor. But Gingerich kept on digging. A few days later he made a new discovery—*Basilosaurus* had legs. Even though *Basilosaurus* was fully aquatic, it still had vestiges of its terrestrial past. Ten million years of whale evolution had passed between *Pakicetus* and *Basilosaurus*, and yet whales still had hind legs and feet. Now the challenge for Gingerich and his colleagues was to fill in the fossil gaps of whale history.

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BACKGROUND

Phil Gingerich and his colleagues have unearthed a drove of fossil evidence that describes transitional steps in the evolution of whales. Since Gingerich's early discovery in Pakistan, a series of **transitional fossils** have been found including 55-million-year-old land-dwelling mesonychids, walking whales called *Ambulocetus* that could also swim, and *Rodhocetus*, mostly aquatic animals that could probably walk a little on land.

It is very unusual to find transitional fossils because only a small proportion of organisms ever become fossils. For this reason it is very unlikely that every transition in the evolution of a species will be recovered. Also, many fossils may represent dead ends in evolutionary branches. Often what we find are fossils from different branches, "close cousins" in the family tree. It is very unlikely to ever find the common ancestor, but close cousins, bearing intermediate traits, suggest a likely path followed by a direct ancestor.

In addition to fossil evidence, paleontologists depend on anatomical evidence to determine evolutionary relationships. For example, the front fin of a whale shares **homologous structures,** including the humerus, radius, and ulna bones, with the front limbs of other mammals such as humans, wolves, and sea lions, indicating common ancestry.

Molecular evidence also contributes to the picture of how whale evolution and other evolution has occurred. Molecular biologists are able to determine and compare the **DNA base sequences** and the **amino acid sequences** of the same proteins from different animals. The less closely related species are, the more differences there are in their DNA base or amino acid sequences, as there would be more time for mutations to accumulate. Conversely, the more closely related species are, the fewer differences there are.

Molecular and anatomical studies have been conducted to determine the whale's relationship to other living mammals. The **phylogeny** determined by each line of evidence is then compared. Current molecular studies of DNA sequences strongly suggest that whales are most closely related to the hippopotamus. This suggested relationship is still being studied as it doesn't precisely match the phylogeny created using anatomical evidence. Just as Darwin presented different lines of evidence to support his theory of evolution, scientists today rely on finding new and multiple lines of evidence—fossil, anatomical, molecular, and **biogeographical**—to determine the evolutionary relationships of different species.

Fossil Dating

Paleoanthropologists have several ways to determine the age of fossils. The simplest, **relative dating,** relies on the fact that older deposits are found below more recent geological layers in places where geological activity has not disturbed the original orientation of the layers. If two objects are found in the same layer, it is assumed they existed in the same time period.

Radiometric dating techniques, which are based on the knowledge that radioactive **isotopes** break down or decay at a constant rate, can give more precise and reliable information. The rates of decay are known as **half-lives,** the time it takes for one-half of the original isotopes in a sample to decay into different isotopes. Each different kind of radioactive isotope decays at a different, known rate. Since scientists know what isotopes the original element will decay into, they can measure the proportion of the original isotope in relation to the proportion of the products of decay and then calculate the years that have passed. For more information on dating, see lomar.edu/time/default.htm (tutorial on fossil formation and hniques from Palomar College).

KNOW MORE

Web Sites

http://www.indiana.edu/~ensiweb/lessons/c.bkgrnd.html (Source of information on transitional fossils in vertebrates)

www.ucmp.berkeley.edu/help/topic.html (Source on fossils, phylogenetics, etc.)

www.ucmp.berkeley.edu/fosrec/ ("Learning from the Fossil Record" collection of the museum)

www.ZoomDinosaurs.com/subjects/dinosaurs/ (Site on fossils, including fossilization, dating of fossils, and fossils found on all the continents; useful for students as well)

Whale Evolution:
www.neoucom.edu/Depts/Anat/whaleorigins.htm (Comprehensive site on Eocene Cetacean evolution by paleontologist Dr. Hans Thewissen)

www.ucmp.berkeley.edu/mammal/cetacea/cetacean.html (Cetacean evolution)

Geologic Time Scales:
geology.er.usgs.gov/paleo/geotime.shtml (USGS short version of time scale)

Books

Darwin, Charles. *The Origin of Species.* New York: The Modern Library, 1993.

Lewin, Roger. *Patterns in Evolution: The New Molecular View.* New York: Scientific American Library, 1999.

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

Wade, Nicholas, ed. *The Science Times Book of Fossils and Evolution.* New York: The Lyons Press, 1998.

Zihlman, Adrienne. *The Human Evolution Coloring Book, Second Edition.* New York: HarperCollins Publishers Inc., 2000.

Zimmer, Carl. *At the Water's Edge.* New York: Touchstone Books, 1999.

Articles

Berta, Annalisa. "What is a Whale?" *Science* 263 (14 Jan. 1994): 180–181.

Blackburn, Daniel G. "Paleontology Meets the Creationist Challenge." *Creation/Evolution* 36 (July 1995): 30–31 (back issues available from National Center for Science Education/NCSE at ncseweb.org/).

Gingerich, Philip D. "The Whales of Tehthys." *Natural History Magazine* (April 1994).

Gould, Stephen Jay. "Hooking Leviathan by Its Past." *Natural History Magazine* (May 1994).

Landau, Matthew. "Whales: Can Evolution Account for Them?" *Creation/Evolution*, (Fall 1982): 14–19. (back issues available from NCSE)

Novacek, Michael. "Genes Tell a New Whale Tale." *Nature* 361 (28 January 1993): 298–299.

Wilford, John Noble. "How the Whale Lost Its Legs and Returned to the Sea" (1994). In *The Science Times Book of Fossils and Evolution*, ed. by Nicholas Wade, 1998, *The New York Times*: 143–148.

Zimmer, Carl. "Back to the Sea" *Discover Magazine* (January 1995): 82–84.

Software

Timeliner, 5.0 (A program for creating, illustrating, and printing timelines available from Tom Snyder Productions, 1-800-342-0236)

pbs.org/evolution

SCILINKS. THE WORLD'S A CLICK AWAY

www.scilinks.org

Topic	Keyword
fossils	EG15A
radiometric dating	EG15B

Online Student Lesson 3: *What Is the Evidence for Evolution?*
Students explore how scientists gather evidence for a process that is typically not observable in a human lifetime.

Leaving a Trail of Evidence

Teacher's Guide Web resources

Video Resources
"Becoming a Fossil"

1. Ask students for examples of the "evidence" of their lives for just one day. Have them make a list of the kinds of evidence they may have left behind (e.g., dirty laundry, e-mails, photos, drawings, trash, locker contents, etc.).

2. Discuss with students:

What could someone tell about your day from the evidence you left?

What can't someone else know from the evidence you have left behind? (e.g., sequence, what exactly happened, how it was done, gaps in the evidence, etc.)

How could the evidence of your life be like the fossil record? (e.g., sedimentary layers in the laundry basket, floor of room, or piles of paper on a desk indicate relative sequence)

What is an **artifact?** Give some examples.

What clues could fossil evidence give that artifacts might not give?

How do we use inference to make sense out of evidence? What are the limitations of inference? What would strengthen an inference?

Take It Further

Online Course for Teachers
Session 3: "What Is the Evidence for Evolution?"

Evolution Web Features
"Deep Time"
"All in the Family"

Extensions
Have students do the "Making Cladograms" lesson on the ENSI site to learn more about phylogenetic relationships **http://www.indiana.edu/~ensiweb/lessons/mclad.html**

To help students understand deep time, do the ENSI "Time Machine" activity **http:// www.indiana.edu/~ensiweb/lessons/time.mac.html**

Winging It

Teacher's Guide Web resources

Video Resources
"Fish with Fingers"

1. Have students compare the bones in a baked chicken wing (after cleaning the meat away from the bones) to the arm and hand of a human skeleton. Ask:

What are the similarities and differences?

Where are the scapula, humerus, radius, and ulna bones of each?

2. Show students examples of other vertebrate forelimbs (bats, dogs, etc.) using the "Fish with Fingers" video and/or illustrations. Ask:

How does the function of the chicken, human, and other vertebrate forelimbs differ?

How might natural selection account for the development of different uses for limbs in different species?

What do these homologous structures tell us about evolution?

Video 3 for Students

How Do We Know Evolution Happens?
In this video, students will see how two lines of evidence, fossil and molecular, contribute to our picture of evolution. Whales provide an excellent opportunity to examine the transition between species because so many intermediate fossils have been found.

Discussion questions:
How do fossils give us a picture of change over time?

What distinguishing feature of the fossil *Pakicetus* skull identified it as related to a whale? Why was this surprising?

Why do scientists seek fossils that are intermediate in form and time between modern forms and their probable earliest ancestors?

A Whale of a Change

Teacher's Guide Web resources

Video Resources
"Whale Evolution"

Handouts
"Whales in the Making"
"Whale Evolution Data Table"

1. Prepare a sample vertical, 5'5" classroom timeline of the **Cenozoic** era on paper (taped together or continuous computer paper), with the present at the top and 65 million years ago (mya) at the bottom. Label every million years, with 1 inch equaling 1 my. Highlight the **Eocene** epoch (55–34 mya). Display in a conspicuous place.

2. Have students work in teams of two to four to prepare a 21" Eocene epoch timeline on paper, using the same scale and markings used in the classroom model.

3. Have each team cut apart the six fossil boxes from the "Whales in the Making" handout and gather the data about each fossil from resources in the *Evolution* Library, the school library, and the Web.

4. Have teams mount diagrams 1 and 2 at proper levels on their timelines. Point out the large gap between these two fossils. Then have students add the remaining fossils, in numbered sequence, by date of discovery.

5. Discuss:

What typical whale-like traits were apparently the earliest to appear? What apparently evolved much later?

As each new "missing link" was found, how many new gaps were formed? What is the relationship between gaps and fossils?

To find fossil evidence to fill the largest remaining gap in whale evolution, what age of sediments would you search?

What distinguishing traits would you expect to find in whale fossils of that age?

Explain why the absence of transitional fossils does not mean that evolution didn't take place.

6. Optional: For an extended version of this lesson, go to **http://www.indiana.edu/~ensiweb/lessons/whale.ev.html**

The Molecular Connection to

(adapted with permission from a Beth Kramer ENSI lesson)

Cytochrome c, an **enzyme** found in virtually all organisms, is needed for the release of energy from food. The amino acid sequences in this protein are compared for several different animals, and the number of differences found are used to infer degrees of relationship. These data are also compared with a **cladogram** constructed for those same animals based on their anatomical features, providing an example of independent confirmation of that evolutionary relationship.

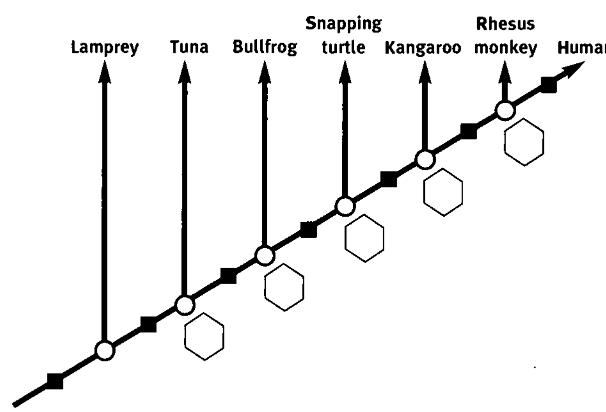
Objective:
Students will recognize how comparisons of molecular structure can suggest evolutionary relationships. They will also understand that if these results are consistent with those derived from anatomical structures, this provides independent confirmation, strengthening the scientific inference of relationship.

Materials:
- Copies of "The Molecular Connection" handout (see **TEACHER'S GUIDE WEB RESOURCES**)
- "Answer Key to the Molecular Connection" (see **TEACHER'S GUIDE WEB RESOURCES**)

Procedures
Preparation: Make copies of the handouts. Read the Answer Key prior to doing the activity.

1. Give students copies of "The Molecular Connection" handout. Have students work in groups of two to four to:
- Find the human, rhesus monkey, kangaroo, snapping turtle, bullfrog, and tuna on the "Amino Acid Sequences in Cytochrome-C Proteins from 20 Different Species" chart provided as a part of "The Molecular Connection" handout and underline their names.

- Compare the human amino acid sequence with each animal by counting the number of times an amino acid in that animal's cytochrome c is different from the amino acid in that same position of the human sequence. For example, there are 10 differences between human and dog. (Do several examples not included in the cladogram to make sure students understand how to count differences.)



- Record the total number of differences for each animal in the polygon below the vertical line for that animal in the cladogram.

2. Then have students answer the analysis questions on the handout.

3. After discussing the analysis questions, have each group write a short paragraph summarizing what important information can be obtained from cladograms.

See Assessment Rubric on p. 35.

Unit 4 How Does Evolution Work?

Evolution TV Show
"Why Sex?"

At a Glance

Learning Goals

Recognize the importance of sexual reproduction for variability in organisms

Understand the process of natural selection and how it accounts for adaptations in organisms

Recognize that populations, not individuals, evolve

Quick Clicks

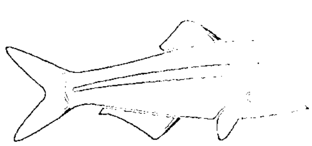
Teacher's Guide Web Resources

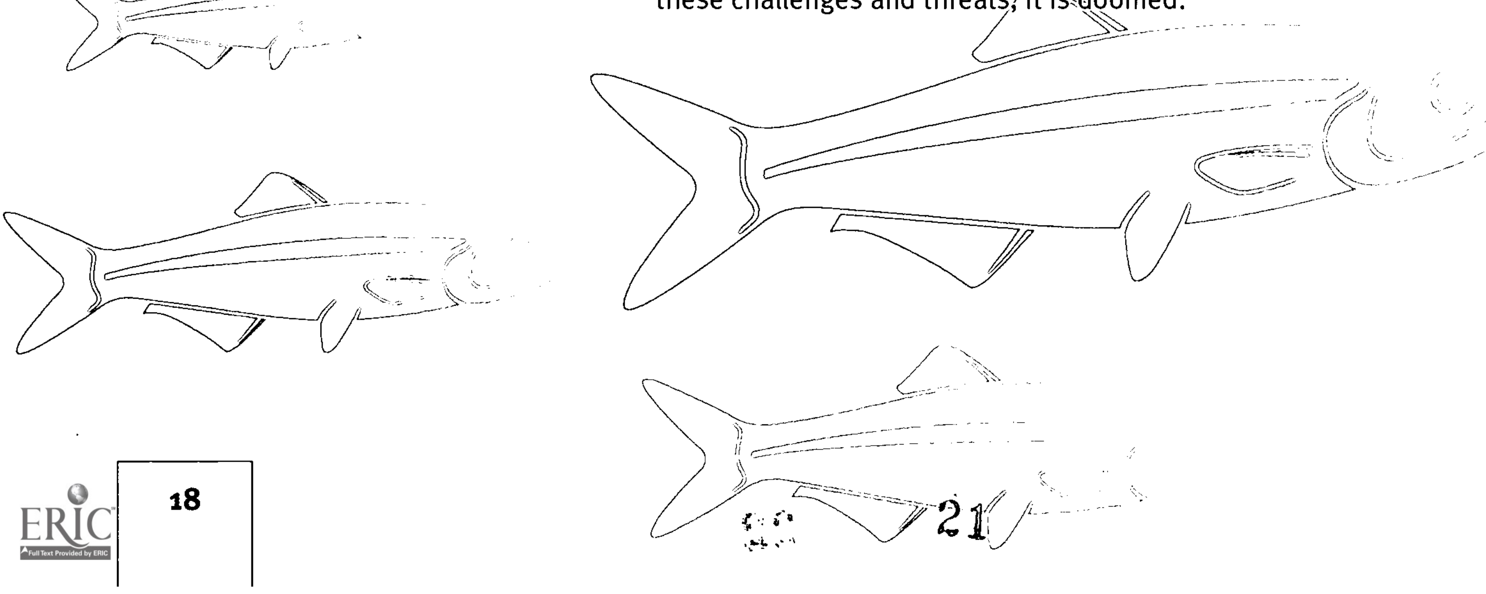
Access the Web resources referenced in this guide—from handouts to video segments to Web features—by going to **pbs.org/evolution** and clicking on Teachers and Students, and then going to the *Evolution Teacher's Guide*, where the material is presented by unit.

For more than 25 years, Robert Vrijenhoek has been returning to the remote hills of the Sonoran Desert in Mexico to study unique populations of minnows. Living side-by-side in the small hillside pools are two different species of minnows, one an asexual reproducer and the other a sexual reproducer. Vrijenhoek has been trying to understand which conditions might favor the sexual minnows and which favor the asexuals. He has noticed that the sexual species tends to predominate in the river where they are 60 percent to 80 percent of the total fish population. Early on Vrijenhoek discovered that 40 percent of all minnows were infected with a parasite that causes black spot disease. Upon closer investigation, he observed an interesting pattern—most of the parasitized fish were asexual reproducers. "Why should they be more parasitized than the sexual reproducers they were living right beside?" he wondered.

At first Vrijenhoek didn't have an answer. Finally it hit him; he was looking at a real world demonstration of the value of sexual reproduction related to an evolutionary hypothesis called the "Red Queen." This hypothesis, suggested by scientist Leigh Van Valen, asked "Does evolution stop when things get perfectly well adapted to their environment?" The answer is no. Evolution is a race like the one in Alice in Wonderland. Alice and the Red Queen are running as fast as they can and Alice says, "Isn't this curious, as fast as we run, nothing seems to change. We're staying in the same place." The Red Queen answers, "Yes, you have to run just as fast as you can to stay in the same place."

Evolution is like that too. We live in a complex world full of parasites, viruses, bacteria, predators, and competitive species—all of them evolving. At the moment any species stops evolving in response to these challenges and threats, it is doomed.





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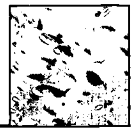
Background



How does the Red Queen hypothesis explain what happens to the minnows? It appears that the asexual minnows have stopped running the race. They are genetic clones of each other and an easy target, especially for a short-lived, quickly evolving parasite. Sexual reproduction creates variability in sexual minnows' offspring so that the parasite cannot easily adapt to them. That is the value of sexual reproduction.

The variability in the sexual minnows is primarily caused by r**ecombination** of chromosomes during sexual reproduction: the random assortment of maternal and paternal chromosomes during the production of sperm and eggs, the random joining of gametes at fertilization, and the crossing over of chromosomes during **meiosis**. Variability can also be caused by **mutations,** but in this example sexual reproduction is the most immediate cause. It is this variability in individuals that allows those best adapted to their environment to survive and reproduce to create future populations. Thus, the sexual minnow population, with its variability, was better adapted to resisting the parasite than the asexual population. This is a clear demonstration of the process of **natural selection** at work—the primary mechanism of evolution in populations.

An interesting change in Vrijenhoek's pools demonstrated another mechanism for evolution. A bad drought dried up the pools and killed most of the minnows. Eventually, the water returned and so did the minnows. They had hopped up stream like trout. But, when Vrijenhoek checked the top pool, he made a surprising discovery. Now the parasites were decimating the sexual minnows and the clones were doing quite well.

Vrijenhoek was stymied. He collected the fish and examined them carefully. He found that the sexual minnow population had lost its genetic variation; it had become inbred and lost its advantage. The sexual fish were clone-like in their variability and since they outnumbered the true clones, they were the biggest targets of the parasites.

To test his idea that reduced variability in the sexual minnow population had caused the turn of events, Vrijenhoek tried an experiment. He brought sexual minnows from a lower pool, where the fish still had genetic variability, up to one of the higher pools. A year later he came back to see what had happened. To his delight, the situation had reversed itself to the normal pattern. Now in fact, the asexual minnows again were more parasite-prone and the genetic variability of the sexual minnows had returned.

The recolonization of the upper pools demonstrated another mechanism for evolution—the **founder effect.** This happens when a small population with limited diversity founds a new population in a new location. Because of this, the limited population of sexual minnows became inbred. This mechanism, unlike natural selection, is random. It is by chance that this particular group of individuals recolonized the upper pools.

Vrijenhoek's work demonstrates key mechanisms for evolution: the genetic variability created by sexual reproduction and the effect of natural selection on individuals within a population. It also showed how a non-selective mechanism, the founder effect, can cause evolution within a small population.

Know More

Web Sites

www.talkorigins.org (In-depth background articles on evolution)

anthro.palomar.edu/synthetic/synth_7.htm (Discussion of natural selection and genotypes, using sickle cell anemia as an example)

bioserve.latrobe.edu.au/vcebiol/cat3/u4a0s2p3.html (Discussion of natural selection and population genetics including founder effect)

www.literature.org/authors/darwin-charles/the-origin-of-species/chapter-04.html (Online version of Darwin's *On the Origin of Species* chapter on natural selection)

Books

Benz, Richard. *Ecology and Evolution: Islands of Change.* Arlington, VA: NSTA Press, 2000.

Dawkins, Richard. *The Blind Watchmaker.* New York: W.W. Norton and Company, Inc., 1996.

Freeman, Scott, and Jon Herron. *Evolutionary Analysis, Second Edition.* Upper Saddle River, NJ: Prentice Hall, 2001.

Quammen, David. *The Song of the Dodo.* New York: Touchstone, 1996.

Ridley, Matt. *The Red Queen: Sex and the Evolution of Human Nature.* New York: Penguin Books, 1993.

Strickberger, Monroe. *Evolution, Third edition.* Boston, MA: Jones and Bartlett Publishers, 2000.

Weiner, Jonathan. *The Beak of the Finch: A Story of Evolution in Our Time.* New York: Vintage Books, Random House, Inc., 1995.

Wilson, Edward O. *The Diversity of Life, College Edition.* New York: W.W. Norton and Company, Inc., 1992.

Zihlman, Adrienne. *The Human Evolution Coloring Book, Second Edition.* New York: HarperCollins Publishers Inc., 2000.

Videos

David Attenborough's "In Paradise" (Wallace's work on sexual selection in birds)

"What Darwin Never Saw" video of Grants' finch research in Galapagos (Kurtis Productions, 1-312-951-5700)

"The Blind Watchmaker" (Films for Humanities and the Sciences, Princeton, NJ)

pbs.org/evolution

SciLinks — THE WORLD'S A CLICK AWAY

www.scilinks.org	Topic	Keyword
	evolution	EG19A
	population genetics	EG19B

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Darwin's Finches

TEACHER'S GUIDE WEB RESOURCES

Evolution Library
"Natural Selection in Real Time"

Handouts
"Grants' Finch Study Data"
"Answer Key to Darwin's Finches"

Evolution Web Feature
"An Origin of Species"

1. Have students look at "Natural Selection in Real Time" (see **TEACHER'S GUIDE WEB RESOURCES**).

2. Review with students the following **postulates** of natural selection:

Individuals within a population vary in their traits.

Some of these variable traits are heritable —passed on to offspring.

More offspring are produced than can survive because of limited resources such as food and nesting sites.

Individuals with advantageous traits will survive and reproduce.

3. Give students a copy of the "Grants' Finch Study Data" handout, covering the period from before to after the drought of 1976–77. Ask students to identify the specific data that supports each postulate and to write a story explaining how the Grants' data supports the occurrence of natural selection of the medium ground finches on Daphne Major.

4. Discuss students' explanations of natural selection of the finches on Daphne Major. Ask:

How do you know that finches' beak depth is heritable?

How did the finch population change from before the drought to after?

Why do you think the average beak depth of the birds increased?

Contrivances

(adapted with permission from an ENSI Lesson)

TEACHER'S GUIDE WEB RESOURCES

Video Resources
"Evolution of the Eye"

1. Give each student a block of wood (1"x2"x2" minimum size to 2"x4"x4," hardwood or softwood) and a screw or nail.

2. Ask them to put the screw or nail as far into the wood as they can without using a typical tool like a screwdriver or hammer. Tell them not to damage any people or property in the process.

3. After five minutes ask who has been successful. Have students share their different strategies. Ask:

- Was that the original intended use for the object they used?
- Did it work as well as a screwdriver or hammer would have worked?

4. Point out that these are all examples of **"contrivances,"** objects used or modified to do something clearly different from their usual use (and usually not as effective).

5. Have students brainstorm examples of traits in humans that are not perfectly adapted for a function (such as joints that wear down easily), including structures that are reduced and have little or no use **(vestigial)**, e.g., wisdom teeth, appendix. Ask:

- How does evolution by natural selection explain these (less than perfect) traits?
- Does natural selection result in perfect adaptations? Give evidence to support your answer.
- How could complex **adaptations** evolve from simple ones? Show students the "Evolution of the Eye" video and discuss.

VIDEO 4 FOR STUDENTS

How Does Evolution Really Work?
This video describes how the process of natural selection operates in populations of rainforest hummingbirds.

Discussion questions:
What are the four components of natural selection?

What determines an individual hummingbird's beak length?

What factors in the environment might select for beak length and shape within hummingbird populations?

How can hummingbird DNA help Dr. Schneider determine the evolutionary history of hummingbirds?

TAKE IT FURTHER

Online Course for Teachers
Session 4: "What Are the Processes for Evolution?"

Evolution Web Features
"Sex and the Single Guppy"
"The Mating Game"
"Microbe Clock"
"The Advantage of Sex"

Evolution Library (URL)
"Red Queen" video segment

Extensions
For an activity that illustrates contrivances in nature: see **www.indiana.edu/~ensiweb/lessons/contriv.html** (orchids and the panda's thumb).

We're Not Perfect

There are examples of natural "contrivances" in living organisms, including humans. Adaptations can often be traced to a structure that served a different function in an ancestral species. For example, an adaptation like the wing of a bat can be traced to an ancestral structure by studies of its embryological development and its homologous anatomy with other vertebrate forelimbs.

Some traits may resemble the original structure in an extinct ancestor, but be less efficient and not perfectly "adapted" for their new job—they are called "adaptive compromises." The location of the larynx in humans is an example of this; its position lower down in the trachea increases our ability to make sounds and communicate, but makes us more vulnerable to choking than other animals since food can become more easily caught in our air path.

(For more on this topic, see Olshansky, S. Jay, Bruce A. Carnes, and Robert N. Butler. "If Humans Were Built to Last," *Scientific American* 284/(March 2001): 50-55.)

Birds, Beaks, and Natural Selection—A Simulation

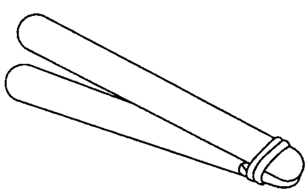
(adapted with permission from "Genetics and the Evolution of Bird Beaks" by Bonnie Chen)

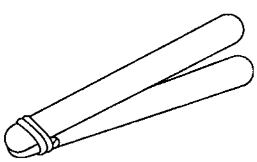
In this simulation, students will gather data to see how beak mutations can influence natural selection.

Objective:
Students will learn about the role of mutations in natural selection and evolution.

Materials:

- *Teaching Evolution Case Studies: Bonnie Chen*—an extended version of this lab (see **TEACHER'S GUIDE WEB RESOURCES**)
- Bird beak materials: wooden tongue depressors (2 per student); 1.5" screws and rubber bands (1 per student)
- Long wooden tongue depressors (2 depressors glued end to end), enough for long beak mutations
- Scissors (1 per team)
- Aquarium or clear plastic container with water level to at least 15 cm (1 per team)
- Simulated food items (4 of each kind/ student) For example: floating (balloons with sugar or sand plus air), middle layer (balloon with sugar or sand, screw, and little air), and sinking food (sugar and screws)
- "Birds, Beaks, and Natural Selection" handout, "Bird Beak Data Sheet" (1 per person) and "Mutation" handout (1 per group) (see **TEACHER'S GUIDE WEB RESOURCES**)





Procedures

Preparation: Watch Teaching Evolution Case Studies: Bonnie Chen *to see how the extended lab worked. Gather and prepare materials and handouts. Glue long wooden tongue depressors ahead of time. Make a bird beak model for students. Make copies of mutation handout; cut into sections and fold.*

1. Group students into three-to-four person teams that represent wading birds within a large population with wild-type beaks made of tongue depressors.

2. Show students the wild-type beak model and ask them to construct similar beaks following the directions on the "Birds, Beaks, and Natural Selection" handout.

3. Explain that students will simulate the wading birds feeding. Instruct them to follow the feeding directions on the "Birds, Beaks, and Natural Selection" handout.

4. Have students compare the average number of food pieces and types of food captured by the team members.

5. After the first set of trials, explain that some birds will undergo mutations in the genes that code for beak length. Have each student pick a folded section of the mutation handout that will explain the kind of mutation and how it will affect the beak size of their offspring.

6. Tell students who received a beak mutation that requires a change to create the new beak for their offspring.

7. Have students now feed as if they were the offspring, Generation 1. Because this time *all members of a group will feed at once* to demonstrate competition for resources, two teams will work together during the feeding of the offspring. While one group feeds, the other group will time and monitor the feeding. Then teams will switch roles. There will be three feeding trials and students will record their feeding data on the "Bird Beak Data Sheet" after each trial.

8. Have students determine the survival rate of their offspring by following directions on the "Bird Beak Data Sheet."

9. Have students compare their data and answer the questions on the "Birds, Beaks, and Natural Selection" handout. Ask teams to share their answers in a class discussion. Ask students if the data turned out as they expected. Have students consider and discuss what variables might have affected their data.

See Assessment Rubric on p. 35.

UNIT 5 HOW DID HUMANS EVOLVE?

Evolution TV Show
"The Mind's Big Bang"

"We had been working really hard that day and were heading back toward camp when one of our teams decided to liven things up by slinging elephant dung at the rest of us," remembered Andrew Hill, a paleontologist on Mary Leakey's team at Laetoli, Tanzania in 1976. "He aimed one at me, and I had to dive out of the way. I ended up flat on my face. I started to rise and saw marks in the ground. I realized they were fossilized raindrops. Then I looked around and saw ancient animal footprints all over the place. We had passed over that ground so many times before that evening, but none of us had noticed a thing. But once we saw the first prints, we could see them everywhere: fossilized tracks of rhino, elephants, antelopes, all sorts of animals." (From Robin McKie, *Dawn of Man*, pp. 10–11.)

Two years later while excavating a set of animal tracks at Laetoli to bring to a nearby museum, more prints were uncovered in the ash—**hominid** footprints that looked incredibly similar to those that people today make as they walk barefoot along a beach. But, these tracks were at least 3.6 million years old.

It was the first time paleontologists had actually found behavioral evidence of bipedalism, the ability to walk upright on two feet, in early hominids. As Ian Tattersall, curator of physical anthropology at the American Museum of Natural History said, "Usually behavior has to be inferred indirectly from the evidence of bones and teeth, and there is almost always argument over inferences of this kind. But at Laetoli, through these footprints, behavior itself is fossilized."

AT A GLANCE

Learning Goals

Know the major characteristics selected for in early hominid evolution—bipedalism and big brains—and the advantages of each

Understand how scientific process is used in paleontology

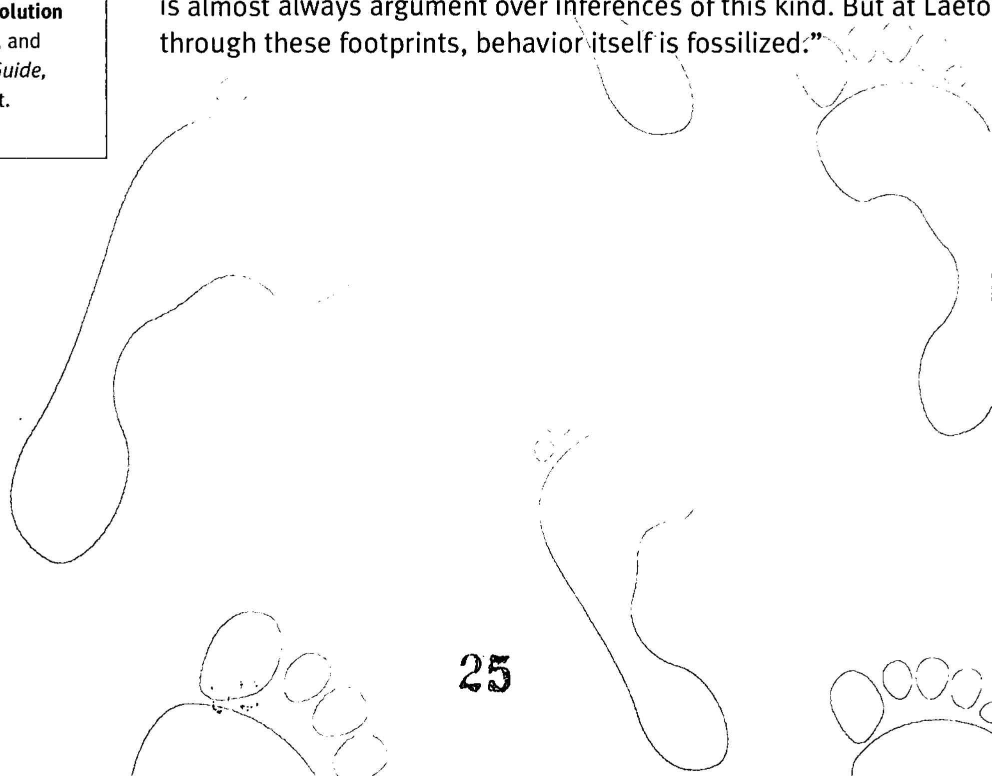
Know hypotheses about evolution of bipedalism

Understand migration patterns of early hominids

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.



BACKGROUND

The footprints at Laetoli are just part of the fossil evidence that depicts human evolution. In 1974, paleontologist Don Johanson's team discovered the skeleton of Lucy, now known as ***Australopithecus afarensis***. Lucy's skeleton was clearly different from other primates. Her knees could lock, her femur slanted inward, and her large toe was in line with her other toes, allowing her to walk upright. The discovery of Lucy surprised paleontologists because although she was unquestionably bipedal, she was remarkably apelike—with a brain about the size of a chimpanzee's.

Bipedalism is a tremendous adaptation for humans and a distinguishing characteristic between humans and other primates. There are many hypotheses about the advantages of bipedalism, including the ability to carry food from place to place, to walk long distances efficiently, the freeing of hands for tool use, and the ability to see further or more clearly during travel. Any or all of these hypotheses may be correct and are being explored by anthropologists today.

A second major adaptive advantage that appeared later in human evolution was an increase in brain size. Fossil evidence allows us to trace the development of the brain as it increased threefold over the last 3 million years. Early hominids such as the **australopithecines** had brains the size of modern apes (400 to 500cc). ***Homo habilis,*** with a brain of about 650cc, was probably the first hominid to make and use stone tools. As brain size increased new capabilities evolved, improving the ability of hominids to adapt to and modify their environments.

Another earlier hominid, ***Homo erectus*** (with an approximate brain size of 900cc), was the first to develop humanlike culture. They used tools, including handaxes, made fires, and were the first hominid species believed to have spread from Africa into Asia. Modern humans, ***Homo sapiens*** (with brains ranging from 1200–1600cc), have even more sophisticated capabilities, probably due to neurological developments within the brain rather than sheer size alone.

Brain size gives only limited information about the internal structure and capabilities of the brain. One later hominid species, ***Homo neanderthalensis,*** had a brain size of over 1300cc, but is considered to have been much less sophisticated than, and possibly even driven to extinction by, modern humans.

The story of human evolution began in Africa, but what was once a minor species, *Homo sapiens,* has now spread to inhabit all continents. Patterns of hominid dispersal are inferred from fossils, which are quite rare, and molecular evidence, which is even more limited. New technologies are allowing paleontologists to reexamine earlier fossil finds. Recently scientists recovered **mitochondrial DNA** from **Neanderthal** skeletons. That molecular evidence differed significantly from modern human DNA and suggests that Neanderthals and modern humans probably did not interbreed.

There are still many questions concerning the shape of the hominid family tree, especially given the ongoing growth in the number of known species as new finds are discovered and added to our already bushy evolutionary tree. In paleontology, as in any scientific field, new evidence continually requires reexamination and revision of old hypotheses.

KNOW MORE

Web Sites

cgi.pbs.org/wgbh/aso/tryit/evolution/ (*Science Odyssey* site on human evolution)

anthro.palomar.edu/tutorials/ (A very comprehensive, up-to-date resource with 23 tutorials, complete with photos and illustrations, on both physical and cultural anthropology from Palomar College)

www.becominghuman.org/ (Institute for Human Origins site with many resources including skull photos and information on anatomy, lineages, culture, and theories of human migration)

cogweb.english.ucsb.edu/EP/Paleoanthropology.html#Genus Line (Site includes photos of comparative skulls)

www.talkorigins.org/faqs/homs/ (Site contains current information about hominid evolution and the fossil evidence)

Books

Boyd, Robert, and Joan Silk. *How Humans Evolved, Second Edition.* New York: W.W. Norton and Company, Inc., 2000.

Jones, Steve (ed.), David Pilbeam (ed.), and Robert Martin (ed.). *The Cambridge Encyclopedia of Human Evolution.* Cambridge University Press, 1995.

Klein, Richard. *The Human Career: Human Biological and Cultural Origins, Second Edition.* Chicago: University of Chicago Press, 1999.

Larsen, Clark Spencer. *Human Origins: The Fossil Record.* Waveland Press, 1998.

Lewin, Roger. *Human Evolution: An Illustrated Introduction, Fourth Edition.* Malden, MA: Blackwell Science, 1999.

McKie, Robin. *Dawn of Man: The Story of Human Evolution.* New York: Dorling Kindersley Publishing, Inc., 2000.

Zihlman, Adrienne. *The Human Evolution Coloring Book, Second Edition.* New York: HarperCollins Publishers Inc., 2000.

Articles

Leakey, Mary. "Footprints in the Ashes of Time." *National Geographic* (April, 1979).

Lovejoy, Owen. "Evolution of Human Walking." *Scientific American*/259 (1988): 118-125.

Tattersall, Ian. "Once We Were Not Alone." *Scientific American* (January 2000): 56–62.

Wade, Nicholas. "Neanderthal DNA Sheds New Light on Human Origins." *The Science Times Book of Fossils and Evolution.* New York: The Lyons Press, 1988: 235-238.

Wilford, John Noble. "The Transforming Leap, from Four Legs to Two." *The Science Times Book of Fossils and Evolution.* New York: The Lyons Press, 1998: 196-203.

Videos

"In Search of Human Origins" *NOVA*, 1994.

pbs.org/evolution

SCILINKS. THE WORLD'S A CLICK AWAY **www.scilinks.org**

Topic	Keyword
human evolution	EG23A

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ONLINE STUDENT LESSON 5: ***How Did Humans Evolve?***
Students find out where humans fit in the larger scope of evolution.

Watch Your Step

(adapted with permission from a Steve Randak lesson)

TEACHER'S GUIDE WEB RESOURCES

Video Resources
"Laetoli Footprints"

Handouts
"Choosing the Best Explanation"
"Laetoli Trackways"
"Teacher Background on Laetoli Trackways"

1. Prepare an overhead transparency of the Laetoli trackways (see **TEACHER'S GUIDE WEB RESOURCES**) and/or hand out one trackway copy (on paper) per team of four students.

2. Ask each team to study and discuss the trackways and record group's answers to the following questions:

What creatures probably made the tracks?

How were these creatures moving (walking, running, etc.)?

What interactions, if any, do the tracks suggest?

What is the evidence for your answers?

3. Conduct a class-wide discussion, sharing different scenarios from each team, and pointing out the evidence for each.

4. Direct students to the seven criteria for "Choosing the Best Explanation" (see **TEACHER'S GUIDE WEB RESOURCES**) to reach a class-wide consensus for the most likely explanation for these trackways.

5. Then, using the Teacher Background information, share with the class what scientists do know about the Laetoli footprints and what inferences they have made.

6. Engage students in a discussion about what footprints can tell us. Do individuals with longer feet also have longer legs? Are people with longer legs taller? Are the number of strides a person takes in a given distance different when he/she is running or walking? Does the person's stride length change with speed? Would the same hold true for early hominids? Can patterns of the present give you clues to patterns in the past?

Chromosome Clues

(adapted with permission from a Larry Flammer lesson)

TEACHER'S GUIDE WEB RESOURCES

Handouts
"Chromosome Clues"
"Chromosome Clues Worksheet"

1. Display an overhead copy of the "Chromosome Clues" diagram. Explain that this diagram shows real chromosomes from a comparison study of three different species. In each set the first chromosome is species A, the second is species B, and the third is species C. Point out that only some of the species C chromosomes have been matched.

2. Model how to compare chromosomes with **inversions**. Use an enlarged overhead copy of chromosomes #4AB and #4C (which is the third chromosome from the left, top row of the box). Show how when #4C is inverted, the region just above and below the **centromere** (constricted region) of #4C matches the same region in #4A.

3. Hand out the "Chromosome Clues" worksheet (one per pair of students) and scissors (one per student). Have students work in pairs to cut apart the 12 chromosomes in the box on the right, then place each in the "C" space where it most closely matches the others.

4. When done, students are to answer the questions on the worksheet. After all teams have completed the discussion questions, reveal the species names on the board or overhead:

Species A is *Homo sapiens* (modern human)
Species B is *Pan troglodytes* (common chimpanzee)
Species C is *Gorilla gorilla* (gorilla)

5. Ask if this new knowledge causes them to reconsider their answers to #6 and #7, and if so, why. Also, ask if anyone correctly predicted the names, and why. Have students discuss their replies to these questions.

6. Explain that analysis of all the chromosomes from these three species reveals that the chromosomes of species A and B are most alike (13 chromosomes are virtually identical); and 9 chromosomes of species A and C are virtually identical. Because of this, scientists recommend that all three species, along with orangutans, be classified in the same family (Hominidae).

VIDEO 5 FOR STUDENTS

Did Humans Evolve?
Fossil and molecular evidence support the evolution of humans from earlier primate ancestors. This video demonstrates some of the evidence for that relationship.

Discussion questions:

What are the occasional mistakes in copying of DNA called and why are they significant for evolutionary change?

How does DNA evidence support the close evolutionary relationship between chimps and humans?

What is the difference between relatedness and descendancy?

What is the relationship between common ancestry and degree of DNA similarities?

What kinds of evidence support the fact that humans have evolved?

TAKE IT FURTHER

Online Course for Teachers
Session 5: "How Did Humans Evolve?"

Evolution Web Features
"Riddle of the Bones"
"Origins of Humankind"
"Is Intelligent Life Inevitable?"

Extensions
Link to **www.nap.edu/readingroom/books/evolution98/** *Teaching about Evolution and the Nature of Science:* Activity 4, "Investigating Common Descent: Formulating Explanations and Models."

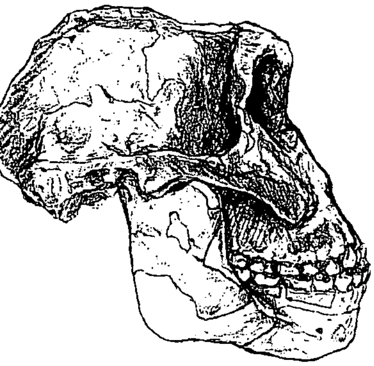
Link to **www.indiana.edu/~ensiweb/lessons/hom.cran.html** for a hominid skull lab.

ERIC Full Text Provided by ERIC

Fossils and Dispersal Patterns of Early Hominids

(adapted with permission from a John Banister-Marx lesson)

Discoveries of fossil hominids around the world have helped scientists determine not only the likely place of origin for the human species, but the path the species took as it spread throughout the world. In this activity, student teams will use representative hominid fossil evidence to determine the possible pattern of dispersal for early hominids.

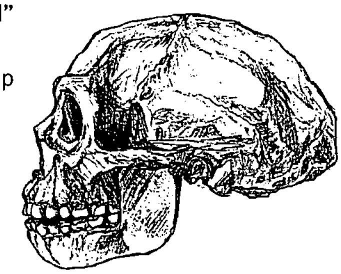


Paranthropus boisei

Objective:
Students use actual data from fossil evidence to determine patterns and to develop/ examine hypotheses that explain the data.

Materials:

- *Evolution* Web features: "Riddle of the Bones" and "Origins of Humankind"
- Small (8.5" x 11") black and white world maps with numerical latitude and longitude axes (see **TEACHER'S GUIDE WEB RESOURCES**) and large world map (approximately 4 x 6 feet or larger)
- Copies of the "Hominid Fossil Skull Drawings" and the "Hominid Fossil Data" handout (see **TEACHER'S GUIDE WEB RESOURCES**), cut into five sections (so that everyone in team will have a copy of their team's data)
- Copies of the "Hominid Migration Discussion Questions" (see **TEACHER'S GUIDE WEB RESOURCES**)
- Colored pencil sets and colored push pins or 1/4" colored adhesive dots (same 4 colors for pencils and pins; box of at least 100 pins)
- Optional: a set of hominid skull casts

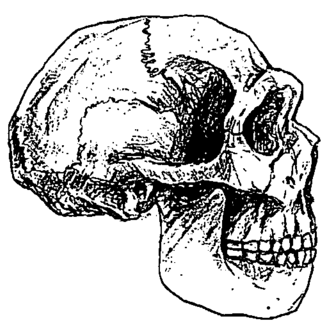


Homo erectus

Procedures

*Preparation: Copy and cut the fossil data sheets into five pieces (by **taxon**), one set of taxa for each team. Students need knowledge of latitude and longitude to plot the locations of the fossils sampled. If time allows, prior to this activity, have students do the related Web features.*

1. Group students into five teams: Australopithecine, *Homo erectus, Homo neanderthalensis,* and two *Homo sapiens* teams.



Neanderthal

2. Introduce the activity by explaining that discoveries of fossil hominids around the world have helped scientists to determine not only a likely origin for the human species, but also a dispersal path throughout the world. The type, dates, and distribution of these representative fossil specimens offer an indication of where humankind's earliest ancestors originated and moved to. Tell students their assignment is to map this distribution.

3. Give each team one part of the fossil evidence from the "Hominid Fossil Data" sheet and colored pencils to match their taxon code (Australopithecines—red, *Homo erectus*—blue, etc.). Point out that the early modern *Homo sapiens* data is divided between two teams because there is more of it. Post the color code key on the board.

4. Tell students that each team will plot its data points by number on a small world map, using its assigned color. Later each team will add their data to the class world map. (Plotting of the 56 points as a class may take 20–30 minutes.) Demonstrate one example of how to plot each coordinate site.

5. Have teams transfer their data to a large world map using colored and/or numbered push pins. Have students check off the fossils on their data sheets as each pin is placed to prevent repeats.

6. Tell students to work in teams to analyze the distribution of fossils on the world map and answer the Hominid Migration Discussion Questions. Have teams discuss their answers.

See Assessment Rubric on p. 35.

ERIC

Unit 6
Why Does Evolution Matter Now?

Evolution TV Shows
"The Evolutionary Arms Race" and "Extinction!"

At a Glance

Learning Goals
Understand how natural selection creates **antibiotic**-resistant bacteria

Recognize the applications of evolutionary principles for medicine, agriculture, and conservation

Understand how science contributes to decisions in the context of society

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.

Siberia once seemed so remote. Not anymore. A drug-resistant strain of tuberculosis (TB) from a Siberian prison has now been tracked to New York City. Using DNA fingerprints, microbiologists at the Public Health Research Institute in New York City have identified over 12,000 different strains of TB from all over the world and are using this information to track the evolution of TB and its spread worldwide. But the strain they recently found in New York is different. It's one of the multi-drug resistant strains from Russia that is very difficult to treat. Russian prisons have become breeding grounds for new multi-drug resistant strains of TB because of crowded conditions, the use of low-quality antibiotics, and inadequate follow-up treatment for prisoners. At least 30,000 Russian inmates now have multi-drug resistant TB.

A disease that had once been considered readily curable, TB has become a considerable foe. TB is on the rise worldwide and now rivals AIDS in the number of lives it claims—between two and three million a year. That's why microbiologists Barry Kreiswirth and Alex Goldfarb of the Public Health Research Institute are focusing on Russian prisons. Kreiswirth says, "What's dramatically affected the spread of TB is our ability to travel. All the strains that are in the Russian prisons among prisoners will eventually come to our doorstep." To meet this challenge head on, Goldfarb has developed a pilot program in the Siberian prison system to change the way that TB is treated, with the hope of preventing the evolution and spread of multi-drug resistant TB.

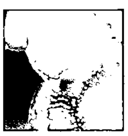
TB is only the tip of the iceberg. Use and misuse of antibiotics, especially in the United States, has spurred the evolution of drug-resistant forms of pneumonia, gonorrhea, and other infectious diseases. Kreiswirth laments, "We've created this problem. Multi-drug resistance is a man-made problem....By developing as many antibiotics as we have over the last 50 years, we've essentially accelerated an evolutionary process. The outcome is that we're going to have more drug-resistant microbes to the point where some of the most dangerous bacteria will not be treatable. We're racing against the microbe everyday, and unfortunately we're losing."

29

Background

Almost daily, evolution-related stories are reported in the press. Some of these reports, like the story about antibiotic-resistant strains of TB, depict serious problems that need to be understood and solved. Clearly, the ubiquitous presence of antibiotics in our environment—antibiotics in animal feed, over-prescribing by doctors, and rampant use in hospitals—has created a crisis in the evolution of drug-resistant **pathogens.** In addition, our bacteria-phobic society has created a potpourri of new antibacterial products from soaps to toys—without considering the possible consequences for bacterial evolution. The presence of substances that select against certain microorganisms will most certainly have an effect on future populations.

At the same time, we regularly see how knowledge gleaned from evolution is providing very practical applications to real-world concerns: finding oil fields by analyzing fossils or understanding how **coevolution** of organisms and their natural parasites contribute to disease and recovery. But sciences such as geology and medicine are not the only arenas where an understanding of evolutionary processes is valuable. Selective breeding of food crops and domesticated animals has created many valuable new varieties and breeds: "burpless" cucumbers, larger tomatoes with fewer seeds, cows that produce ten times more milk than cows of a century ago, and hens that lay four times as many eggs. All have been bred by the process of artificial selection, which is evolution guided by humans.



Perhaps the reports we remember most are those that are controversial. They often deal with biotechnology or conservation and environmental management. For example, efforts to avert plant and wildlife extinction through controls on over-cutting of timber or over-fishing often place conservationists at odds with the lumber or fishing industries.

Genetically engineered foods are another controversial issue. In this case, genes of a desirable trait in one organism are introduced into another organism. There are already many **bioengineered food** crops in the marketplace, many designed to resist pests. Today we have biotech corn that has been engineered to produce a pesticide that kills the corn-borer larvae. These so-called biopesticides are used to improve our food supply and to reduce our dependence on commonly used chemical pesticides. No one knows yet what the long-term consequences of bioengineered foods, both positive and negative, will be. But, we've already seen **genetic drift** of corn pollen from biotech corn to other corn crops. Once the genes are released into the environment via wind and pollinators, there is no getting them back.

Human activities influence evolution in many other ways. During the last 50 years, over 500 species of insects and mites have become resistant to pesticides. Scientists are now using evolutionary principles to slow down the evolution of **pesticide-resistant insects** and to develop alternative methods of pest control. Our destruction of habitats has endangered species and reduced populations so that their genetic diversity has decreased, and so too their ability to adapt to environmental changes. The list goes on and on. Our use of technology is allowing us to alter the evolution of many species besides our own. We have a responsibility to continue to learn how to use our knowledge of evolution wisely to minimize the deleterious effects we have on the **biosphere.**

SciLINKS. THE WORLD'S A CLICK AWAY www.scilinks.org

Topic	Keyword
antibiotic resistance	EG27A
tuberculosis	EG27B

Know More

Web Sites

www.rci.rutgers.edu/~ecolevol/fulldoc.html (Comprehensive report on evolution, science, and society sponsored by the National Science Foundation and the A.P. Sloan Foundation)

www.fda.gov/fdac/features/795_antibio.html (FDA site with article on how antibiotic resistance develops)

www.who.int/emc/amr.html (WHO site on anti-infective drug resistance, including report on resistant TB worldwide)

http://www.healthsci.tufts.edu/apua/Products/pamphlet_01.html (Alliance for the Prudent Use of Antibiotics pamphlet)

www.pbs.org/wgbh/gmfoods/ (Provides articles, interviews, interactive activities, and resources related to *NOVA/Frontline* show: "Harvest of Fear")

www.bio.org/about.html (Offers the Biotechnology Industry Organization's position on food and agricultural biotechnology)

http://www.accessexcellence.org/AB/ (Comprehensive site about biotech including issues and ethics, applications, and careers)

www.ucsusa.org/ (Union of Concerned Scientists' view on genetically engineered crops and reasons for modifications as well as information on antibiotic resistance)

endangered.fws.gov/hcp/index.html (U.S. Fish and Wildlife site on endangered species and habitat conservation)

esa.sdsc.edu/invas3.htm (Ecological Society of America's fact sheet on invasive species)

Books

Chadwick, D. J. and J. Goode, (eds.). *Antibiotic Resistance: Origins, Evolution, Selection and Spread.* John Wiley & Sons, 1997.

Ewald, Paul. *Evolution of Infectious Disease.* London: Oxford University Press, 1996.

Levy, Stuart B. *The Antibiotic Paradox: How Miracle Drugs Are Destroying The Miracle.* New York: Plenum Publishers, 1992.

McHughen, Alan. *Pandora's Picnic Basket: The Potential and Hazards of Genetically Modified Foods.* London: Oxford University Press, 2000.

Nesse, Randolph M., and George C. Williams. *Why We Get Sick: The New Science of Darwinian Medicine.* New York: Vintage Books, 1994.

Palumbi, Stephen R. *The Evolution Explosion: How Humans Cause Rapid Evolutionary Change.* New York: W. W. Norton, 2001.

Wilson, Edward O. *The Diversity of Life—College Edition.* New York: W.W. Norton, 1992.

Articles

"Drug Resistance: The New Apocalypse." Special Issue of *Trends In Microbiology,* Vol. 2, No. 10 (October 1, 1994): 341–425.

Glausiusz, Josie. "The Great Gene Escape." *Discover* (May 1998): 90–97.

Levy, Stuart. "The Challenge of Antibiotic Resistance." *Scientific American,* see www.sciam.com/1998/0398issue/0398levy.html

Schultz, T. "Ants, Plants, and Antibiotics." *Nature* 398 (1999): 747–748.

"Seeds of Change." *Consumer Reports* (September 1999): 41–46.

Specter, Michael. "The Pharmageddon Riddle: Did Monsanto just want more profits, or did it want to save the world?" *The New Yorker* (April 10, 2000): 58–71.

Video

"The Mouse That Laid the Golden Egg." (*Secrets of Life,* David Suzuki)

CD-ROM

Wilson, E.O., and D.L. Perlman. *Conserving Earth's Biodiversity* (Interactive CD ROM) Washington, DC: Island Press, 2000.

pbs.org/evolution

ONLINE STUDENT LESSON 6: *Why Does Evolution Matter Now?*
Students discover how evolutionary theory helps us reap greater harvests, fight disease, and protect the Earth.

Back to the Future to

TEACHER'S GUIDE WEB RESOURCES

Evolution Library

Outside Resources
The Web, old magazines, photographs, drawings

1. Photojournalists can tell vivid stories through photo essays. Ask students to create a pictorial representation (using magazine pictures, photographs, drawings, paintings, video, or downloaded photos) depicting a chain of events impacting a particular species because of changes in the environment (e.g., habitat destruction, introduction of non-native predator, pest, or competitor). Have students base their representation on research and evidence about the species and environmental change they have chosen. Ask students to include a prediction of how the environmental change might affect future evolution of the species.

2. Before students' presentations are final, ask students to pair up and review each other's presentations. Each partner will write or tell a story that describes what he or she sees in the other's work. Then students will compare their partner's story to their intended result and revise their picture if the meaning was unclear.

3. Finally, have students put their pictures on display, presenting to each other key highlights of their story.

TAKE IT FURTHER

Online Course for Teachers
Session 5: "How Did Humans Evolve? Is Evolution Still Happening?"

Web Features
"Microbe Clock"
"Babies by Design"
"A Modern Mass Extinction?"
"The Evolving Enemy"

Extensions
For a decision-making activity related to habitat destruction of rain forests, see **www.accessexcellence.org/AE/AEPC/WWC/1991/rainforest_role.html.**

When An Apple A Day Isn't Enough

TEACHER'S GUIDE WEB RESOURCES

Video Resources
"Cholera: Domesticating Disease"
"Double Immunity"

Evolution Web Feature
"The Evolving Enemy"

1. Have students watch the video segments "Cholera: Domesticating Disease" and "Double Immunity" in the **TEACHER'S GUIDE WEB RESOURCES.**

2. Raise the following questions during a class discussion:

How does an understanding of evolution help doctors manage infectious diseases?

What factors affect the evolution of disease organisms to make them become more virulent?

What is the relationship between HIV resistance and the Black Death?

How have disease organisms coevolved with humans?

VIDEO 6 FOR STUDENTS

Why Does Evolution Matter Now?
Have your students watch this to learn about the transmission of tuberculosis and why the evolution of multi-drug resistant strains of TB in Russia affects us all.

Discussion questions:
How does the misuse of antibiotics affect the evolution of disease-causing bacteria like TB? Describe in terms of natural selection.

What is responsible for the evolution of TB strains that are resistant to multiple drugs?

Why is the Russian prison system considered to be "ground zero" in the fight against TB?

How does globalization affect the transmission of diseases? Give an example that includes the way TB is transmitted.

Evolution in the News

TEACHER'S GUIDE WEB RESOURCES

Evolution Library

Outside Resources
Newspaper and magazine articles

1. Evolution is in the news more often than most people realize. Many news stories based on evolutionary concepts never mention the word *evolution*. Ask students to collect newspaper and magazine articles related to evolution. Before they do, brainstorm the kinds of topics that might be related to evolution so they will know what to look for. Examples include:

- Dinosaur fossils
- Human fossils
- Antibiotic-resistant pathogens
- Habitat destruction
- Oil spills
- Endangered species
- Biotech corn in food
- Genetically modified animals
- Teaching evolution in schools
- Comets and dinosaur extinction
- Domestication of animals
- Breeding new plant varieties

2. Ask each student to select a single article and to write an essay describing how it is related to evolution. Have students make as many links as possible and be specific in their explanations, using the vocabulary of science and evolution (e.g., mutation, evidence, natural selection, variation, common ancestor, etc.).

3. Discuss the articles in class.

4. Post students' articles on a bulletin board and have students cluster articles with like topics and then give the category a title.

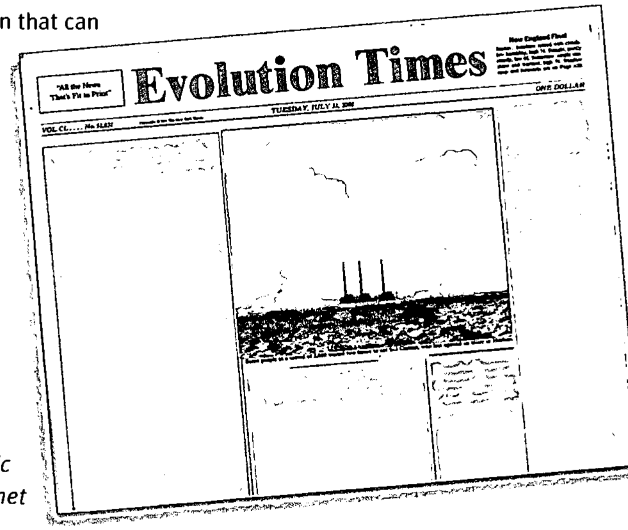
5. Have students create a class concept map of the evolutionary concepts they are finding in the news, showing the links and relationships between topics. (See Online Teacher Course Session 1 for information on creating concept maps.)

6. Have students continue to bring in and discuss evolution articles over a month's time to help them understand the relevance of evolution to their daily lives.

Big Decisions to

Science must work in the context of society. No matter what the scientific evidence, people make decisions based on a variety of criteria, including economics, health, aesthetics, politics, and ethics. These decisions can ultimately affect the evolution of organisms.

Objective:
Students learn different perspectives in a situation that can have possible evolutionary implications.



Materials:
- Resource materials related to topic you choose (See the "Know More" section to begin)
- Copies of the "Evaluating Internet Information" pages available at **http://www.lib.vt.edu/research/libinst/idle/evaluating.html**
- Copies of story "A Sound of Thunder" by Ray Bradbury (in his book *R is for Rocket).* Also available at **http://www.sba.muohio.edu/snavely/415/thunder.htm**

Procedures
Preparation: Gather resources relevant to the topic you choose. Make copies of the "Evaluating Internet Information" pages and "A Sound of Thunder."

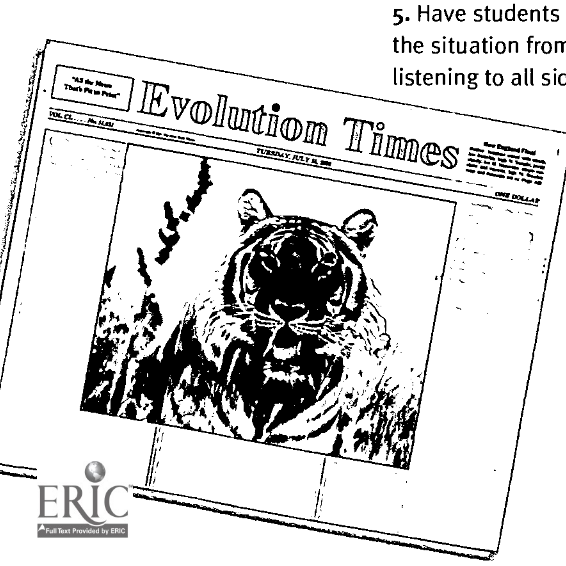
1. Divide students into teams of four or five.

2. Give students a situation (such as pesticide use on lawns or crops, use of biotech foods, habitat destruction and endangered species, introduction of a non-native predator competitor, etc.).

3. Give each student in the team a different role (e.g., environmental activist, farmer, parent with young children, doctor, biotech company CEO, politician). Ask each student to define the point of view for his or her role and to seek out scientific arguments and evidence that might support or refute it.

4. As students find information to support their role's point of view, have them consider the evolutionary, economic, health/medical, environmental, political, and ethical implications of the situation. Students may use the Web, library, and other resources. Give students pointers on evaluating the reliability of sources. (See "Evaluating Internet Information" Web site referenced above.)

5. Have students dress in their roles for a "town meeting" to discuss the implications of the situation from each point of view. Have the town make a decision on the situation after listening to all sides.



6. Ask students to write an article for a newspaper that compares and weighs each point of view. (Or have students write a paper that describes what they learned and what their actual point of view is now.)

7. Have students read the short story "A Sound of Thunder" by Ray Bradbury and have a class discussion about how this story (which describes how the ripple effect can have major impact over time) relates to human intervention and the effect on future evolution.

See Assessment Rubric on p. 35.

ERIC Full Text Provided by ERIC

Unit 7 Dealing with Controversy

***Evolution* TV Show**
"What About God?"

Online Student Lesson 7

Why Is Evolution Controversial?
Students explore why evolution has always been a controversial topic.

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.

"The imposition of a fundamentalist viewpoint about the interpretation of Biblical literature...is in conflict with the perspective on Biblical interpretation characteristically maintained by Biblical scholars and theological schools in the mainstream of Protestantism, Roman Catholicism, and Judaism. Such scholars find that the scientific theory of evolution does not conflict with their interpretation of the origin of life found in Biblical literature."

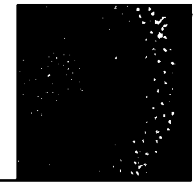
—United Presbyterian Church in the USA (adopted by the General Assembly, 1982)

In the mid-1990s, a conflict over the teaching of evolution shook a small New Hampshire town. A newly elected school board introduced a proposal to teach **creationism** in high school biology classes. Almost overnight, the community became divided over issues of science education, educational quality, religion in the schools, and community values. The national media beat a path to Merrimack, New Hampshire's door. Teachers felt besieged and the school and community divided. In the end, the proposal was withdrawn. A year and a half later, a new school board was elected and science education was back on track. But years later damage from the conflict still lingers.

The story of controversy over the teaching of evolution has been repeated in many different forms and in many different communities since the famous Scopes trial in Tennessee almost 80 years ago. In 1999, the Kansas state school board voted to eliminate evolution from the state science standards. Two years later, after much dissension and discussion, the school board election brought new members and a return of evolution to the Kansas standards.

In 2001, a bill was introduced in the Michigan legislature to allow "teaching the [intelligent] design hypothesis as an explanation for the origin and diversity of life." In one Kentucky community, the superintendent had teachers glue together the pages of the earth science text that presented the **big bang theory** because the story of Genesis was not also included. How frequent are the controversies over evolution and creationism? From 1996 to 1999 the National Center for Science Education tracked an average of one new state or local problem per week.

Despite many decisions by educators, curriculum and standards committees, school boards, and the courts supporting the teaching of evolution, the conflict keeps reemerging. Biology teachers understand their responsibility to develop scientifically literate students who are able to use scientific process to determine patterns and to critically analyze alternative explanations for natural phenomena. They want their students to understand the unifying theme of evolution. But they also want to be respectful of diverse religious beliefs in their community. This is the challenge.



WHAT ARE STRATEGIES FOR PREVENTING POTENTIAL CONFLICT?

Distinguish between science and religion

Help students understand that science and religion are two different ways of knowing the world. They are not necessarily in conflict; they are two perspectives, two different lenses.

Science develops explanations for the natural world by gathering evidence. Explanations that are supported by evidence stand and those that are not are discarded. Science does not include **supernatural** explanations that cannot be tested by scientific processes.

Religion is a system of beliefs based on faith, not bound by evidence from nature. It offers a distinctly different path for understanding the purpose of the natural world and our place in it. It is not better or worse than science, it is just different. As such, people don't need to choose between the two.

Acknowledge that many scientists are religious and that many religions support the teaching of evolution. To see what major religious denominations say about teaching evolution, see the *Science and Faith* Web feature and **www.ncseweb.org/resources/articles/4650_statements_from_religious_orga_3_13_2001.asp**

Understand that the courts distinguish between science and religion in the classroom. It is not a matter of "fairness" to present creationism along with evolution in a science classroom. It is inappropriate to teach religion in a science classroom.

The decisions:

–*Edwards v. Aguillard*, 482 U.S. 578 (1987) (USSC+):
The U.S. Supreme Court has determined it is unconstitutional to require educators who teach evolution to also teach creationism.

–*Epperson v. Arkansas*, 393 U.S. 97 (1968): The U.S. Supreme Court has determined it is unconstitutional to restrict an educator's right to teach evolution.

–*McLean v. Arkansas* Board of Education, 529 F. Supp. 1255 (1982): A Federal Court has determined that a "balanced treatment" statute to give balanced treatment to "creation-science" and "evolution-science" is unconstitutional. It declared that "creation-science" is not science.

Understand that **"intelligent design"** and "**creation science**" arguments ultimately are religious explanations that rely on supernatural causes and thus are outside of science. Become familiar with some of the "creation science" arguments such as "intelligent design" using the lens of science, but don't introduce this examination into your classroom because introducing religion into a science classroom is inappropriate. For information on creationist arguments, see **ncseweb.org/link.asp?category=5**

TEACHER'S GUIDE WEB RESOURCES

Video 7 for Students
"Why Is Evolution Controversial Anyway?" (for teacher's background)

Evolution Web Features
"Science and Faith"
"n FAQ"

Focus on science and scientific literacy

Use precise language. Watch how you use the terms *belief, theory,* and *fact.* Help students distinguish between everyday usage and scientific meanings. People might say "it's just a theory," meaning a guess or hunch. In science, a theory is an overarching explanation that connects many tested hypotheses and observable facts.

One does not "believe" in evolution. It is a theory that scientists accept as the best, current scientific explanation. As a biology teacher, you are asking students to understand evolution and the scientific evidence that supports the theory, not to accept it.

Give students experience using the scientific process. Help students understand that science involves creating testable hypotheses and using critical thinking to analyze and synthesize data. It depends on objective tests of alternative explanations and uses multiple lines of evidence to confirm explanations. Students who understand science process and theory formation are more likely to have respect for the evidence that supports the theory of evolution.

Present scientific information based on the best current evidence. Emphasize that scientific ideas may have varying degrees of support, depending on available evidence. Help students use criteria to assess ideas, such as the veracity and number of lines of independent evidence that support a hypothesis or theory.

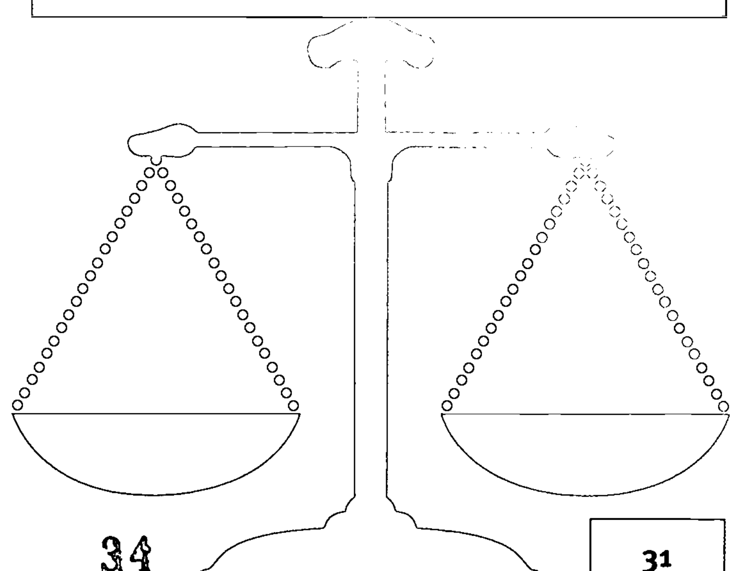
TEACHER'S GUIDE WEB RESOURCES

Video 1 for Students
"Isn't Evolution Just a Theory?"

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

Online Student Lesson
Lesson 1 "What Is the Nature of Science?"

Teacher's Guide
Unit 1: "What Is the Nature of Science?" (pp, 6–9)
Unit 2: "Who Was Charles Darwin?" (pp. 10–13)



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What are strategies for preventing potential conflict?

Be knowledgeable about evolution and dispel misinformation

Recognize that the theory of evolution is considered a cornerstone of biology. Know that the foremost science and science education organizations support the position that evolution is a central unifying concept of biology and should be included as part of K-12 science frameworks and curricula. For position statements on teaching evolution by the National Science Teachers Association, National Association of Biology Teachers, and American Association for the Advancement of Science, go to: **www.nap.edu/readingroom/books/evolution98/** *Teaching about Evolution and the Nature of Science, Appendix C,* and **www.ncseweb.org/resources/articles/33_national_ science_teachers_ass_1_9_2001.asp**

Thoroughly understand the evidence for evolution as well as the current understanding of mechanisms for evolutionary change.

Give examples of how evolution is relevant to our daily lives (such as antibiotic resistance, pest control in agricultural crops, invasive species, etc.). By giving students an understanding of the role of evolution in society, they can be better-informed citizens and decision-makers.

Correct misconceptions about the process of evolution when they occur (e.g., we didn't evolve from apes, but we share a common ancestor with the apes that exist today; evolution happens in populations, not individuals).

Teacher's Guide Web Resources

Online Course For Teachers
Sessions 1 through 7

Online Student Lessons
Lessons 1 through 7

Teaching Evolution Case Studies
"Ken Bingman"
"Marilyn Havlik"
"Bonnie Chen"

Evolution Web Feature
"Evolution FAQ"

Evolution TV Shows
Shows 1 through 7

Create a respectful learning environment

Model respectful listening for students.

Interrupt any putdowns between students and insist on respectful interactions.

Gently redirect questions about religion back to science.

Respect and communicate that students may have a wide range of beliefs about religion and that religious beliefs are a personal issue.

Point out that students are expected only to learn about evolution, not accept it. How they integrate it with their own beliefs is a personal matter.

Accept your "creationist" students without prejudice.

Teacher's Guide Web Resources

Teaching Evolution Case Studies
"Ken Bingman"
"Marilyn Havlik"
"Bonnie Chen"

Use sound pedagogy

Engage students with active learning experiences that develop deeper understanding of key concepts.

Present science as an ongoing process, not final conclusions. In science, change is expected and accepted. If something isn't testable, it isn't science. In science you never prove, only disprove. Therefore, statements such as "evolution hasn't been proven" aren't meaningful; gravity hasn't been "proven" either.

Bring preconceptions to the surface early on as students build knowledge on what they previously understood to be true.

Give students practice applying their knowledge to new situations.

Teacher's Guide Web Resources

Online Course for Teachers
Sessions 6 and 7

Teaching Evolution Case Studies
"Ken Bingman"
"Marilyn Havlik"
"Bonnie Chen"

ERIC

What do you do if conflict emerges?

Get the support of your colleagues, school administration, and school board. You may also get valuable advice from the National Association of Biology Teachers and the National Science Teachers Association. For examples of how different communities handled controversy, see TV Show 7: "What About God?" and *Teaching Evolution Case Studies:* "Dealing with Controversy."

Know the legal prohibitions against the teaching of creationism and legal support for teaching evolution. For a list of significant court decisions regarding evolution and creationism issues, see **www.nap.edu/readingroom/books/evolution98/** *Teaching about Evolution and the Nature of Science, Appendix A,* and **www.ncseweb.org /resources/articles/3333_eight_significant_court_decisi_2_15_2001.asp**

Communicate with parents, administrators, and school boards about the importance of scientific literacy for students. Emphasize that teaching evolution is good science education, and omitting or qualifying it deprives students of an important scientific understanding.

Invite local scientists to explain how they use scientific process in their work and/or how their work relates to evolution.

Teacher's Guide Web Resources

Online Course for Teachers
Session 8: "How Do You Deal with Controversy?"

Teaching Evolution Case Studies
"Dealing with Controversy"

Evolution TV Show
Show 7: "What About God?"

Know More

Web Sites

www.ncseweb.org/ (National Center for Science Education; nationally-recognized clearinghouse for information and advice to keep evolution in the science classroom)

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

http://www.nabt.org/sub/position_statements/evolution.asp (National Association of Biology Teachers position statement about teaching evolution)

www.nsta.org/handbook/evolve.asp (National Science Teachers Association position statement on teaching evolution)

http://ncseweb.org/article.asp?category=7 (An update of Voices)

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pbs.org/evolution

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Topic	Keyword
evolution in the classroom	EG33A

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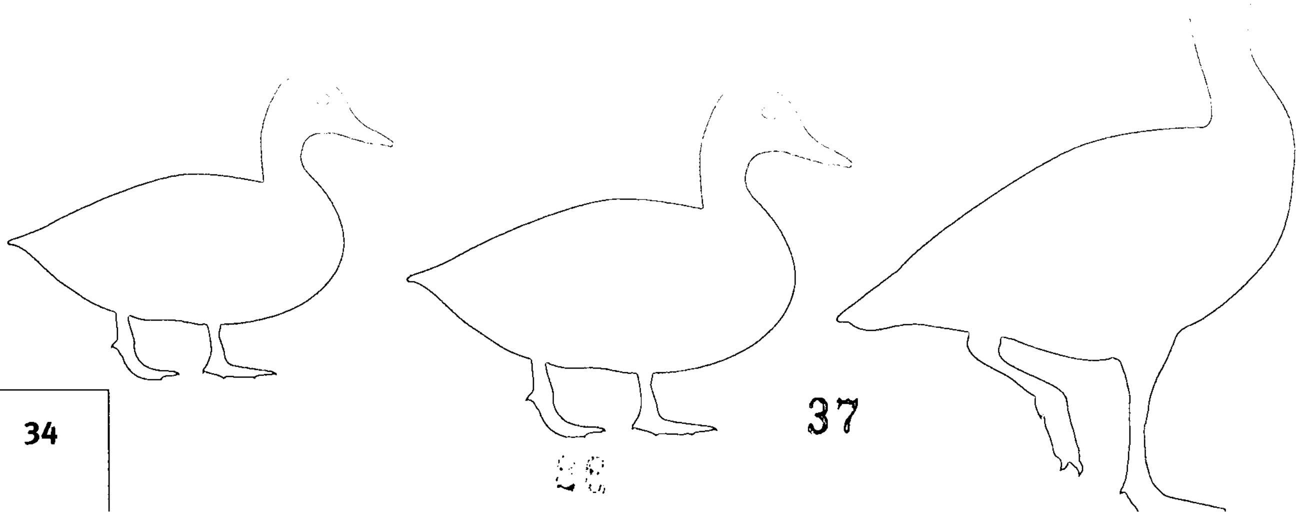
TEACHER'S GUIDE UNIT 1–WHAT IS THE NATURE OF SCIENCE? *In-depth Investigation Assessment Rubric*

	Excellent	Satisfactory	Needs Improvement
Team Process	Work well together to arrange available evidence (puzzle pieces) • Listen to all team members' ideas before deciding on hypotheses • Collaborate well with other teams, listening to others' hypotheses and reasons before revising their own	Work together to arrange puzzle pieces, but have problems discussing the hypotheses reflected by the evidence • Listen to other teams' hypotheses, but not sure how to use information to refine own hypotheses	Don't work together to arrange puzzle pieces • Don't listen to each other's suggested hypotheses and cannot agree on hypotheses • Don't look at other teams' evidence or listen to other teams' hypotheses and reasons
Team Product	Build their puzzle from all available pieces of evidence • Create several hypotheses and refine final hypothesis based on their evidence and collaboration with other teams • Give reasons for their hypothesis.	Build their puzzle from all available pieces • Create hypotheses, but can't explain how their final hypothesis reflects their evidence and evidence of other teams	Don't use all pieces of evidence in their puzzle • Don't create hypotheses that reflect their evidence • Can't give reasons for their hypotheses
Discussion	Answer all guiding questions • Thoroughly understand how the simulation demonstrates the nature of science and what the limitations of the simulation are	Able to answer some of the guiding questions • Partially understand how the simulation demonstrates the nature of science and what the limitations of the simulation are	Don't answer guiding questions • Don't understand how the simulation demonstrates the nature of science and what the limitations of the simulation are

TEACHER'S GUIDE UNIT 2–WHO WAS CHARLES DARWIN? *In-depth Investigation Assessment Rubric*

	Excellent	Satisfactory	Needs Improvement
Team Process	Work well together to design and conduct their experiment • Listen to all team members' ideas • Work well to analyze their data and create a presentation of their results	Work together to design and conduct their experiment • Listen to each other fairly well • Have some problems analyzing their data and creating a presentation of results	Don't work together to design and conduct their experiment • Don't listen to each other's suggestions and cannot agree on a design • Don't understand how to analyze their data and don't work well together to create a presentation of results
Team Product	Team Product Data is well organized • Their conclusions accurately reflect their data • Their visual display and presentation are well done	Data is fairly well organized • Their conclusions don't quite reflect all of their data • Their visual display and presentation are adequate, but not exceptional.	Data is not well organized • They do not know how to use the data to reach a conclusion • Their visual display and presentation are poor
Discussion	Answer all guiding questions • Thoroughly understand how their experiment relates to the colonization of islands by plants • Thoughtfully compare their results with Darwin's	Able to answer some of the guiding questions • Partially understand how their experiment relates to the colonization of islands by plants • They partially understand how their results compare with Darwin's	Don't answer guiding questions • Don't understand how their experiment relates to the colonization of islands by plants • Don't understand how their results compare to Darwin's



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Teacher's Guide Unit 3—What Is the Evidence for Evolution? *In-depth Investigation Assessment Rubric*

	Excellent	Satisfactory	Needs Improvement
Team Process	Work well together, dividing the job of counting amino acid differences in the different animals • Do backup counts and check with each other to confirm counting accuracy, re-counting if there is not a match • Help each other with any questions of understanding or procedure	Work together to divide the job of counting amino acid differences • Do not double check each other • Do not often take the initiative of asking questions or checking each other's understanding	Do not divide the counting task • One or two do the counting, while the others are not engaged • Little or no effort by anyone to get everyone involved or to offer or seek help in understanding
Team Product	Record their counts in the proper spaces on the cladogram • Find that their results are consistent with the counts by other teams	Find and record the differences for all requested animals, but they may not all be confident of the accuracy of all counts, or there may be errors • Do not check this with other teams	Do not get total counts for every animal requested • Cladogram spaces are not all completed
Discussion	Discuss each question before arriving at a consensus response for each question • Any student at random can explain any given answer, and can accurately explain the main points of the objective • All analysis questions are accurately answered	Do not always initiate discussion or seek help when needed • Some students may not be involved in the process • May not be able to explain all answers or the main points of the objective • Able to answer most of the analysis questions	Do not understand the questions • Cannot explain any of the objective items • Do not answer most of the analysis questions

Teacher's Guide Unit 4—How Does Evolution Work? *In-depth Investigation Assessment Rubric*

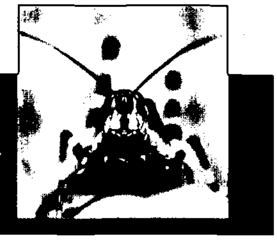
	Excellent	Satisfactory	Needs Improvement
Team Process	Work well together to create beaks and conduct their simulation • Work well to analyze their data	Work together to create beaks and conduct their simulation • Have some problems analyzing their data	Don't work together to create their beaks and conduct their simulation • Don't understand how to analyze their data
Team Product	Data is well organized • Their conclusions accurately reflect their data	Data is fairly well organized • Their conclusions don't quite reflect all of their data	Data is not well organized • They do not know how to use the data to reach a conclusion
Discussion	Thoroughly understand how their simulation relates to natural selection and how it is similar and different than the real world	Partially understand how their simulation relates to natural selection and how it is similar and different than the real world	Don't understand how their simulation relates to natural selection and how it is similar and different than the real world

Teacher's Guide Unit 5—How Did Humans Evolve? *In-depth Investigation Assessment Rubric*

	Excellent	Satisfactory	Needs Improvement
Team Process	Work well together to map the data • Work well to analyze the data and answer discussion questions • Listen to all team members' ideas	Work together fairly well to map the data • Have some problems analyzing the data and answering discussion questions • Listen to each other fairly well	Don't work together to map the data • Don't understand how to analyze the data and answer the discussion questions • Don't listen to each other's suggestions
Team Product	Data is mapped accurately • Their conclusions accurately reflect the data	Data is mapped fairly accurately • Their conclusions don't quite reflect the data	Data is not mapped accurately • They do not understand how to interpret the data
Discussion	Answer all discussion questions • Thoroughly understand how to interpret hominid migration from the fossil data	Able to answer some of the discussion questions • Partially understand how to interpret hominid migration from the fossil data	Don't answer discussion questions • Don't understand how to interpret hominid migration from the fossil data

Teacher's Guide Unit 6—Why Does Evolution Matter Now? *In-depth Investigation Assessment Rubric*

	Excellent	Satisfactory	Needs Improvement
Team Process	Excellent research using many reliable resources	Research includes a few good resources	Poor research, relying on few sources whose reliability is questionable
Team Product	Provide excellent information from assigned point of view • Do excellent job staging and running Town Meeting • Article is well written and offers conclusions based on the variety of information presented	Provide adequate information from assigned point of view • Do fairly good job staging and running Town Meeting • Article is fairly well done and is mostly based on information presented	Doesn't provide information from assigned point of view • Do poor job staging and running Town Meeting • Article is poorly written and does not reflect information in class presentations
Discussion	Thoroughly understand different points of view about the topic and can discuss the pros and cons of each position	Partially understand different points of view and can discuss the pros and cons of some positions	Don't understand the different points of views and cannot intelligently discuss the pros and cons of different positions



adaptation
any heritable characteristic of an organism that improves its ability to survive and reproduce in its environment; also used to describe the process of genetic change within a population, as influenced by natural selection

amino acid sequence
a series of amino acids, the building blocks of proteins, usually coded for by DNA (exceptions are those coded for by the RNA of certain viruses, such as HIV)

antibiotic resistance
a heritable trait in microorganisms that enables them to survive in the presence of an antibiotic

artifact
an object made by humans that has been preserved and can be studied to learn about a particular time period

artificial selection
the process by which humans breed animals and cultivate crops to ensure that future generations have specific desirable characteristics; in artificial selection, breeders select the most desirable variants in a plant or animal population, and selectively breed them with other desirable individuals

australopithecine
a group of bipedal hominid species belonging to the genus *Australopithecus* that lived between 4.2 and 1.4 mya

Australopithecus afarensis
an early australopithecine species that was bipedal; known fossils date between 3.6 and 2.9 mya (for example, Lucy)

big bang theory
theory that states that the universe began in a state of compression to infinite density and that in one instant all matter and energy began expanding and they have continued expanding ever since

bioengineered food
food that has been produced through genetic modification using techniques of genetic engineering

biogeography
the study of patterns of geographical distribution of plants and animals across the Earth, and of the changes in those distributions over time

biosphere
the part of the Earth and its atmosphere capable of sustaining life

Cenozoic
the era of geologic time from 65 mya to the present, a time when the modern continents formed and modern animals and plants evolved

centromere
a point on a chromosome that is involved in separating the copies of the chromosome produced during cell division; during this division, paired chromosomes look somewhat like an X, and the centromere is the constriction in the center

cladogram
a branching diagram that illustrates hypotheses about the evolutionary relationships among groups of organisms; cladograms can be considered as a special type of phylogenetic tree that concentrates on the order in which different groups branched off from their common ancestors

coevolution
evolution in two or more species, such as a predator and its prey, or a parasite and its host, in which evolutionary changes in one species influence the evolution of the other species

contrivance
an object or characteristics used or modified to do something clearly different from its usual use

creationism
the religious doctrine that all living things on Earth were each created separately, in more or less their present form, by a supernatural creator, as stated in the Bible; the precise beliefs of different creationist groups vary widely

"creation science"
an assortment of many different, non-scientific attempts to disprove evolutionary theory, and efforts to prove that the complexity of living things can be explained only by the action of an "intelligent designer"

DNA base sequence
a chain of repeating units of deoxyribonucleotides (adenine, guanine, cytosine, thymine) arranged in a particular pattern

enzyme
a protein that acts as a catalyst for chemical reactions

Eocene
from 54 to 38 mya, the second oldest of the five major epochs of the Tertiary Period; it is often known for the rise of mammals

evolution
in general terms, biological evolution is the process of change by which new species develop from preexisting species over time; in genetic terms, evolution can be defined as any change in the frequency of alleles in populations of organisms from generation to generation

fact
a natural phenomenon repeatedly confirmed by observation

fossil
most commonly, an organism, a physical part of an organism, or an imprint of an organism that has been preserved from ancient times in rock, amber, or by some other means; new techniques have also revealed the existence of cellular and molecular fossils

founder effect
the loss of genetic variation when a new colony is formed by a very small number of individuals from a larger population

genetic drift
changes in the frequencies of alleles in a population that occur by chance, rather than because of natural selection

genetic engineering
removing genes from the DNA of one species and splicing them into the DNA of another species, using the techniques of molecular biology

half-life
the amount of time it takes for one half of the atoms in a radioactive isotope to decay to a stable form

hominids
members of the family Hominidae, which includes only modern humans and their ancestors

Homo erectus
a species of hominid that lived between 1.8 mya and 300,000 years ago; the first *Homo* species to migrate beyond Africa

Homo habilis
a species of hominid that lived between 1.9 and 1.8 mya, the first species in genus *Homo*, and the first hominid associated with clear evidence of tool manufacture and use

Homo neanderthalensis
a species of hominid that lived between 150,000 and 30,000 years ago in Europe and Western Asia, originally thought to be a geographic variant of *Homo sapiens*, now generally accepted to be a distinct species

Homo sapiens
modern humans, evolved to present form about 100,000 years ago

homologous structures
structures shared by a set of related species because they have been inherited, with or without modification, from their common ancestor (for example, the bones that support a bat's wing are similar to that of a human arm)

hypothesis
an explanation of one or more phenomena in nature that can be tested by observations, experiments, or both; in order to be considered scientific, a hypothesis must be falsifiable—which means that it can be proven to be incorrect

intelligent design
the non-scientific argument that complex biological structures have been designed by an unidentified supernatural or extra-terrestrial intelligence

inversion
a segment of a chromosome that has been turned around so that the order of the nucleotides in the DNA is reversed (specifically, where a small portion of a chromosome is upside down compared to the same region of an otherwise identical chromosome)

isotope
an atom that shares the same atomic number and position as other atoms in an element but has a different number of neutrons and thus a different atomic mass

law
a description of how a natural phenomenon will occur under certain circumstances

meiosis
a type of cell division that occurs only in the reproductive cells of organisms, during which paired chromosomes are separated into different daughter cells, reducing the number of chromosomes in those daughter cells by half

mitochondrial DNA
DNA found in the mitochondrion, a small round body found in most cells, that produces enzymes to convert food to energy; because mitochondria are generally carried in egg cells but not in sperm, mitochondrial DNA is passed to offspring from mothers, but not fathers

mutation
a change in genetic material that results from an error in replication of DNA; mutations can be beneficial, harmful, or neutral

natural selection
a process by which the forms of organisms in a population that are better adapted to their local environment increase in frequency relative to less well-adapted forms over one or more generations

Neanderthal
a hominid, similar to but distinct from, modern humans, that lived in Europe and Western Asia about 150,000 to 30,000 years ago

paleoanthropologist
someone who uses fossil evidence to study early human ancestors

paleontologist
a scientist who studies fossils to better understand life in prehistoric times

pathogen
a microorganism that causes disease

pesticide-resistant insects
insects with the ability to survive and reproduce in the presence of pesticides; these resistant variants increase in frequency over time

phylogeny
the study of ancestral relations among species, often illustrated with a "tree of life" branching diagram, which is also known as a phylogenetic tree

postulate
a basic principle

radiometric dating
a dating technique that uses the decay rate of radioactive isotopes to estimate the age of an object

recombination
the appearance in offspring of different gene combinations than are present in either parent; in most organisms whose cells have a nucleus, recombination occurs because of two processes that occur during the production of eggs and sperm; one process involves the random sorting of chromosomes into eggs and sperm; the other process, called crossing-over, involves exchange of DNA between chromosomes

relative dating
the process of ordering fossils, rocks, and geologic events from oldest to youngest; because of the way sedimentary rocks form, lower layers in most series are older than higher layers, making it possible to determine which fossils found in those layers are oldest, and which are youngest; by itself, relative dating cannot assign any absolute age to rocks or fossils

science
a way of knowing about the natural world based on observations and experiments that can be confirmed or disproved by other scientists using accepted scientific techniques

species
usually defined as a group of organisms capable of mating and producing fertile offspring with one another

supernatural
relating to phenomena that cannot be described by natural laws, cannot be tested by scientific methodology, and are therefore outside the realm of science

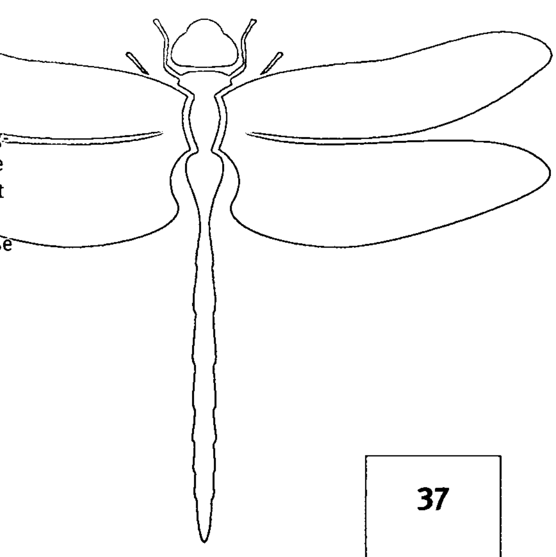
symbiosis
a relationship of mutual benefit between two organisms that live together

taxon
a group in biological classification such as species, genus, family, order, class, and phylum

theory
a well-substantiated explanation of some aspect of the natural world that typically incorporates many confirmed observations, laws, and successfully verified hypotheses

transitional fossil
a fossil, or group of fossils, representing a series of similar species, genera, or families, that link an older group of organisms to a younger group; often, transitional fossils combine some traits of older, ancestral species with traits of more recent species (for instance, a series of transitional fossils documents the evolution of fully aquatic whales from terrestrial ancestors)

vestigial
structures that have been greatly reduced in size and function over evolutionary time to the extent that they now appear to have little or no current function



Evolution Series Index

The entire *Evolution* TV series is available on home video on seven videocassettes, with a total viewing time of eight hours. For your convenience, we have described the series by program segments. You may want to use specific segments to focus classroom discussions and activities. To find a segment, queue up to the approximate starting time and look for the starting image.

Show One: Darwin's Dangerous Idea (two hours)

Summary: Introduction to Charles Darwin and his theory of evolution by natural selection.

Segment 1
Length: 4 min.
Starting image: Darwin and Fitzroy lead horses
Ending image: portrait of Darwin
Commentary from Daniel Dennet, Stephen Jay Gould, and James Moore.

Segment 2
Approximate starting time: 4 min.
Length: 6 min.
Starting image: London, ships at dock
Ending image: Darwin talking to Fitzroy
Darwin returns from voyage; tries to piece together data; discovers he has 13 species of finches.

Segment 3
Approximate starting time: 10 min.
Length: 7 min., 30 sec.
Starting image: Darwin and Erasmus at Geological Society
Ending image: Darwin drawing tree of life
Darwin encounters controversy at the Geological Society; Owen speaks of divine will.

Segment 4
Approximate starting time: 17 min., 30 sec.
Length: 3 min.
Starting image: river in Ecuador
Ending image: hummingbird
Biologist Chris Schneider studies rainforest biodiversity; ornithologist Tom Smith studies the beaks of hummingbirds.

Segment 5
Approximate starting time: 20 min., 30 sec.
Length: 1 min., 30 sec.
Starting image: tree of finches
Ending image: James Moore
Stephen Jay Gould and James Moore emphasize the importance of Darwin's idea that all finches are related to a common ancestor finch.

Segment 6
Approximate starting time: 22 min.
Length: 7 min., 30 sec.
Starting image: rainforest
Ending image: fog over mountains
Chris Schneider and Tom Smith compare animals in the mountains to those found in lowland rainforest; hummingbirds hibernate at night and have different beak lengths.

Segment 7
Approximate starting time: 29 min., 30 sec.
Length: 9 min.
Starting image: arrow hitting target
Ending image: Darwin in chair
Darwin courts Emma; talks about artificial and natural selection; reads Malthus' essay about population.

Segment 8
Approximate starting time: 38 min., 30 sec.
Length: 1 min., 30 sec.
Starting image: James Moore
Ending image: beetles
Discusses beetles' protective coloring as example of natural selection.

Segment 9
Approximate starting time: 40 min.
Length: 11 min., 30 sec.
Starting image: HIV cells
Ending image: man swimming
Jeff Gustavson and Clarence Johnson have been battling HIV for years; virus evolves drug-resistance; Dr. Veronica Miller found that if patient went off drugs, virus returned to wild-type, then she could attack the virus with drugs.

Segment 10
Approximate starting time: 51 min., 30 sec.
Length: 6 min., 30 sec.
Starting image: man pushing wheelbarrow
Ending image: Emma looking down
Erasmus tries to convince Darwin to publish; Owen has assembled sloth and thinks divine creator made blueprint.

Segment 11
Approximate starting time: 58 min.
Length: 11 min.
Starting image: James Moore
Ending image: trees outside cottage
Kenneth Miller discusses how the intricacy of the eye was considered proof of God; Dan-Eric Nilsson studies eye evolution, models different types of eyes.

Segment 12
Approximate starting time: 69 min.
Length: 12 min.
Starting image: Darwin looking through microscope
Ending image: Annie's gravestone
Darwin studying barnacles, assembling evidence for theory; Annie becomes ill and dies; Darwin refuses to enter church, cannot believe a God could exist that would kill an innocent child.

Segment 13
Approximate starting time: 81 min.
Length: 5 min.
Starting image: children singing
Ending image: James Moore
Kenneth Miller, author of *Finding Darwin's God*, believes religion compatible with evolution.

Segment 14
Approximate starting time: 86 min.
Length: 13 min.
Starting image: Darwin at party
Ending image: Darwin with Erasmus
Owen presents views on human superiority; Huxley champions Darwin's ideas; Darwin publishes a joint paper with Wallace; Darwin publishes *On the Origin of Species*.

Segment 15
Approximate starting time: 99 min.
Length: 4 min., 30 sec.
Starting image: man with beard
Ending image: DNA from different animals
Creationists against evolution because believe human soul at stake; DNA now used to show comparisons between animals.

Segment 16
Approximate starting time: 103 min., 30 sec.
Length: 4 min.
Starting image: Chimp Dr. license plate
Ending image: river
Psychologist Sally Boysen compares developmental milestones in chimps and humans.

Segment 17
Approximate starting time: 107 min. 30 sec.
Length: 2 min.
Starting image: church in England
Ending image: Darwin's face
Darwin died in 1882 and was interred at Westminster Abbey.

Show Two: Great Transformations (one hour)

Summary: Examines the history of life on Earth, including the role of transitional fossils in deciphering the fossil record.

Segment 1
Length: 2 min., 30 sec.
Starting image: pole vaulter
Ending image: dolphin
How did each creature alive today evolve so differently?

Segment 2
Approximate starting time: 2 min. 30 sec.
Length: 11 min., 30 sec.
Starting image: sunrise on mountains
Ending image: whale bones
Paleontologist Phil Gingerich found a fossil in Pakistan that looked like part of a wolf-like creature but had the inner ear of a whale; some skeletons have been found of whales with legs.

Segment 3
Approximate starting time: 14 min.
Length: 3 min.
Starting image: dolphins
Ending image: river bank
Frank Fish studies how mammals swim—fish flex their spine from side to side and mammals move it up and down.

Segment 4
Approximate starting time: 17 min.
Length: 6 min.
Starting image: Volvo on road
Ending image: fish fossil
Limbs developed first on aquatic creatures; Jenny Clack found a fish with fingers.

Segment 5
Approximate starting time: 23 min.
Length: 3 min.
Starting image: Neil Shubin
Ending image: fossil
Evolution is not a goal-directed process; it's a tinkering.

Segment 6
Approximate starting time: 26 min.
Length: 5 min.
Starting image: fossil
Ending image: fossil
During the Cambrian explosion, many diverse animals suddenly appear on Earth; in 1913, Charles Walcott found 540 million-year-old sea creatures in the Burgess Shale.

Segment 7
Approximate starting time: 31 min.
Length: 13 min., 30 sec.
Starting image: Shubin
Ending image: Levine
Bill McGinnis and Mike Levine found the "master switch," a gene turned on in a band in an early embryo.

Segment 8
Approximate starting time: 44 min., 30 sec.
Length: 10 min.
Starting image: people at café
Ending image: Shubin
Liza Shapiro studies the movement of living primates; chimpanzees share 99% of their DNA with humans; a series of chance coincidences led to human bipedalism.

Show Three: Extinction! (one hour)

Summary: Traditionally, extinction and evolution have been in balance. Today, extinction far outpaces the evolution of new species.

Segment 1
Length: 2 min.
Starting image: forest
Ending image: debris
Extinction is the termination of a species; an average lifetime for a species is 4 million years.

Segment 2
Approximate starting time: 2 min.
Length: 4 min., 30 sec.
Starting image: bird flying
Ending image: animation sequence
There have been five mass extinctions; geologist Peter Wards studies mass extinctions.

Segment 3
Approximate starting time: 6 min., 30 sec.
Length: 11 min.
Starting image: open plain
Ending image: wheat in sunset
End of Permian, all but a few species became extinct; Mike Novacek studies small mammals that lived alongside dinosaurs and survived the mass extinction.

Segment 4
Approximate starting time: 17 min., 30 sec.
Length: 3 min., 30 sec.
Starting image: asteroid
Ending image: footprints in ash
In the K-T event, an asteroid crashed on earth and dinosaurs became extinct but mammals survived.

Segment 5
Approximate starting time: 21 min.
Length: 1 minute
Starting image: people boarding boat
Ending image: barges on river
6 billion people inhabit the earth; current rate of extinction now 100 times greater than normal.

Segment 6
Approximate starting time: 22 min.
Length: 2 min., 30 sec.
Starting image: fog over trees
Ending image: raft down river
Alan Rabinowitz of the Wildlife Conservation Society studies total number of species in Kaeng

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Krachan National Park in Thailand.

Segment 7
Approximate starting time: 24 min., 30 sec.
Length: 10 min.
Starting image: animated sun
Ending image: men walking through woods
The presence of healthy carnivores, at the top of the food chain, indicates a healthy forest; number one cause of extinction is habitat destruction by humans.

Segment 8
Approximate starting time: 34 min., 30 sec.
Length: 5 min.
Starting image: shoreline of Hawaii
Ending image: tree close-up
Number two cause of extinction is invasive species; paleontologist David Burney studies the biological invaders brought to Hawaii by the Polynesians.

Segment 9
Approximate starting time: 39 min., 30 sec.
Length: 3 min., 30 sec.
Starting image: plane
Ending image: sky over water
Modern transportation has increased rate of species invasion.

Segment 10
Approximate starting time: 43 min.
Length: 2 min., 15 sec.
Starting image: sky
Ending image: face of scientist
Weed species are mobile, adaptive, flexible; humans are the most successful weeds of all time.

Segment 11
Approximate starting time: 45 min., 15 sec.
Length: 5 min., 15 sec.
Starting image: North Dakota farm
Ending image: truck driving away
Sy Kittleston has introduced the flea beetle, a non-native species, to his farm to keep an invading weed in check.

Segment 12
Approximate starting time: 50 min., 30 sec.
Length: 4 min.
Starting image: fog over trees
Ending image: room of animal skulls
Rabinowitz's team found photos of carnivores; maybe it's still possible to avoid a mass extinction.

Show Four: Evolutionary Arms Race (one hour)

Summary: Predators and their prey evolve alongside one another in an escalating arms race.

Segment 1
Length: 1 min., 50 sec.
Starting image: Moscow traffic
Ending image: crowd
Idea of evolutionary arms race; disease in Russian prisons released to population at large.

Segment 2
Approximate starting time: 1 min., 50 sec.
Length: 6 min., 30 sec.
Starting image: Oregon landscape
Ending image: newt in tank
Edmund Brodie, Jr. and his son study a poisonous newt in an arms race against a garter snake.

Segment 3
Approximate starting time: 8 min., 20 sec.
Length: 3 min.
Starting image: E.O. Wilson
Ending image: pills on conveyor belt
Predator and prey relationship drives evolution; humans' only predator since civilization is infectious disease.

Segment 4
Approximate starting time: 11 min., 20 sec.
Length: 14 min., 30 sec.
Starting image: cell door
Ending image: multiplying microbes
Antibiotic-resistant strains of tuberculosis reign in crowded Russian prisons; microbiologist Alex Goldfarb trying to change the way TB treated.

Segment 5
Approximate starting time: 25 min., 50 sec.
Length: 5 min., 30 sec.
Starting image: man walking dog
Ending image: man walking away from camera
Evolution can domesticate a disease.

Segment 6
Approximate starting time: 31 min., 20 sec.
Length: 7 min.
Starting image: cheetah fur
Ending image: lion's face
Geneticist Stephen O'Brien studies feline resistance to immunodeficiency virus; O'Brien found mutation in humans that protects against HIV infection.

Segment 7
Approximate starting time: 38 min., 20 sec.
Length: 3 min.
Starting image: E.O. Wilson
Ending image: girl wearing glasses
Introduces mutualistic symbiosis.

Segment 8
Approximate starting time: 41 min., 20 sec.
Length: 9 min.
Starting image: tropical forest
Ending image: "antibacterial" label
Ted Schultz and Ulrich Mueller studying leafcutter ants in the Amazon rainforest; grad student Cameron Currie found alliance of four organisms.

Segment 9
Approximate starting time: 50 min., 20 sec.
Length: 4 min.
Starting image: doctor in hospital
Ending image: boy leading cows
Pediatrician Erika Von Mutius treats allergies and asthma; compares children of farmers and nonfarmers.

Segment 10
Approximate starting time: 54 min., 20 sec.
Length: 1 minute, 30 sec.
Starting image: crowd
Ending image: crowd
E.O. Wilson: mistake for us to separate ourselves from all other organisms.

Show Five: Why Sex? (one hour)

Summary: Examines how sex evolved as the means of reproduction.

Segment 1
Length: 2 min.
Starting image: molting peacock
Ending image: walrus couple in sunset
Prologue outlines topic of sexual selection.

Segment 2
Approximate starting time: 2 min.
Length: 5 min.
Starting image: Texas landscape
Ending image: Meredith Small
Jerry Johnson studies a type of lizard that clones itself.

Segment 3
Approximate starting time: 7 min.
Length: 7 min., 15 sec.
Starting image: Mexican village
Ending image: men playing basketball
Robert Vrijenhoek studies a minnow that uses both sexual and asexual reproduction; sex generates variability among offspring and is the best defense against evolving enemies.

Segment 4
Approximate starting time: 14 min., 15 sec.
Length: 3 min.
Starting image: single-celled organisms
Ending image: flying peacock
Sex evolved from a random encounter of two single-celled creatures; males and females evolved with sperm and eggs.

Segment 5
Approximate starting time: 17 min., 15 sec.
Length: 8 min.
Starting image: Marion Petrie
Ending image: Katharine Hepburn
Males compete for the right to mate with females and females choose the mate with the best genes; Petrie has found that peahens choose peacocks with the largest tails.

Segment 6
Approximate starting time: 25 min., 15 sec.
Length: 5 min., 30 sec.
Starting image: man walking in woods
Ending image: jacana chick
Stephen Emlen studies songbirds; 40% of chicks do not belong to the father raising them; female Wattled Jacanas have taken on a male role.

Segment 7
Approximate starting time: 30 min., 45 sec.
Length: 8 min., 30 sec.
Starting image: Tree of Life animation
Ending image: animation of early humans
Chimpanzees and bonobos have evolved very different social systems due to an ancient drought; chimps make war and bonobos make love.

Segment 8
Approximate starting time: 39 min., 15 sec.
Length: 7 min.
Starting image: Meredith Small
Ending image: masculine computer image
Evolutionary psychologists study how human evolutionary history affects the way we think today; Victor Johnston studies the correlation between beauty and fertility.

Segment 9
Approximate starting time: 46 min., 15 sec.
Length: 5 min., 30 sec.
Starting image: men walking on campus
Ending image: Picasso painting
Geoffrey Miller believes that artistic expression comes from a drive to impress the opposite sex.

Segment 10
Approximate starting time: 51 min., 45 sec.
Length: 2 min., 30 sec.
Starting image: cranes courting
Ending image: family
The ancestors who had the most surviving offspring were those who found sex to be fun and parenting rewarding.

Show Six: The Mind's Big Bang (one hour)

Summary: Examines the evolution of the human mind.

Segment 1
Length: 2 min., 30 sec.
Starting image: flashlight beam in cave
Ending image: people running past sunset
Archaeologist Randy White studies cave paintings; modern humans developed communication and culture.

Segment 2
Approximate starting time: 2 min., 30 sec.
Length: 1 minute
Starting image: skull
Ending image: Rick Potts
Rick Potts studies stone tools from the Great Rift Valley in East Africa; hominids made the same stone axes for about 1 million years.

Segment 3
Approximate starting time: 4 min., 15 sec.
Length: 2 min.
Starting image: large rocks and trees
Ending image: group of modern humans
The humans of about 40,000 years ago would be recognizable to us, in terms of both behavior and physical appearance.

Segment 4
Approximate starting time: 6 min., 15 sec.
Length: 30 sec.
Starting image: Steven Pinker
Ending image: world map showing migration routes
Mary Stiner and Steve Kuhn have found shell beads from 43,000 years ago; the beads show the path of migration.

Segment 5
Approximate starting time: 6 min., 45 sec.
Length: 3 min.
Starting image: person sitting at table with laptop
Ending image: beads
Randy White demonstrates the bead-making techniques used 35,000 years ago.

Segment 6
Approximate starting time: 9 min., 45 sec.
Length: 2 min., 15 sec.
Starting image: fire
Ending image: modern human skeleton decorated with beads
Modern humans in ancient Europe encountered Neanderthals, a species that shared many characteristics but were more massive and less sophisticated.

Segment 7
Approximate starting time: 12 min.
Length: 4 min., 30 sec.
Starting image: modern human skull
Ending image: John Shea pulling spear out of ground
John Shea is trying to understand the differences between Neanderthals and modern humans by recreating some of their activities.

Segment 8
Approximate starting time: 16 min., 30 sec.
Length: 1 minute, 30 sec.
Starting image: ancient arrowheads
Ending image: shell necklace
Neanderthals lived in isolated pockets, while modern humans lived in larger groups and used portable art as a means of communication.

Segment 9
Approximate starting time: 18 min.
Length: 1 min.
Starting image: fire in cave
Ending image: stalactites in cave
Michel Lorblanchet studies the technique of cave painting; he can reproduce "spit painting."

Segment 10
Approximate starting time: 19 min.
Length: 1 minute, 30 sec.
Starting image: trees
Ending image: Steven Pinker
Richard Klein thinks modern humans became innovative because of a change in the brain; Stephen Pinker thinks there were many changes over a long period of time.

Segment 11
Approximate starting time: 20 min., 30 sec.
Length: 13 min.
Starting image: Richard Wrangham walking in forest
Ending image: boy signing
Chimpanzees use the threat of physical force for social climbing; with humans, language is the key to complex relationships; in 1980, deaf village children developed their own sign language in Managua.

Segment 12
Approximate starting time: 33 min., 30 sec.
Length: 4 min., 30 sec.
Starting image: Richard Dawkins watering flowers
Ending image: two girls talking
Dawkins thinks that those who could use language left the most offspring; Robin Dunbar has

found that 2/3 of all conversations are gossip about social relationships.

Segment 13
Approximate starting time: 38 min.
Length: 5 min., 30 sec.
Starting image: Richard Dawkins
Ending image: Susan Blackmore
Susan Blackmore studies memes; today cultural evolution more likely than genetic evolution.

Segment 14
Approximate starting time: 43 min., 30 sec.
Length: 1 min.
Starting image: two people running on plain
Ending image: cave painting of hand
The mind's "Big Bang" led to a new era of the evolution of ideas.

Show Seven: What About God? (one hour)

Summary: Examines the controversy surrounding evolution.

Segment 1
Length: 1 min., 30 sec.
Starting image: blue sky behind cliff
Ending image: skull outside classroom
Christian fundamentalists debate with scientists and teachers over the future of religion, science, and science education.

Segment 2
Approximate starting time: 1 min., 30 sec.
Length: 4 min.
Starting image: church exterior
Ending image: Ken Ham
Ken Ham, a fundamentalist, argues that if the Bible is wrong in regards to science, why trust it for morality?

Segment 3
Approximate starting time: 5 min., 30 sec.
Length: 2 min., 15 sec.
Starting image: speaker in front of crowd
Ending image: folk singer
Since the Scopes Monkey Trial in 1925, 37 anti-evolution bills have been passed in 20 states.

Segment 4
Approximate starting time: 7 min., 45 sec.
Length: 12 min.
Starting image: light coming through crevice
Ending image: Nathan Bard at counter
Rachel Benton, an anthropologist, discusses with students from Wheaton College how scientists determine the age of a watering hole; Nathan Bard tries to reconcile God with science.

Segment 5
Approximate starting time: 19 min., 45 sec.
Length: 3 min., 30 sec.
Starting image: students exiting building
Ending image: professor talking to students
Emi Hayashi, a student at Wheaton, is comfortable with both science and religion.

Segment 6
Approximate starting time: 23 min., 15 sec.
Length: 7 min.
Starting image: Wheaton College sign
Ending image: professor's face
Faculty at Wheaton sign a statement of faith; Kansas State University geologist Keith Miller said in a lecture at Wheaton that he sees no conflict between evolution and religion.

Segment 7
Approximate starting time: 30 min., 15 sec.
Length: 4 min., 30 sec.
Starting image: group of boys on stage
Ending image: discussion group
Peter Slayton, an anthropology major and young Earth creationist, says you can't pick sides because then you're doing bad science or bad theology.

Segment 8
Approximate starting time: 34 min., 45 sec.
Length: 1 minute
Starting image: Ken Ham in hallway
Ending image: Students at lockers
Ham thinks people will develop a sense of purposelessness if they're just a mixture of chemicals.

Segment 9
Approximate starting time: 35 min., 45 sec.
Length: 3 min., 30 sec.
Starting image: classroom
Ending image: science teacher Stephen Randak
Claire McKinney is both a Christian and a science teacher; over half the students and 35 faculty members at Jefferson High petitioned for special creation to be taught alongside evolution.

Segment 10
Approximate starting time: 39 min., 15 sec.
Length: 4 min., 15 sec.
Starting image: Eugenie Scott
Ending image: school board meeting
Eugenie Scott, of the National Center for Science Education, said, "All evolution as a science can tell us is *what* happened. Can't tell us who done it."

Segment 11
Approximate starting time: 43 min., 30 sec.
Length: 2 min.
Starting image: open book
Ending image: Eugenie Scott
In 1961, Henry Morris and John Whitcomb published a book called *The Genesis Flood* in which they selected scientific evidence to demonstrate that the Earth was created as described in Genesis.

Segment 12
Approximate starting time: 45 min., 30 sec.
Length: 6 min.
Starting image: students at podium
Ending image: Claire McKinney
Students at Jefferson High asked for the teaching of special creation alongside evolution; the school board decided that they could address the students' concerns through a humanities class.

Segment 13
Approximate starting time: 51 min., 30 sec.
Length: 3 min.
Starting image: a Christian a capella group at Wheaton
Ending image: a sunset
Stan Jones agrees that Wheaton is placing students' faith at risk by helping them examine difficult questions, but in the real world their faith is always at risk.

National Science Education Standards: Grades 9–12

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Science As Inquiry - Content Standard A						
Abilities Necessary to do Scientific Inquiry						
Identify Questions and Concepts That Guide Scientific Investigations	√	√				
Design and Conduct Scientific Investigations	√	√				
Formulate and Revise Scientific Explanation and Models Using Logic and Evidence		√	√			√
Recognize and Analyze Alternative Explanations and Models	√	√		√	√	
Communicate and Defend a Scientific Argument		√	√			√
Understandings about Scientific Inquiry	√	√	√	√	√	√
Life Science - Content Standard C						
The Molecular Basis of Heredity				√	√	
Biological Evolution			√	√	√	
The Interdependence of Organisms				√		√
The Behavior of Organisms					√	
Earth and Space Science - Content Standard D						
The Origin and Evolution of the Earth System			√		√	
Science in Personal and Social Perspective - Content Standard F						
Personal and Community Health						√
Natural and Human-Induced Hazards						√
Science and Technology in Local, National, and Global Challenges						√
History and Nature of Science - Content Standard G						
Science as a Human Endeavor		√	√		√	√
Nature of Scientific Knowledge	√	√	√	√	√	√
Historical Perspectives		√				

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Director of Educational Print and Outreach
Karen Barss

Director of Evolution Initiatives
Julie Benyo

Manager of Educational Print
Sonja Latimore

Editorial Project Director
Susan Reed

Assistant Editor
Erica Thrall

Outreach Coordinator
Susan Buckey

Outreach Intern
Kristal McKanders

Writer
Carol Bershad

Contributor
Larry Flammer

Designers
Laura Varacchi
Kathleen Hogan

Print Production
Mark Hoffman

Photography

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Evolution Executive Producer
Richard Hutton

Clear Blue Sky Productions Executive-in-Charge
Jody Patton

Evolution Teacher's Guide Advisory Board
John Banister-Marx
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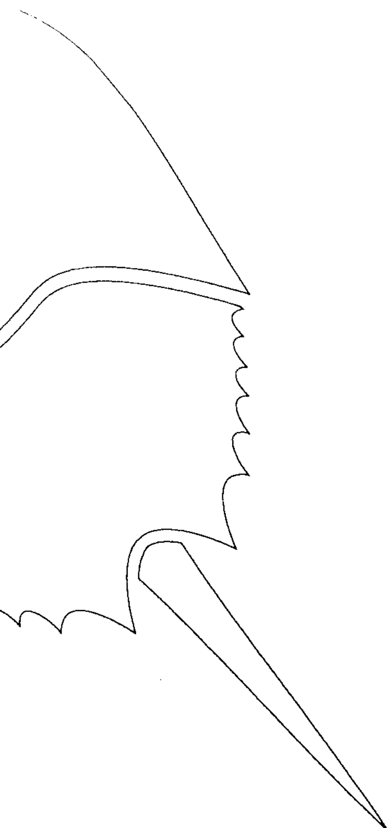

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Signature: Sonja Latimore	Position: Print Manager
Printed Name: Sonja Latimore	Organization: WGBH Boston
Address: 125 Western Avenue Boston MA 02134	Telephone Number: (617) 300-4379
	Date: 10.27.00

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